COMMONWEALTH OF AUSTRALIA
DEPARTMENT OF NATIONAL DEVELOPMENT
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN No. 51

THE PRECAMBRIAN MINERAL BELT OF NORTH-WESTERN QUEENSLAND

BY

E. K. CARTER, J. H. BROOKS, and K. R. WALKER

VOLUME I — TEXT

Issued under the Authority of Senator the Hon. W. H. Spooner, Minister for National Development.

1961

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

Minister: SENATOR THE HON. W. H. SPOONER, M.M.

Secretary: H. G. RAGGATT, C.B.E.

STATE OF QUEENSLAND

DEPARTMENT OF DEVELOPMENT AND MINES

Minister: THE HON. E. EVANS, M.L.A.

Under Secretary: G. F. CLARK

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Director: J. M. RAYNER

This Bulletin was prepared in the offices of:

Bureau of Mineral Resources, Geological Branch: Chief Geologist, N. H. FISHER

Geological Survey of Queensland: Chief Government Geologist, A. K. DENMEAD

Wholly set up and printed in Australia by
Mercury Press Pty. Ltd.,
91-93 Macquarie Street, Hobart, Tasmania

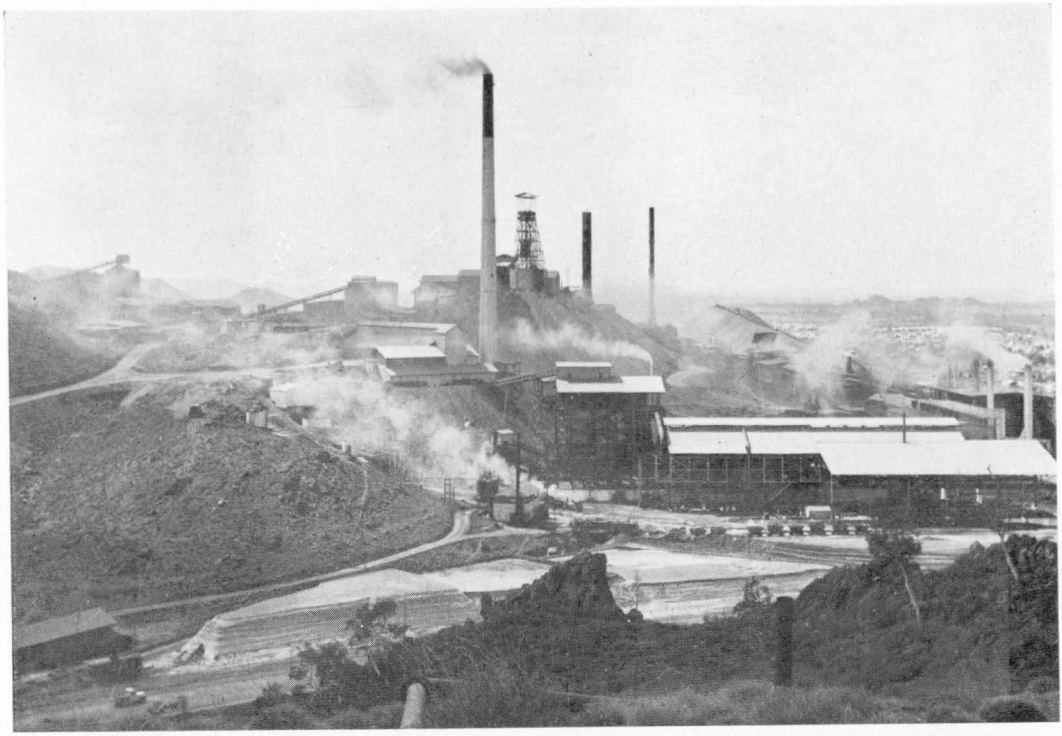


Fig. 1. View of Mount Isa Mines Ltd treatment plant, Mount Isa, 1955.

Fig. 2. Open cut, Mary Kathleen uranium deposit, looking north-west. The treatment plant is in the middle distance. 1956.

PREFACE

This bulletin presents the results of a geological survey carried out jointly by the Bureau of Mineral Resources and the Geological Survey of Queensland, and it is a pleasure to record the large measure of friendly co-operation which has attended the investigation at all times.

The Bulletin is presented, for convenience, in two volumes: Volume I contains the text and accompanying illustrations, and Volume II is an atlas.

The survey began in 1950 and systematic field work was largely completed in 1954. However, since 1953 the region has undergone notable development; the opening of Mount Isa Mines Ltd's copper smelter in 1953 led to the reopening of many old copper 'shows' and the search for others; the discovery of uranium in 1954 initiated a year of spectacular activity and resulted in the location of the important Mary Kathleen uranium deposit; and extensive testing of the Constance Range iron deposits gives promise of large-scale development. Investigations connected with these developments, detailed mapping of several areas, and considerable regional check work in the years 1955-58 have added greatly to our knowledge and understanding of the region; the results are incorporated in the bulletin.

As the Precambrian of North-Western Queensland forms an entity and had not previously been systematically described and interpreted as a unit it was deemed necessary to give a full account of the region, including details of climate, topography, vegetation, and history. A lengthy report has resulted. For ease of use the bulletin has therefore been designed as a reference book, with more or less self-contained sections. This form of presentation has inevitably led to a fair amount of repetition.

It is hoped that the bulletin will prove useful to a wide variety of readers, who will seek to obtain very varied information from it. By use of the detailed list of contents, appendices, and the geographical index it is hoped that all readers will be able to find readily the information they require. To help further the bulletin has been divided into two parts: Introduction and General Geology, on the one hand, and Economic Geology, on the other. An outline of the geology, and the geological history, is given for the general reader on pp. 36-55. In Part II brief descriptions of the surface expression and the secondary zone of mineral deposits are given to help the prospector evaluate surface and shallow sub-surface indications.

CONTENTS

Page

SUMMARY 13

PART I: GENERAL GEOLOGY

INTRODUCTION

Locality .. 15
Communications and access .. 15
Climate .. 16
Physiography .. 18
Surface water .. 20
Vegetation .. 21
History .. 22
PREVIOUS GEOLOGICAL INVESTIGATIONS .. 25
Geological maps of the region .. 29
PRESENT INVESTIGATIONS .. 30
GEOMORPHOLOGY .. 33
REGIONAL SETTING .. 36

OUTLINE OF THE GEOLOGY OF THE PRECAMBRIAN

STRUCTURE .. 38
SEDIMENTATION .. 42
IGNEOUS ACTIVITY .. 42
METAMORPHISM AND METASOMATISM .. 44
GEOLOGICAL HISTORY .. 45
Lower Proterozoic .. 45
Upper Proterozoic .. 55

STRATIGRAPHY AND LITHOLOGY

PRECAMBRIAN .. 56
Cloncurry Complex .. 58
Yaringa Metamorphics .. 58
Other ?Archaean rocks .. 59
Leichhardt Metamorphics .. 60
Argylla Formation .. 62
Leander Quartzite .. 64
Mount Guide Quartzite .. 65
Ballara Quartzite .. 67
Soldiers Cap Formation .. 68
Marraba Volcanics .. 71
Eastern Creek Volcanics .. 73
Mitakoodi Quartzite .. 76
Marimo Slate .. 80
Answer Slate .. 82
Staveley Formation .. 83
Kuridala Formation .. 84
Corella Formation .. 85
Mount Philp Agglomerate .. 90
Charley Creek Formation .. 92
Roxmere Quartzite .. 93
Knapdale Quartzite .. 94
Chumvale Breccia .. 95

Page

Deighton Quartzite 96
Myally Beds 97
Judenan Beds 100
Ploughed Mountain Beds 101
Surprise Creek Beds 102
Gunpowder Creek Formation 104
Paradise Creek Formation 105
Mingera Beds 107
Mount Isa Shale 108
Lawn Hill Formation 110
Undifferentiated Lower Proterozoic strata 112
Cliffdale Volcanics 113
Westmoreland Conglomerate 114
Peters Creek Volcanics 115
Wollogorang Formation 116
Constance Sandstone 117
Mullera Formation 119
Gold Creek Volcanics 120
Pilpah Sandstone 121
Makbat Sandstone 122
Quamby Conglomerate 123
Colless Volcanics 124
Camooweal Dolomite 124
Riversdale Formation 125
Undifferentiated ?Upper Proterozoic strata 125
CAMBRIAN 125
MESOZOIC 125
TERTIARY 127
Carl Creek Limestone 127
STRATA OF UNKNOWN AGE 127
OTHER OUTCROPS 128
Mount Brown 128
Mount Fort Bowen 128
AGE OF THE PRECAMBRIAN STRATA 129
FOSSILS IN THE PRECAMBRIAN 131

PETROLOGY

HYPABYSSAL ROCKS 132
Acid Intrusives 132
Basic Intrusives 133
PLUTONIC ROCKS 143
Kalkadoon Granite 143
Ewen Granite 145
Wimberu Granite 147
Naraku Granite 148
Williams Granite 148
Sybella Granite 149
Wonga Granite 152
Weberra Granite 154
Nicholson Granite 155

Page

Age Relationships and mode of emplacement 156
METAMORPHISM 161
Regional Metamorphism 162
Contact Metamorphism 166
Metamorphic subdivisions and unconformities 167
METASOMATISM 170
Soda and chlorine metasomatism 171
Potash metasomatism and granitization 173
GENERAL HYDROTHERMAL ALTERATION 175
PNEUMATOLYSIS 178

STRUCTURE 178

LOWER PROTEROZOIC EASTERN BELT
Folding 181
Faulting 184
Jointing 185
Cleavage, schistosity, and foliation 185

LOWER PROTEROZOIC WESTERN BELT
Folding 186
Faulting 187
Jointing 188
Cleavage 188

UPPER PROTEROZOIC
Folding 188
Faulting 189
Jointing 189

POST-PRECAMBRIAN 189

PART II: ECONOMIC GEOLOGY

MINING HISTORY
CLONCURRY AND MOUNT ISA GOLD AND MINERAL FIELDS 191
MOUNT ISA MINES 196
URANIUM PROSPECTS 198
LAWN HILL (BURKETOWN MINERAL FIELD) AND CONSTANCE RANGE AREAS .. 198

GENERAL DISCUSSION OF MINERALIZATION 199
SECONDARY ORE DEPOSITS 201
AGE OF MINERALIZATION 202

METALLIC MINERALS
COPPER 203
DISTRIBUTION 204
SURFACE EXPRESSION 204
FEATURES OF THE SECONDARY ZONE 205
CONTROLS 205
MINERALOGY 208
ORE GENESIS 208
PRINCIPAL COPPER MINES 210
Mount Isa 210
Mount Elliott 211
Duchess 211

Page

Trekelano 212
Hampden 212
Mount Oxide 213
Mount Cuthbert and Kalkadoon 213
Dobbyn 214
Orphan 214
Wee MacGregor 214
Great Australia 214
St Mungo 215
Mighty Atom 215
Federal 215
Rosebud 216
Mount Mascotte 216
Answer 216
Magnet 217
Lady Annie 217
Small copper deposits 217

SILVER-LEAD-ZINC 218
DISTRIBUTION 218
SURFACE EXPRESSION 219
FEATURES OF THE SECONDARY ZONE 220
CONTROLS 221
MINERALOGY 222
ORE GENESIS 223
PRINCIPAL SILVER-LEAD-ZINC MINES 223
Mount Isa 223
Northern leases 226
Dugald River 226
Lawn Hill area 226
Silver King 227

URANIUM 228
DISTRIBUTION 228
SURFACE EXPRESSION 228
FEATURES OF THE SECONDARY ZONE 229
CONTROLS 230
MINERALOGY 230
ORE GENESIS 231
PRINCIPAL URANIUM MINES AND PROSPECTS 232
Mary Kathleen 232
Counter 233
Skal 233
Milo 233
Six Kangaroos 234

GOLD 234
Copper-gold deposits 235
Alluvial deposits 235
Reef deposits 235
Gilded Rose 236

Page

SILVER 236
Silver in lead-zinc ores 236
Silver in copper ores 237
Occurrences of silver ores 237

COBALT 237
Distribution 237
Mineralogy 238
Principal occurrence 238
Mount Cobalt 238

IRON 239
DISTRIBUTION 239
MINERALOGY 239
PRINCIPAL OCCURRENCES 239
Mount Philp 239
Constance and Little's Ranges 240
Hematite Siding 240
Lochness 240

CADMIUM 241

TUNGSTEN 241

BISMUTH 241

MANGANESE 242

OTHER METALLIC MINERALS
Antimony 243
Arsenic 243
Molybdenum 244
Nickel 244
Rare Earths 244
Tantalum 245
Thorium 245
Tin 245
Titanium 245

NON-METALLIC MINERALS
LIMESTONE AND CARBONATE ROCKS 246
QUARTZ (SILICA) 247
CONSTRUCTION MATERIALS 248
Road Metal 248
Dam construction materials 248
Building materials 249
BERYL 249
MICA 249
OTHER NON-METALLIC MINERALS
Andalusite, sillimanite, kyanite, cordierite 250
Barytes, feldspar, fluorite, graphite 251
Gypsum, selenium, sulphur 252
WATER SUPPLY 252

CONCLUSIONS 254
Guides to prospectors 254
Large-scale exploration 256
Usefulness of various geophysical techniques 257

Page

ACKNOWLEDGMENTS 258

BIBLIOGRAPHY

PUBLISHED REFERENCES 259

UNPUBLISHED REFERENCES 268

APPENDIX 1.—PETROGRAPHICAL DESCRIPTIONS OF SELECTED ROCK SPECIMENS 277

APPENDIX 2.—TABLES OF PRODUCTION 299

INDEX 335

TABLES

I Climatic statistics for Cloncurry 19

II Summary of Upper Proterozoic stratigraphy . . . . . opp. p. 38

III Summary of Lower Proterozoic and ?Archaean Stratigraphy . . . . opp. p. 39

IV Previously published stratigraphic names in order of first use . . opp. p. 56

V Lower Proterozoic basic intrusives 134

VI Suggested timetable of Lower Proterozoic igneous, and related, events opp. p. 136

PLATES

Plate 1, Fig. 1.—View of Mount Isa Mines Ltd treatment plant, Mount Isa; 1955 . . . . . } Frontispiece

Plate, 1, Fig. 2—Open cut, Mary Kathleen uranium deposit; treatment plant in middle distance; 1956 . . . . }

Plate 2, Fig. 1—Mesozoic cappings on Soldiers Cap Formation . . } between pages 32 and 33

Plate 2, Fig. 2—Well-exposed strata of Soldiers Cap Formation, with Mesozoic cappings . . . . . }

Plate 3, Fig. 1—Scene in Argylla Ranges . . . . . }

Plate 3, Fig. 2—Typical relief in Argylla Ranges . . . . . }

Plate 4, Fig. 1—Terrain produced by acid lavas of the Argylla Formation . }

Plate 4, Fig. 2—Typical land surface produced by Eastern Creek Volcanics }

Plate 5, Fig. 1—Strike valley in Surprise Creek Beds . . . . . }

Plate 5, Fig. 2—Gently dipping, mainly dolomitic, strata of the Paradise Creek Formation . . . . . }

Plate 6, Fig. 1—Stock of Williams Granite . . . . . }

Plate 6, Fig. 2—Typical topographic expression of Mullera Formation . . }

Plate 7, Fig. 1—Two beds of oolitic iron ore in Mullera Formation . . }

Plate 7, Fig. 2—Scarp at eastern margin of Constance Range . . }

Plate 8, Fig. 1—Dip slope of Westmoreland Conglomerate . . . . }

Plate 8, Fig. 2—Barkly Tableland, north of Camooweal . . . . }

Plate 9, Fig. 1—Metamorphosed limestone of the Staveley Formation . . }

Plate 9, Fig. 2—Typical exposure of the calc-silicate rocks of the Corella Formation . . . . . }

Plate 10, Fig. 1—Contortions in calc-silicate rocks of the Corella Formation } between pages 80 and 81

Plate 10, Fig. 2—Sedimentary breccia in the Corella Formation . . . . }

Plate 11, Fig. 1—Oblique arrangement of metamorphic minerals, relative to bedding, in Corella Formation . . . . . }

Plate 11, Fig. 2—Granite tongues cutting calc-silicate rocks of the Corella Formation . . . . . }

Plate 12 —Air photograph of unconformity between Deighton }

Page

Quartzite and underlying strata .. .. between
Plate 13, Fig. 1—Basal conglomeratic arkose of Eastern Creek Volcanics pages
Plate 13, Fig. 2—Near-basal Myally Beds .. .. 80 and 81
Plate 14, Fig. 1—Stereoscopic pair of air photographs showing contact between Argylla Formation and Surprise Creek Beds .. .. ..
Plate 14, Fig. 2—Contact between Eastern Creek Volcanics and Mount Isa Shale .. ..
Plate 15, Fig. 1—Dolomitic strata of the Paradise Creek Formation .. between
Plate 15, Fig. 2—Coarse cross-bedded sandstone in the Westmoreland Conglomerate .. .. pages 120 and 121
Plate 16, Fig. 1—Open cut and 'glory hole', Mount Isa, showing west-dipping Mount Isa Shale, 1956 .. ..
Plate 16, Fig. 2—Small-scale contortions, with eroded upper surface, in Mount Isa Shale . .. .
Plate 17 —Air photograph of unconformity between Lawn Hill Formation and Constance Sandstone . .. .
Plate 18 —Metadoleritic dyke swarm in Leichhardt Metamorphics ..
Plate 19, Fig. 1.—Xenoliths in Kalkadoon Granite .. ..
Plate 19. Fig. 2.—Xenoliths in fine-grained Sybella Granite .. .. ..
Plate 20, Fig. 1—Large porphyroblasts of microcline in Sybella Granite
Plate 20, Fig. 2.—Fine-grained granite cutting coarse-grained granite, Wonga Granite .. ..
Plate 21, Fig. 1—Relict structure shown by orientation of feldspar phenocrysts in Sybella Granite .. ..
Plate 21, Fig. 2—Relict sedimentary crenulations in Wonga Granite ..
Plate 22, Fig. 1—Colonial stromatolites in Paradise Creek Formation ..
Plate 22, Fig. 2—'Cylindrical' stromatolites near Paradise Creek, plan view
Plate 23, Fig. 1—Close-up view of individual 'cylindrical' stromatolites ..
Plate 23, Fig. 2—Compound hemispherical stromatolite, Pandanus Creek .
Plate 24, Fig. 1—Granulite in the Corella Formation .. ..
Plate 24, Fig. 2—Banded metamorphic rock, Corella Formation .. ..
Plate 25 —Fountain Range Fault .. .. between
Plate 26, Fig. 1—Folding in the Soldiers Cap Formation .. .. .. pages 144 and 145
Plate 26, Fig. 2—Stereoscopic pair of air photographs showing folding in the western belt and the Mount Gordon Fault .. ..
Plate 27 —Air photograph showing jointing in the Westmoreland Conglomerate .. ..
Plate 28, Fig. 1.—Red soda-feldspar replacement veins cutting finely banded calc-silicate hornfels .. ..
Plate 28, Fig. 2—Crystals of andalusite in andalusite-garnet-mica schist, Soldiers Cap Formation .. ..
Plate 29, Fig. 1—Staurolite, biotite and garnet porphyroblasts in mica schist, Corella Formation .. ..
Plate 29, Fig. 2.—Lady Annie copper mine, 1957 .. ..
Plate 30, Fig. 1—Pyroxene-plagioclase-hornblende granulite. Photomicrograph .. ..
Plate 30, Fig. 2—Medium-grained dolerite. Photomicrograph .. ..
Plate 31, Fig. 1—Granophyre, showing texture. Photomicrograph ..
Plate 31, Fig. 2—False-cleaved quartz-biotite-muscovite schist, Soldiers Cap Formation. Photomicrograph .. ..
Plate 32. Fig. 1—Garnet-andalusite-biotite-muscovite schist, Soldiers Cap Formation. Photomicrograph .. ..

Page

Plate 32, Fig. 2—Staurolite and garnet porphyroblasts in a base of quartz, biotite and muscovite. Corella Formation. Photomicrograph .. .. } between pages 144 and 145
Plate 33, Fig. 1—Cordierite-anthophyllite schist, Corella Formation. Photomicrograph .. .. }
Plate 33, Fig. 2—Scapolite spotting a low-grade calc-schist. Photomicrograph .. .. }
Plate 34 —Structure map of the Precambrian of north-western Queensland, also showing the distribution of volcanics and granite. Scale 1 inch: 10 miles .. .. } at back of Bulletin
Plate 35 —Schematic cross-sections through the Precambrian of north-western Queensland. Scale 1 inch: 10 miles. }

FIGURES

Fig. 1. Locality map with limits of outcropping Precambrian 17
Fig. 2. Distribution of major Precambrian units 37
Fig. 3. Time relationships of Precambrian units 39
Fig. 4. Lower Proterozoic tectonic elements 40
Fig. 5. Evolution of the Lower Proterozoic orogenic belt 46
Figs. 6 and 7. Schematic sections showing development of Lower Proterozoic orogenic belt 48, 49
Fig. 8. Schematic representation of relationships of Precambrian stratigraphic units 57
Fig. 9. Superpositional relationships of Precambrian stratigraphic units opp. p. 58
Fig. 10. Detail of folding and faulting in the Mitakoodi Quartzite . .. 78
Fig. 11. Structure in the north-pitching anticlinorium south-west of Cloncurry 79
Fig. 12. Cambrian and Ordovician correlation chart, north-western Queensland .. .. opp. p. 125
Fig. 13. Distribution of named granite bodies 144
Fig. 14. Metamorphic units 169
Fig. 15. Structural sketch map 179
Fig. 16. Fault directions in the Precambrian 180
Fig. 17. Distribution of Lower Proterozoic faults by 4-mile sheets . .. 182
Fig. 18. Analysis of Precambrian fault directions 183
Fig. 19. Distortion of the Lower Proterozoic conjugate fault system by the final folding 184
Fig. 20. Representative level plan and section showing structure of Mount Isa lead-zinc and copper orebodies 224
Fig. 21. Districts within the Cloncurry and Burketown Mineral Fields as used in Appendix 1 300

VOLUME II — ATLAS

Plate 1—Geological map of north-western Queensland. Scale 1 inch: 10 miles
Plate 2—Westmoreland, 4-mile geological series, Sheet E54/5
Plate 3—Lawn Hill, 4-mile geological series, Sheet E54/9
Plate 4—Camooweal, 4-mile geological series, Sheet E54/13
Plate 5—Mount Isa, 4-mile geological series, Sheet F54/1
Plate 6—Urandangi, 4-mile geological series, Sheet F54/5
Plate 7—Dobbyn, 4-mile geological series, Sheet E54/14
Plate 8—Cloncurry, 4-mile geological series, Sheet F54/2
Plate 9—Duchess, 4-mile geological series, Sheet F54/6

SUMMARY

An area of 25,000 square miles in the extreme north-west of Queensland contains outcrops of Precambrian rocks, ranging in age from probable Archaean to late Upper Proterozoic. They form part of the Australian Precambrian Shield. The rock types include granite, metamorphics, and little-altered sediments and lavas. The belt is extensively mineralized; it contains the important Mount Isa silver-lead-zinc and copper orebodies and the Mary Kathleen uranium deposit. In addition to these deposits copper and uranium occur widely, Upper Proterozoic sediments contain large sedimentary iron ore deposits, and a great diversity of other economic minerals has been found in small amounts.

The region was mapped by joint Bureau of Mineral Resources and Geological Survey of Queensland teams from 1950 to 1958. This Bulletin reports the results of the investigation. A general geological map at 10 miles to one inch and eight maps at four miles to one inch are bound separately.

As the region lies several hundred miles west of Townsville, the nearest developed port, costs of exploration and mining operations are high, and are made still higher by difficulty of access within the region, particularly during the summer months. The climate, which is continental-tropical, is healthy, but trying in the hot season.

Only a few square miles of outcropping metamorphic rocks south-west of Mount Isa have been tentatively assigned to the Archaean; but other exposed rocks, including granite, may be as old.

The Lower Proterozoic belt early developed two depositional basins, of which the easterly had the more complex history. They were separated by a welt or tectonic land (see Fig. 4). Probably the oldest Lower Proterozoic rocks are acid lavas which are exposed only in the eastern belt, including the site of the welt. These were overlain by a considerable thickness of basalt and interbedded sediments, which are also extensively developed in the western belt. Sedimentation was continuous thereafter in the western geosyncline, but was interrupted in the east. Widespread basic igneous intrusions of several ages took place, particularly in the east.

Two major orogenic compressive phases resulted in strong folding and faulting of the Lower Proterozoic strata. The first, however, did not affect the western geosyncline as strongly as that in the east. Folding was on roughly meridional axes. Each orogeny was probably associated with extensive granite emplacement. The strata in the eastern belt range from the greenschist to amphibolite metamorphic facies, but some moderately high-grade metamorphics occur. Soda and potash metasomatism is also widespread, and is particularly noticeable in the Corella Formation. Apart from portions of the Eastern Creek Volcanics and underlying strata, the rocks in the western belt have generally been only slightly metamorphosed.

The Corella Formation has yielded plastically to give complex structures, but otherwise folds in the eastern belt, though strong, are generally simple. Anomalous folding occurs south-west of Cloncurry. Minor fold axes tend to be overturned to dip east in the east of the region and west in the west. In the western belt the folding is generally moderate to strong, with open folds. West of the Mount Gordon Fault zone, folds tend to be of the dome-and-basin type.

The region is most extensively faulted. The history of faulting is complex; widespread faulting extended into post-Cambrian times. Most of the faults belong to a conjugate strike-slip system, but there are some normal faults. Strike faulting is widespread, and high-angle reverse faults occur south of Cloncurry and west of Mount Isa.

Upper Proterozoic sediments and lavas crop out over more than 2,000 square miles in the extreme north-west of the region. They are gently to moderately folded; the major axis is east-west, but basins are well developed south of the Nicholson River. The oldest

succession, the Cliffdale Volcanics, (which is probably Lower Proterozoic) is intruded by granite, but the other units overlie the granite. West of Mount Isa lies another extensive area of gently folded Upper Proterozoic sediments — the Pilpah Sandstone. Faulting is common in the Upper Proterozoic strata.

The region is surrounded by Palaeozoic and Mesozoic sediments or by soil and alluvium beneath which lie such sediments.

Gold, copper, lead, zinc, silver, and cobalt, and minor amounts of other minerals, have been produced from the region, mainly from Mount Isa and the belt east of it. The large uranium deposit at Mary Kathleen has become Australia's largest source of uranium in the last two years; and extensive iron ore deposits in the Upper Proterozoic sediments of the Constance Range are being tested.

Copper is by far the most widespread economic mineral in the region. Many hundred surface showings have been worked, but only eight deposits have been worked in the primary zone and only six mines have produced more than 10,000 tons of copper. Copper mineralization is generally localized by fractures. Very few replacement bodies have been found; the Mount Isa copper orebody is by far the largest of this type known and is the only large producer at present.

Mount Isa is also the only major producer of silver-lead-zinc. The ore occurs in bedding replacement bodies separate from the copper orebodies. Silver-lead-zinc also occurs in the Lawn Hill and Dugald River areas.

Gold has been won largely from copper-gold orebodies, but early production was from gold ores. No gold is being produced at present.

Uranium is widely distributed. Most of the known occurrences are in the Eastern Creek Volcanics or the Corella Formation, or in the Upper Proterozoic strata north of the Nicholson River. Many types of deposit occur; all are low-grade; most are too poor or small to constitute orebodies, but some of the larger deposits should be workable at a profit if a market were available for the product.

The region as a whole is highly mineralized and has as yet been quite inadequately tested by modern prospecting techniques. Conclusions as to the control and distribution of mineralization are set out in the text.

PART I: GENERAL GEOLOGY

INTRODUCTION

Locality

This Bulletin deals with the belt of outcropping Precambrian rocks in north-western Queensland, and includes the Cloncurry and Mount Isa Gold and Mineral Fields and the Burketown Mineral Field (see Fig. 1). Its greatest length is 300 miles, from north-north-west to south-south-east, and its greatest width is 100 miles. Approximately 29,000 square miles, lying between 17°04′S and 22°07′S, and 138°E and 140°56′E, were mapped. The only sequence of possible Precambrian age not dealt with here is the Camooweal Dolomite, which is discussed by Öpik (1956a and b, and bulletin in preparation), and Noakes (1956).

The principal towns in the region are Mount Isa* (population 7,432—1954 census) and Cloncurry (1,955), which are linked by rail (122 miles), road (82 miles), and air (66 miles). Other settlements are Dobbyn (population 45—1954 census), Selwyn (11), Dajarra (199), Kajabbi (60), Quamby (23), Malbon (34), Kuridala (10), Duchess (55), and the newly developed mining township of Mary Kathleen (about 1,200). Mount Isa, Dobbyn, Selwyn, and Dajarra are termini of railway lines, and all the others except Mary Kathleen are on railways.

Cloncurry is 440 air-route miles from Townsville, the nearest port on the eastern coast of Australia, and 950 air-route miles from Brisbane.

Communications and Access

External. The region is linked by a single railway line, of 3ft. 6in. gauge, to Townsville, which is 481 miles by rail from Cloncurry. This is the main supply line for the district.

A system of formed and graded earth roads provides a second means of communication to the east; these roads become impassable for short periods after heavy rains. Roads north to Burketown and Normanton, on the Gulf of Carpentaria, serve to link these small settlements to the supply centre of Cloncurry, rather than to provide an outlet for the region. The shallowness of the Gulf of Carpentaria, and of estuaries opening into it, has inhibited the development of a deep-sea port to the north.

Mount Isa is linked to Camooweal (117 miles), and Tennant Creek, in the Northern Territory (420 miles), by the bitumen-sealed Barkly Highway, and thence to Darwin (an additional 650 miles) or Alice Springs (315 miles) by the Stuart Highway, also of bitumen. Alice Springs is the terminus of the railway from South Australia.

Both Mount Isa and Cloncurry have all-weather aerodromes, and regular air services connect them with Sydney, Brisbane, Townsville, Darwin, and Tennant Creek.

---

* Co-ordinates for all place names and other geographical features, mineral deposits, and geological faults mentioned in the text (other than Appendix II) appear in the Geographical Index. Co-ordinates given have been measured from the maps and do not represent instrumental determinations.

Internal. The rail network is shown in Figure 1.

Regular air services link some of the homesteads and small settlements in the surrounding area, and many other properties have emergency landing strips. The Mary Kathleen uranium mine also has an airstrip, which is used frequently.

A highway is being constructed between Mount Isa and Cloncurry, via Mary Kathleen.* All communities and many homesteads in the region are linked by formed and graded roads, which are sometimes damaged during heavy rain. In the plains country that surrounds the strongly folded Precambrian, 'fire-ploughed' tracks provide serviceable roads.

The hilly country of the outcropping Precambrian rocks is commonly too rough and stony for good roads to be easily made. The larger stream valleys generally provide reasonable access, but as numerous creek beds have to be crossed travel is necessarily slow. In the mineralized parts rough tracks have from time to time been opened up by prospectors and small mine operators; they rapidly deteriorate if they cease to be used; in a few years erosion and the growth of vegetation may make them unusable without extensive repair work. Access at any time is therefore dependent on the current level of prospecting and mining activity. All roads and tracks are apt to be impassable for varying periods after heavy rain; some mines and homesteads may be cut off from vehicular traffic for weeks at a time.

Much of the region can be penetrated beyond the tracks by the use of properly equipped 4-wheel-drive vehicles. In general the areas of outcrop of the Ploughed Mountain, Judenan, Myally, and Surprise Creek Beds can be penetrated only to a limited extent, without track construction, owing to the deep incision of the creeks. Throughout the Argylla Ranges, between Mount Isa and Mary Kathleen, the rough, bouldery surface severely restricts access even by horse. This factor, complicated by the dissected flat-lying Mesozoic caps, with their numerous re-entrants, also makes access extremely difficult in the headwater areas of the Williams, Fullarton, and McKinlay Rivers and Bustard Creek (see Plates 2-8).

Many of the homesteads in the south of the area are linked by telephone. Nearly all other homesteads and some mining camps are served by the radio-communication system of the Royal Flying Doctor Service, which has a base radio station, light aircraft, and medical facilities at Cloncurry. The Service also transmits and receives telegrams regularly.

Climate

The area mapped lies between the latitudes of 17°04′S and 22°07′S, entirely within the tropics and from 50 to 300 miles from the Gulf of Carpentaria.

* Throughout this bulletin reference to the Mount Isa-Cloncurry road is to the old road which passes Federal copper mine and through Deighton Pass, and not to the road now in use, which goes via Mary Kathleen. The road from Cloncurry to Mary Kathleen is a first-class sealed road.

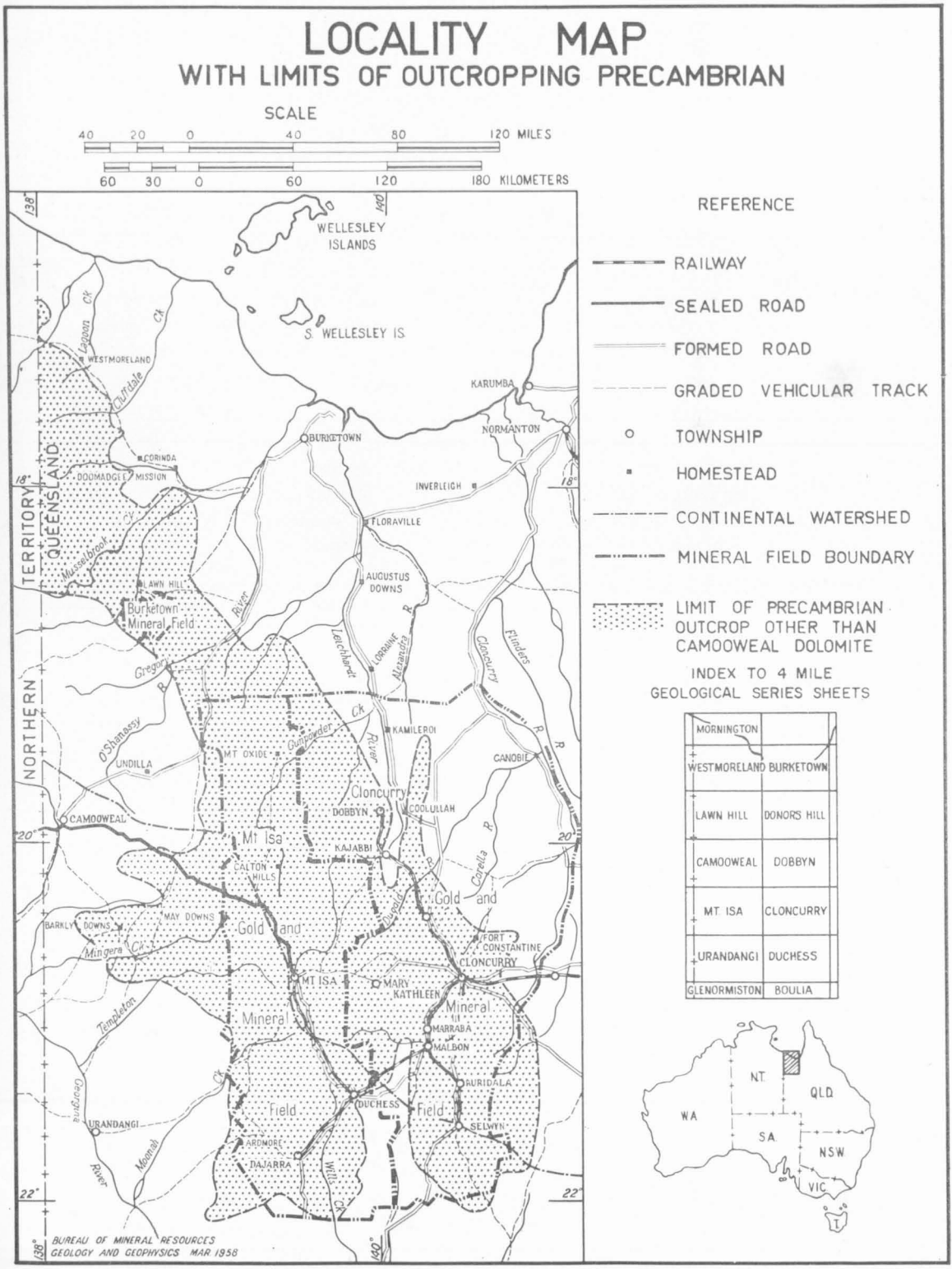

LOCALITY MAP
WITH LIMITS OF OUTCROPPING PRECAMBRIAN
SCALE
40 20 0 40 80 120 MILES
60 30 0 60 120 180 KILOMETERS
REFERENCE
RAILWAY
SEALED ROAD
FORMED ROAD
GRADED VEHICULAR TRACK
TOWNSHIP
HOMESTEAD
CONTINENTAL WATERSHED
MINERAL FIELD BOUNDARY
LIMIT OF PRECAMBRIAN OUTCROP OTHER THAN CAMOOWEAL DOLOMITE
INDEX TO 4 MILE GEOLOGICAL SERIES SHEETS
MORNINGTON
WESTMORELAND
BURKETOWN
LAWN HILL
DONORS HILL
CAMOOWEAL
DOBBYN
MT. ISA
CLONCURRY
URANDANGI
DUCHESS
GLENORMISTON
BOULIA
WELLESLEY ISLANDS
S. WELLESLEY IS.
KARUMBA
NORMANTON
BURKETOWN
INVERLEIGH
FLORAVILLE
AUGUSTUS DOWNS
KAMILEROI
CANOBIE
COOLULLAH
KAJABBI
CLONCURRY
FORT CONSTANTINE
MARY KATHLEEN
MARRABA
MALBON
BURIDALA
SELWYN
DUCHESS
URANDANGI
ARDMORE
DAJARRA
MT. OXIDE
UNDILLA
CAMOOWEAL
DOOMADGEE MISSION
CORINDA
WESTMORELAND
BARKLY DOWNS
MAY DOWNS
Mt Isa
Gold and
Mineral Field
NT
QLD
WA
SA
NSW
VIC
TERRITORY
QUEENSLAND
NORTHERN
BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS MAR. 1958

Fig. 1.

The climate is therefore tropical, and ranges from a tropical moderate-rainfall coastal climate in the north to a tropical low-rainfall continental climate in the south. The topographic range is less than 2,000 feet, and does not greatly influence climate, except perhaps for a slightly increased rainfall in the higher country.

Average annual rainfall ranges from about 28 inches in the north-west (27 inches at Burketown) to about 11 inches in the south-west. The average annual rainfall at Cloncurry is 16.89 inches. Rain falls principally during summer storms, which sweep across belts of country a few miles or tens of miles wide; a typical storm may yield 1 to 3 inches of rain. For this reason the distribution of rain within the region in any year is generally patchy. Some general monsoonal rains drench the whole countryside. From May to October falls generally do not exceed two inches. Rainfall and other climatic statistics for Cloncurry are shown in Table I.

Average maximum daily temperature throughout the year is about 90°F. for the whole area. Both the diurnal and seasonal variations increase from north to south; the greatest extremes are experienced in the south-west, where the average maximum daily temperature exceeds 100°F. during December and January. In the same area, below-freezing ground-temperatures are occasionally recorded during the winter; but, as humidity is generally very low, frosts are rare.

As is to be expected, cloud cover, humidity, and rainfall decrease away from the coast. Relative humidity figures for Cloncurry, which are probably about average for the whole area, are given in Table I.

Prevailing winds in the winter months, particularly from June to August, are from the south-east. These are cold dry winds and produce a sharp drop in temperature, particularly in the south of the region; their effect is not so noticeable in the north. In the summer winds are generally moisture-laden monsoonal winds from the north-west.

Physiography

The Precambrian belt forms a watershed of continental importance. The only streams which cut across the Lower Proterozoic rocks are the Gregory River and Lawn Hill Creek in the west of the region. Musselbrook Creek, in the same area, cuts across Upper Proterozoic strata. The line of the watershed is shown in Figure I. South and west of the divide, streams drain inland as parts of the Georgina-Diamantina system which terminates in Lake Eyre in South Australia. Water only rarely reaches Lake Eyre, however—at intervals of several years. The streams, even within the area of outcropping Precambrian rocks, are heavily alluviated and braided. North of the divide, streams drain into the Gulf of Carpentaria. These streams are more or less entrenched in the plains of the Gulf Country, but develop complex distributary systems in their lower courses.

The height of the divide has not been determined in detail. It is about 800 feet at the Queensland-Northern Territory Border, 875 feet on the Camooweal-

TABLE I. CLIMATIC STATISTICS FOR CLONCURRY*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Average rainfall, inches ..	4.73	3.96	1.86	0.62	0.48	0.80	0.23	0.12	0.16	0.44	1.59	1.90	16.89
Number of wet days	7	7	4	2	1	2	1	0	1	2	3	5	35
Maximum temperature, °F.	98.8	96.8	94.6	90.3	83.1	77.4	76.7	81.7	88.3	95.1	98.3	99.7	90.1
Minimum temperature, °F.	76.3	75.4	72.8	67.0	59.7	54.1	51.5	54.8	61.2	68.6	73.4	75.9	65.9
9 a.m. Relative humidity, %	44	48	47	37	39	44	41	32	30	29	34	39	39
3 p.m. Relative humidity, %	29	32	32	26	27	30	27	20	19	20	24	26	26

* Taken from R.O. Slatyer, 'Climate of the Leichhardt-Gilbert area' in 'General report of the Leichhardt-Gilbert area, Queensland' Commonwealth Scientific and Industrial Research Organization, Land Research Series (in preparation).

Burketown road, 1,000 feet on the Yelvertoft Dip-Thorntonia road, 1,400 feet on the Barkly Highway, nearly 1,500 feet on the Mount Isa-Duchess railway, 1,166 feet at Bungalien on the Duchess-Malbon railway, and 1,235 feet at Selwyn Railway Station. These, of course, represent low points on the divide. The greatest topographic relief along the divide is from Mount Guide eastwards towards Bungalien railway siding, where the highest points rise roughly 500-700 feet above lowest points.

The configuration of the land surface is determined largely by rock type and other geological features such as jointing and the presence of flat-lying strata, and hence varies considerably through the area. These features are discussed on pp. 34-36. They are matters of detail; the whole region can be described as a highly dissected peneplain with lesser relief and greater alluviation on the inland—southern and south-western—side of the divide than on the northern and eastern side. The average altitude of the Barkly Tableland along the south-west margin of the hills is 800-1,000 feet; that of the Gulf country to the north at the foot of the ranges is 200-400 feet; and that of the western edge of the plains to the east is 350-700 feet. For this reason the watershed lies nearer the inland margin of the outcropping Precambrian rocks than the seaward margin.

Surface Water

Only four watercourses in the region are perennial. Of the majority, the smaller watercourses only flow for a few days or weeks each year; the larger ones may flow for several months. The exceptions are the Gregory and O'Shanassy Rivers and the Lawn Hill and Widdallion Creeks, which are fed from underground sources in Cambrian limestone. Within the region of Precambrian outcrops they flow strongly throughout the year. The flow of the Gregory River, below its junction with the O'Shanassy River, has been measured; it is more than 100 cusecs in June (Whitehouse, 1940, p. 52). Even these streams, however, diminish considerably or fail altogether lower in their courses.

Several small streams at the heads of the Corella and Williams Rivers and Sandy Creek (the one north of the Williams River) have small flows which in good seasons last the whole year; but the flows do not persist for many miles. All the larger watercourses, and in the more rugged country some of the smaller ones, have a number of permanent waterholes. For two or three months after the end of the 'wet season' surface water is fairly easy to find in most parts of the region. Later in the year, however, large areas are for most practical purposes devoid of surface water. Many of the permanent waterholes in the more rugged country are of little use for pastoral purposes because of difficulty of access, but they are invaluable for the prospector and small miner. The questions of conservation of surface water and the availability of underground water supply are discussed on pp. 252-254.

Homesteads and townships depend on both surface water and underground water. Mount Isa township and mines draw some of their water from Rifle

Creek Dam, which was built by Mount Isa Mines Ltd. It has a capacity of 2,200 million gallons and serves Mount Isa by a pipeline 20 miles long. This source is supplemented by numerous bores along the valley of the West Leichhardt River. A considerably larger dam, of 17,000 million gallons capacity, on the Leichhardt River, about 10 miles downstream from Mount Isa, was completed in 1957. Cloncurry is supplied from surface water and water in the sands of the Cloncurry River near the township; the supply is inadequate.

Mary Kathleen township and mine are supplied from a dam on the Corella River, completed in 1956. A second dam has recently been built on the East Branch of the Leichhardt River.

Vegetation

The wide climatic range has caused considerable diversity of vegetation through the region, particularly in the plain country.

The plains are generally sparsely timbered, except in the extreme north, where extensive tropical savannah with eucalyptus, scrub ti-tree *(Melaleuca* spp.) and acacias provide moderate tree cover. The 'black soils' support good grass, including Mitchell grass *(Astrebla* spp.*)* and Flinders grass *(Iseilema* spp.): trees are confined to sandy rises and the margins of watercourses, where coolibah (*Eucalyptus microtheca*) and similar mallee-type eucalypts grow to 10-30 feet.

Sandy soil in the south of the area carries mulga (*Acacia aneura*), 'emu apple' *(Ovenia vernicosa),* and similar typical semi-arid-zone trees. Gidyea (*Acacia georginae* and *A. cambagei*) and whitewood (*Atalaya hemiglauca*) are also common and extend farther north than the other types. Generally, north of the latitude of Cloncurry, bauhinia *(Bauhinia cunninghamii)* grows on the river flats, particularly where the soil is rich in lime. Silver-leaf box (*Eucalyptus prunosa*) and similar eucalypts are abundant, particularly in the north of the region, wherever soil is adequate and is well-drained.

The stony hill country supports, in the way of trees, mainly eucalypts, including snappy gum (*Eucalyptus brevifolia*), mountain gum (*E. dichromophloia*), and stunted boxes; these grow 10-25 feet high. Where subsurface water is available, for example in limestone or strongly jointed quartzite or granite, small isolated groups or individuals of the beautifully symmetrical kurrajong (*Brachychiton* sp.) may be seen in the rockiest places. In addition to these there is commonly a moderate to heavy cover of scrub, composed largely of assorted varieties of acacia (e.g. *Acacia lysiphloia,* 'turpentine'), and ti-tree, which impede progress, whether by vehicle, horse, or foot.

Throughout the whole region one or more varieties of the needle-sharp resinous grass spinifex (*Triodia* spp.) thrives wherever the soil is poor or scanty and is well-drained. Under favourable conditions it may grow more than five feet tall and present a serious obstacle to progress. Generally, however, it is only 1-2 feet high and is a nuisance during cross-country travel, rather than an impediment.

Along all the main watercourses large river gums (*E. camaldulensis*) and carbeen (*E. papuana*) and similar trees thrive, providing excellent shade. Wherever permanent or near-permanent surface water exists, towering ti-trees or 'paper barks' (*Melaleuca* spp.) overhang the main watercourses, particularly in the northern half of the region. Generally north of latitude 20°30′S pandanus and cabbage palms (*Livistona* sp.) occur in a similar environment. Other non-eucalypts also become important in the more northerly parts of the region.

On the Yelvertoft Dip-Thorntonia track and elsewhere dense stands of the straight-trunked lancewood (*Acacia shirleyi*) grow on and about lateritic cappings.

Pasture grasses are more abundant in the plains country surrounding the outcropping Precambrian than within the hill country, but good grasses grow in the open country and valleys near watercourses. The hills are generally poorly grassed. Types of grasses differ according to rainfall and soil; they tend to be coarser and more rank in the north of the region than farther south. Granitic soil generally supports light types of grass; heavy-textured soils, such as those derived from basic igneous rocks or dolomite, support the good pasture grasses, Mitchell and Flinders grass.

To generalize: in the areas of outcropping Precambrian, vegetation is composed dominantly of sparse to moderately dense stunted eucalypts, acacia, and other shrubs, and spinifex, and light grasses in varying proportions according to environment.

The trees are of little economic value. The river gums and ti-trees can provide building timber, but are not sufficiently abundant for systematic cutting. Gidyea is a hard, durable, and termite-resisting timber and is used extensively for fencing. Lancewood (*Acacia shirleyi*), bloodwood (*Eucalyptus terminelus*), and beefwood (*Grevillea striata*) are also useful for construction purposes. Many of the eucalypts make excellent firewood. Virtually no timber available locally is suitable for mining purposes, except as small rough mine timbers.

History

Although the history of settlement in north-western Queensland dates from the eighteen-sixties it was not until the early part of the twentieth century, when rail communications were extended to the district, that substantial mining activity developed. A period of rapid progress from 1910-20 was followed by a severe setback in the early nineteen twenties, until the discovery of the major base-metal deposit at Mount Isa in 1923 heralded a period of sustained development which has continued to the present.

The first explorers to traverse the mineral province of north-western Queensland were Burke and Wills on their ill-fated expedition to the Gulf of Carpentaria of 1860-61. They named the Cloncurry River and noted the mineralized appearance of some of the rocks of the district. McKinlay led an expedition in search of

Burke and Wills in 1861 and also entered the district. He reported on its pastoral potentialities and noticed a specimen of rock containing copper; this was the first indication of the metalliferous wealth of north-western Queensland. Leichhardt, in 1844-45, had previously touched on the extreme northern fringe, near Wollogorang, on the Northern Territory border. A. C. Gregory and party also passed through the same area in 1856. Landsborough (1862) and Hodgkinson (1877) followed the Gregory River.

After earlier visits in search of new pastoral country, Ernest Henry and his partner Roger Sheaffe took up a holding at Fort Constantine on the Cloncurry River in 1867 and were the first settlers in the Cloncurry District, although Gregory Downs and the township of Burketown were established in 1865. As a result of Henry's discovery of the Great Australia* copper deposit, the settlement of Cloncurry was founded nearby on the banks of the Cloncurry River. The first influx of population came in 1872, when the short-lived Top Camp goldrush took place. Henry established the first store in Cloncurry and performed a great pioneering task in prospecting the area and opening up tracks connecting the various homesteads and mining centres with Cloncurry and keeping the settlers supplied with the necessities of life. One of the most notable pioneers in the pastoral industry was Alexander Kennedy, who took up Buckingham Downs Station in 1877. He subsequently owned Noranside, Teddington Loch (Bushy Park), Devoncourt, and Calton Hills properties, and took an active part in local public life. In these early days the development of both the pastoral and mining potential of north-western Queensland was fraught with many and great difficulties and was barely profitable because of the paucity of communications, the distance from a seaport, and the lack of permanent water supplies.

The white settlers found the district inhabited by large numbers of aborigines. The Mitakoodi tribe lived in the vicinity of Cloncurry, and the Kalkadoons inhabited the rugged country to the west and the region of the Selwyn divide. The Kalkadoons gave the settlers more trouble than any other tribe in north-western Queensland. Several settlers were killed and depredations by the Kalkadoons on the cattle were severe. In contrast to many other early settlers Ernest Henry sought to befriend the aborigines, and they helped him find several copper deposits, among which were the Argylla and Mount Oxide deposits.

Chinese were prominent from early times in the winning of the alluvial gold wealth at Top Camp and other centres. Later, when the alluvial deposits were worked out, they gradually left the district for other alluvial fields.

The Cloncurry district was declared a Goldfield in 1889 and a Mineral Field in 1899. In 1957 it was divided into the Cloncurry and Mount Isa Gold and Mineral Fields, which together cover an area of about 22,100 square miles. To the end of the nineteenth century the population of the Field rarely exceeded

* Lees (1907) gives the date of the first discovery of copper by Henry as 1865, but Dunstan (1913) states that copper was first discovered, at the site of the Great Australia, in 1867.

500 and fluctuated widely in accordance with the degree of activity in the mining industry. Even as late as 1904 the population was estimated at only 487, and not until the prosperous 1910-20 period did it increase appreciably. The population in 1918 was estimated at 7,795.

A coach service to Cloncurry from the east was begun in 1884 by Cobb and Co. This provided the first regular passenger link with the eastern coast. The completion of the Overland telegraph line to Cloncurry in 1883 provided a further link with the outside world. In 1908 the railway line from Townsville was completed to Cloncurry; this event initiated a period of marked expansion and development in the district. The line was later extended to the mining centres of Selwyn (1910), Duchess (1912), Ballara (1914), and Mount Cuthbert (1915). These centres, with the addition of Kuridala (Hampden), were flourishing townships in the 1910-20 period, but when the copper mines and smelters closed down their populations dwindled rapidly, until today Ballara and Mount Cuthbert are 'ghost' towns, while the other three townships have only a handful of people in them. The inauguration of an airmail service to Cloncurry in 1922 by Qantas marked the beginning of air communication. Air transport has done much to lessen the effects of remoteness, which has been a basic problem in the development of north-western Queensland. Australia's first Flying Doctor base was established at Cloncurry in 1928, and today more than 200 radio transceiver sets give direct communication with Cloncurry to people scattered throughout north-western Queensland and adjacent areas.

From the earliest times Cloncurry was the principal settlement, and today, although the population is only 1,955 (1954 census), it remains the seat of local government and the centre of communications. Mount Isa grew up astride the Leichhardt River and adjacent to the mine to which it owes its existence. The railway from Duchess to Mount Isa was completed in 1929, and in the same year the Rifle Creek dam and pipeline was completed by Mount Isa Mines Ltd. The dam had a capacity of 1,400 million gallons. These events were followed by a considerable increase in population as the tempo of development at the mine increased. After a temporary check during the 1939-45 war period, steady expansion has been maintained up to the present time. To cope with this expansion the retaining wall at the Rifle Creek dam was raised 5 feet in 1953 to give it a capacity of 2,200 million gallons. In 1954, the population of Mount Isa reached 7,432 (it is now over 10,000), and Mount Isa Mines Limited in 1958-9 employed approximately 3,400 people. As the population of the whole Cloncurry Shire was 10,512 at the time of the 1954 census it can be seen that mining is still the dominant industry of the district.

Mount Isa Mines Ltd have made every effort to attract competent working staff to Mount Isa, and to help offset the hardships associated with living in this remote area, with its severe summer climate. Measures adopted include extensive housing projects, support for co-operative building societies, and provision of library and recreational facilities and of numerous other amenities. Employees share in the

prosperity of the company by way of a 'lead bonus' which varies according to the price of lead.

The pastoral industry (cattle, except for southern districts, where sheep predominate) has also had severe fluctuations due to drought and economic depression. It draws its main strength from the surrounding districts, rather than the region under consideration. In 1913 a railway line was constructed from Duchess to Dajarra, which is now the main cattle-trucking centre for the rich Barkly Tableland. Kajabbi, on the Cloncurry-Dobbyn line, similarly serves the Gulf country.

The discovery of uranium, 20 miles north of Mount Isa, in March 1954, led to a spectacular burst of prospecting activity. Although uranium mineralization proved to be widespread, only one mine is producing at present (1960). This is the Mary Kathleen mine, 30 miles west of Cloncurry, which has been proved to contain a large body of ore. It is being worked by open cut. The workings, treatment plant, and ancillary services employ about 600 persons.

The history of mining in the region is given in Part II (p. 191) and previous geological work is detailed in the next section.

Previous Geological Investigations

A considerable amount of geological work has been done from time to time in this area, much of it by geologists of the Geological Survey of Queensland and by company geologists. They examined, for the most part, small areas of economic interest. A full list of all published, and many unpublished, reports of this type is included in the Bibliography. Popular accounts of the mining fields are generally not included, but several such references covering the early years of the fields may be found in Ball (1908, p. 7, and 1911, p. 51) and Dunstan (1920, p. 5). In addition to the references listed in the Bibliography, the Annual Reports of the Queensland Department of Mines, which have been issued since 1878, contain the reports of wardens, commissioners, and inspectors of mines. These have not been listed, except where special reference to one of the annual reports has been made in the text.

This section is confined largely to a review of work that has contributed to the understanding of the regional geology of the area. However, reference should be made to the work of Reginald C. H. Uhr, who was first warden for the Cloncurry field (1878-1885), and an enthusiastic propagandist for the region.

The first recorded geological observation in the region was by Leichhardt (1849), who, in the course of his overland journey from Brisbane to Port Essington in 1844-45, passed the extreme north edge of the outcropping Precambrian. He recorded a 'piece of granite and a fragment of fortification agate' in a creek, near the present Northern Territory border, probably west of the border, and inferred the existence of 'a rocky, primitive country' to the south. A. C. Gregory

(1861) in 1856 recorded granite and upturned sandstone in the headwaters region of the Nicholson River (in the Northern Territory), and sandstone farther east.

A few years later, the explorers Burke and Wills passed in a northerly direction, east of Standish Range and down the Cloncurry River. Burke recorded general observations on the lithology of the country through which they passed (Jackson, 1862). McKinlay (1863) made notes on the lithology of the eastern edge of the outcropping Precambrian, and recorded a specimen of copper, and Landsborough (1862) made some (very inaccurate) observations of the lithology along the Gregory and O'Shanassy Rivers. Hodgkinson (1877), a surveyor, also made random, and inaccurate, geological observations in the west of the region.

By analogy with the metamorphics of Victoria, Daintree (1872) regarded all the metamorphic rocks of Queensland as probably Lower Silurian or older (loc. cit., p. 301, and pl. 9, opp. p. 270). In his map he showed an area of about 10,000 square miles, entirely surrounded by Cretaceous, mainly south of Cloncurry, and extending south-east to the Diamantina River, as pre-Devonian metamorphics. No granite was shown. He recorded belemnites from the Cloncurry district (Daintree, 1868).

Copper and gold having been discovered in the Cloncurry district in 1867, R. L. Jack was directed to examine the district to determine the usefulness of a railway to Cloncurry and beyond. He carried out several traverses from Cloncurry, the most extensive being from Cloncurry to Gregory Downs and Carl Creek Police Post (Riversleigh). His reports were descriptive and no attempt was made to subdivide the mineralized rocks into stratigraphical units or to determine their age. He collected Lower Cretaceous fossils east of the Leichhardt River. His reports were first published as Parliamentary Papers (Jack, 1885) and re-issued with revisionary notes as a Geological Survey of Queensland publication (Jack, 1898). It is interesting to note that the outline of the metamorphic belt in the map issued by Jack in 1892* is more accurate than in any subsequent map issued before 1920.

Rands (1895-1896) examined the field and reported on some of the known deposits, but added little to the geological knowledge of the area. Jack (1895) considered the mineralized rocks of the area to be between Silurian and Archaean in age. In 1896 he reported to the Royal Society of Queensland on fossils, including *Orthoceratites,* forwarded to him from the Cairns (Toko) Range south-west of Glenormiston (Jack, 1897, pp. 47-8). He considered their age to be Ordovician (Lower Silurian). For many years this evidence was cited by writers as indicative of a Silurian age for the Cloncurry Series.

Cameron (1900a and b, 1901) was the first geologist whose report on the Lawn Hill lead-zinc field is available.† He recorded an unconformity between the

---

* Geol. Surv. Qld Publ. 90.

† Ball (1911, p. 51) states that R. A. F. Murray, who visited the mines on the field in 1898, was the first geologist to report on the field, but Ball did not know the title of his report and was not able to obtain a copy.

mineral bearing strata and those of the Constance Range and Dentalium Plateau and considered that the limestone and sandstone of the Constance Range might form separate units. He also considered that the sediments along Gunpowder Creek were younger than those around Cloncurry. Following the 1899 geological map of Queensland, he showed, in a map of north-western Queensland (Cameron, 1901, opp. p. 186), the older strata as Silurian and the younger as Devonian (?). It is also of interest that he suggested (p. 189) that the granites of the Cloncurry district are the extreme products of metamorphism.

Rutherford (Rutherford & Kitchener, 1904) is reported to state that the sandstones and limestones of the Cloncurry field unconformably overlie the schists and slates. It is not clear to what sediments Rutherford refers; in fact, he appears to have grouped all arenaceous sediments of the region together, but we must give him credit for the first recognition of an unconformity in the Cloncurry mineral field. Ball (1908, pp. 16, 17) dismisses the possibility of an unconformity.

As a result of a systematic examination of the field Ball (1908) made a lengthy report on the area, comprising a first part dealing with the history and general geology of the area and a second part of more than 360 pages of descriptions of workings. He also included a general geological map of the Cloncurry field, in which he did not indicate the age of the mineral-bearing strata, as he considered the evidence inadequate. However, he recorded (p. 8) 'indistinct traces of a lamellar *Stromatopora*' from Pumpkin Gully. He was certainly mistaken in this, but the evidence was used by later workers in support of a Silurian age for the strata. Other records of interest made by Ball include the existence of porphyries, which he recognized as probably of extrusive origin (p. 21); staurolite from Cattle Creek area; and a suggestion (p. 30 and elsewhere) that the copper deposits of the district were derived from basic igneous rocks.

The publication in 1911 of a similar report on the Lawn Hill field (Burketown Mineral Field) (Ball, 1911) added considerably to the knowledge of the deposits of that area, but did not significantly increase knowledge of the regional geology.

Woolnough (1912), as a result of a traverse from Darwin to Cloncurry, regarded the rocks of the Barkly Tableland and around Carlton Station (Calton Hills Station) as Cambrian and the metamorphic rocks to the east as Precambrian. (Gregory (1910-11) has a map which shows a region of 'Archaean and plutonic' rocks in north-western Queensland; his evidence for this is not known.)

Dunstan (1913, pl. 20) still shows the Cloncurry Series as extending west from Cloncurry and Boulia to the Northern Territory Border. In Dunstan (1920, pl. 1) the limits of the Cloncurry Series are fairly accurately shown, except that an area west of the Georgina River is included. It is still indicated on the map as Silurian, although doubt is expressed in the text. Numerous small bodies of granite are shown. The surrounding area, including the Barkly Tableland, is shown as Jurassic.

In 1923 Saint-Smith made the first report on the newly-discovered Mount Isa lead-zinc deposits, and in the following year (1924a) recorded the discovery (by

Campbell Miles, one of the discoverers of Mount Isa — see Dunstan, 1925, p. 141) of Cambrian trilobites in the headwaters region of the Templeton River. This provided the first direct evidence of the probable Precambrian age of the mineral-bearing strata to the east. Dunstan (1925, pp. 140-1) also describes a pioneer attempt to use aerial photography as an aid to mapping; though the photographs do not seem to have been put to practical use.

Shepherd, who succeeded Saint-Smith as government geologist for the Cloncurry Field, in 1927 made the first stratigraphical subdivision of the Precambrian strata into named units. His classification was submitted to an interstate conference in 1928, but was not published (Shepherd, 1928, unpubl.; see Shepherd 1946d, p. 144: Introductory remarks by L.C.B.). David (1932) used it in his 'Geology of the Commonwealth of Australia,' which contained the first published stratigraphical subdivision of the Precambrian of the region. David regarded as Archaean all the mineralized belt extending to and beyond the Nicholson River in the north-west, with the exception of the Mount Isa Shales and Corella Limestone, which he called (?)Older Proterozoic. Shepherd (1946d) subsequently published his classification, which he had apparently modified from that used by David.

In 1935 the Aerial, Geological and Geophysical Survey of North Australia, a Commonwealth Government organisation whose role was to carry out geological and geophysical investigations of known mineral fields, began work in the district. They were the first to use air photographs for geological mapping in the area and were also pioneers in the use of geophysical prospecting techniques in Australia. Their systematic mapping, with air photographs, was mainly confined to the most strongly mineralized zones. In all, eleven areas, totalling 3,500 square miles, were mapped, and five mine areas were tested geophysically. Reports on these areas are listed in the Bibliography (see under A.G.G.S.N.A., Broadhurst, Honman, Jensen, Nye, Rayner, E.O., and Rayner, J.M.). Traverses were carried out to link the several areas mapped in some detail and a general geological map of the area was published in the report for the period ended 31st December 1935 (A.G.G.S.N.A., 1936a, pl. 1); this was modified in the following year (A.G.G.S.N.A., 1937a, pl. 4), and a final general geological map of the area was included in Nye & Rayner (1940, pl. 1).

The rocks of the region were subdivided into Proterozoic and Archaeozoic. Two periods of granitic intrusion were considered to have taken place. Jensen (1941a and b and A.G.G.S.N.A. 1940a and b) regarded the sandstone and limestone of the Constance Range and Dentalium Plateau as lower Middle Cambrian (on fossil evidence) and the mineralized Lawn Hill series as Lower Cambrian or Upper Proterozoic. He placed the Constance Range series in the middle of the volcanic sequence north of the Nicholson River (A.G.G.S.N.A., 1940b, p. 12). Noakes & Traves (1954, pp. 34-37) regarded the whole mineral belt of north-western Queensland, which they called the Carpentaria Complex, as Lower Proterozoic. They considered that it probably included undifferentiated Upper Pro-

terozoic strata in the north-west. They also classified the arenaceous sediments of the Pilpah Range, 65 miles west-north-west of Mount Isa, as Upper Proterozoic.

Officers of A.G.G.S.N.A. also added considerably to an understanding of the mineralization controls in the region. Blanchard & Hall (1937 and 1942) and S. R. Carter (1950, 1952, 1953) have made the major contributions to our knowledge of the Mount Isa lead-zinc orebodies, and Knight (1953, pp. 352-360) to that of their regional setting. The copper orebodies at Mount Isa have not yet been adequately described, but S. R. Carter (1958) has given a brief account of them.

Edwards & Baker (1954), in their study of scapolitization in the district, and Joplin (1955), in her preliminary account of metamorphism and of the granites of the district, have given the first systematic accounts of the petrology of the region.

Edwards (1954), McAndrew & Edwards (various) and Whittle have contributed to the mineragraphy and petrology of the uranium deposits, and Carter (1955) has given an account of their field occurrences. Edwards (1957-1959) has described the mineralogy of the Constance Range iron ores.

Geological Maps of the Region

Daintree (1872, pl. 9) — Sketch map of the geology of Queensland; scale approximately 1 inch to 100 miles.

Jack (1886) — Geological map of Queensland; scale 1 inch to 32 miles. Department of Works and Mines.

Jack (1892) — Geological map of Queensland (in six sheets); scale 1 inch to 16 miles. Geological Survey of Queensland Publication 90. Also issued as folio to accompany Jack, R.L. and Etheridge, R. Jun. (1892) — see Bibliography.

Jack (1899) — Ditto. Second edition. G.S.Q. Publ. 145.

Cameron (1900) — Geological sketch map of Cloncurry district; scale 1 inch to 4 miles. In G.S.Q. Publ. 153.

Cameron (1901) — Geological map of north-western Queensland; scale 1 inch to 40 miles. In G.S.Q. Publ. 159.

G.S.Q. Publ. 182 (1902) — Geological sketch map of Queensland; scale 1 inch to 40 miles.

Department of Mines — Annual reports for 1902, 1903, 1904. Geological maps of Queensland; scale 1 inch to 40 miles.

G.S.Q. Publ. 206 (1906) — Geological sketch map of Queensland (showing mineral localities); scale 1 inch to 40 miles.

G.S.Q. Publ. 217 (1908) — Ditto, third edition; scale 1 inch to 40 miles.

Ball (1908) — Geological sketch map of the Cloncurry mining district; scale 1 inch to 18 miles. In G.S.Q. Publ. 215.

Dunstan (1913, pl. 21) — Geological map of the district of Gregory North and Burke; scale 1 inch to 71 miles. In G.S.Q. Publ. 241.

Dunstan (1920, pl. 1) — Geological sketch map of part of western Queensland; scale 1 inch to 32 miles. In G.S.Q. Publ. 265.

By 1920 the outline of the outcropping Precambrian of north-western Queensland had been fairly accurately established; therefore later geological maps of Queensland are not listed.

A.G.G.S.N.A. (1936a, pl. 1) — Preliminary geological sketch map of the Cloncurry district; scale 1 inch to 6 miles.

A.G.G.S.N.A. (1937a, pl. 4) — Geological sketch map of the Cloncurry district; scale 1 inch to 6 miles.

Nye & Rayner (1940, pl. 1) — Cloncurry Gold and Mineral Field; scale 1 inch to 6 miles.

Shepherd (1946a) — Geological sketch map, Cloncurry area; scale 1 inch to 36 miles.

In addition, all published A.G.G.S.N.A. reports on mining districts have lithological maps in colour.

Present Investigations

The intention of the mapping programme was to define the limits of the mineralized rocks in north-western Queensland, to determine the structure and stratigraphy, and to interpret the geological history of the area in an attempt to determine the factors controlling mineralization in the area. It was expected that this basic information would make possible the selection of specific targets for closer investigation by geological, geophysical, and geochemical methods, and, where warranted, by drilling. At the time of writing considerable "follow-up" work had been done, both by government agencies and by mining companies.

Mapping was done by joint B.M.R.* and G.S.Q.† teams, under the leadership of Bureau geologists. Field work began in August 1950. The following geologists took part:—

1950—K. A. Townley, B.M.R., party leader, W. C. Smith, B.M.R., D. J. Gates, B.M.R., P. Healy, G.S.Q.

1951—K. A. Townley, B.M.R., party leader, E. M. Bennett, B.M.R., D. J. Gates, B.M.R., P. Healy, G.S.Q.

1952—K. A. Townley, B.M.R., party leader, E. K. Carter, B.M.R., W. M. B. Roberts, B.M.R., B. W. Hawkins, G.S.Q.; J. F. Ivanac, B.M.R., party leader, E. M. Bennett, B.M.R., R. A. Searl, B.M.R., J. H. Brooks, G.S.Q.

1953—E. K. Carter, B.M.R., officer-in-charge of field work, E. M. Bennett, B.M.R., party leader, R. A. Searl, B.M.R., party leader, K. R. Walker, B.M.R., R. B. Fraser, B.M.R., B. W. Hawkins, G.S.Q., J. H. Brooks, G.S.Q.

1954—E. K. Carter, B.M.R., party leader, R. B. Fraser, B.M.R., J. H. Brooks, G.S.Q.
K. A. Townley joined the party for one month.

Further check work was done by E. K. Carter for several weeks in 1955, 1956 and 1959, and by K. R. Walker in 1954, 1955 and 1957.

---

* Bureau of Mineral Resources, Geology and Geophysics.

† Geological Survey of Queensland.

Extensive petrological work on the igneous and metamorphic rocks has been done by K. R. Walker from 1954 to 1957.

Method of Operation

All mapping was done with the aid of vertical air photographs, taken by the Royal Australian Air Force from a height of 25,000 feet to give a scale of 1:50,000 (approximately 1 inch to ¾ mile). These provided the only available accurate record of the topography of the region. Owing to the relatively low density of vegetation and scanty soil cover geological features such as trend lines, faults, dykes, and lithological boundaries generally show up well on the air photographs. The region is particularly well suited to photo-geological methods.

Mapping was done by foot-traverse, vehicles being used only for access. Field observations were made along lines of traverse at right angles to observed structural (bedding) trends and boundaries. At no time were boundaries 'walked out'. As a result subsequent mapping will show some boundaries to be very inexact. The distance apart of traverses was determined by ease of photo-geological interpretation, complexity, economic and geological interest of the area, and accessibility.

Generally traverses were from 2 to 5 miles apart, but in places were as far apart as 25 miles. Density of mapping was greater in the Cloncurry and Duchess 4-mile Sheets* than elsewhere. Much of the area between Paradise Creek, which flows into Gunpowder Creek, and the upper reaches of Fiery and Sandy Creeks, on the Camooweal 4-mile Sheet, has not been mapped, owing to difficulty of access and limited time available. This area has been photo-interpreted only.

Topographic base maps at air-photo scale and at a scale of 1 inch to 4 miles were prepared by National Mapping Section, Department of the Interior. These were compiled from air photographs by the slotted template method, controlled by astrofixes at a few ground stations, which were identified on the air photographs. For some of the 4-mile Sheets these compilations were not available when the field work was done and topography had to be plotted on rough base maps by field geologists.

Final airphoto-scale compilations on transparent media include lithology by symbols and stratigraphical boundaries. These compilations were photographically reduced to 1 inch to 4 miles and the published maps were produced from the reductions.

The airphoto-scale (1:50,000) sheets, which contain more structural and lithological detail than the 1 inch to 4 mile published maps, may be inspected at the office of the Geological Branch, Bureau of Mineral Resources, Canberra.

Short accounts of the general geology of the region, based on the survey, appear in Carter (1958) and Carter & Brooks (1960). The interpretations given in these papers are modified below.

* An index to the 4-mile geological series map Sheets appears in Figure 1.

The petrological work was done mainly on specimens collected along regional traverses for purposes of rock identification and petrographic description. A collection made in this way does not provide adequate material for petrogenetic studies. Therefore the basic and acid igneous rock specimens which were collected in greater detail from a few critical areas and used in other petrological investigations (Walker, 1958, unpubl., Joplin & Walker, in press) have also been used in conjunction with the 'grab' collection for the petrogenetic studies. By combining all petrological information with known field relations, it is hoped that the essentials of the complex igneous, metamorphic, and metasomatic histories have been recognized, though not as yet adequately demonstrated in detail.

Concurrent Related Investigations

During 1951 a party led by K. W. B. Iten, and including Searl and Brooks, mapped the environs of the Mount Elliott, Hampden, and Crusader copper mines (Searl, 1952a, b, c, unpubl.).

Towards the close of the 1953 field season Carter, Brooks, and Fraser made a plane-table survey of Mount Philp iron deposit (Carter & Brooks, 1955).

In 1954 Carter and K. R. Levingstone (G.S.Q.) examined the more important known radioactive occurrences and reported independently to their respective organisations (see Bibliography). Brooks and D. Carruthers (G.S.Q.) also reported on uranium deposits in 1954, and during most of 1955 Brooks was in the district reporting on current developments in uranium and copper exploration and development.

The ?Upper Proterozoic Camooweal Dolomite and Cambrian strata on the Lawn Hill, Camooweal, Mount Isa, Urandangi, and Duchess 4-mile Sheets were mapped in some detail by A. A. Öpik between 1952 and 1957. He was assisted by J. N. Casey and M. A. Randal in 1953 (Öpik, in preparation).

Some geochemical testing was done by A. H. Debnam in the Mount Isa area (Debnam, 1953 unpubl. and 1954-55). Several mine areas and prospects were geophysically tested by J. Horvath, W. Oldham, K. Tate, W. Langron, and D. Rowston in 1951-53 (Horvath et al., unpubl., several references, and Langron, 1956, unpubl.).

Subsequent Investigations

In 1956 a Bureau party led by W. C. White mapped in some detail an area of 500 square miles in the Kuridala-Mount Cobalt area and 140 square miles round the Dugald River lead-zinc prospect (White, 1960).

A joint party, under the leadership of F. de Keyser, mapped 1200 square miles in the Paradise Creek area, north-west of Mount Isa, during the 1957 field season. The results of these two seasons' work have been incorporated in the 4-mile maps and in this bulletin. See also Robertson (1960).

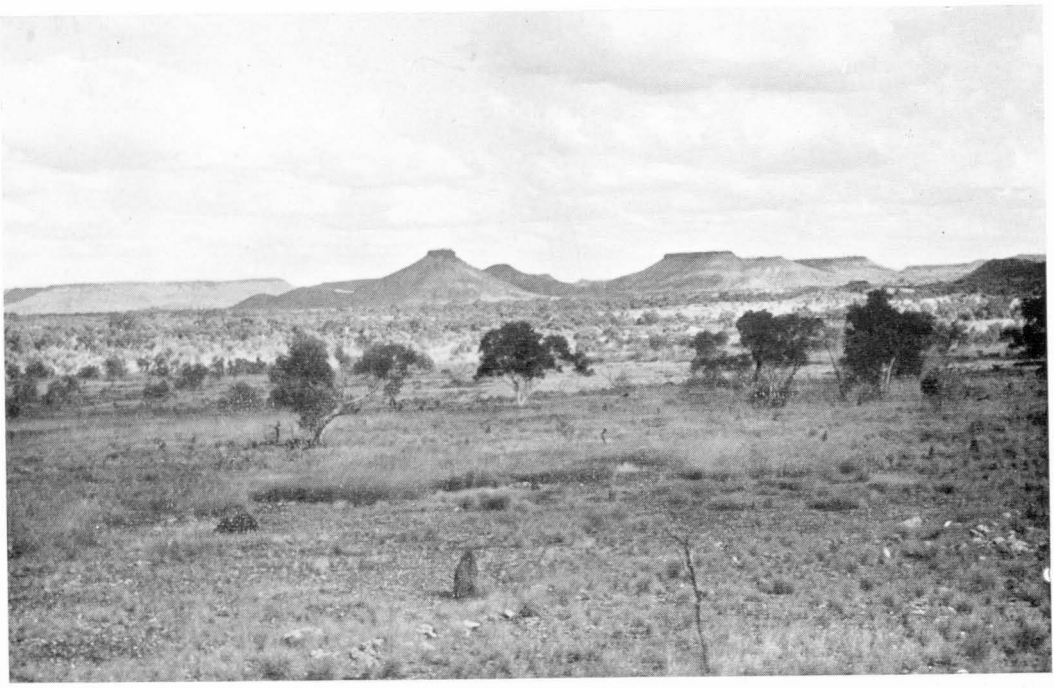


Fig. 1. Mesozoic cappings on Soldiers Cap Formation. Terrain is open and Precambrian strata are poorly exposed. Hill left of centre is Devil's Hill.

Fig. 2. Well-exposed strata of Soldiers Cap Formation, with Mesozoic cappings, showing rough terrain.

Fig. 1. Scene in the Argylla Ranges, showing typical rock outcrop, minor water-course and vegetation.

Fig. 2. Typical relief in Argylla Ranges. Quartzite in foreground and right middle distance. Calc-silicate rocks of Corella Formation in distance. View about 4 miles north-west of Mary Kathleen uranium mine.

Fig. 1. Terrain produced by acid lavas of the Argylla Formation. View in Argylla Ranges from Mount Isa-Cloncurry road, about 23 miles from Mount Isa.

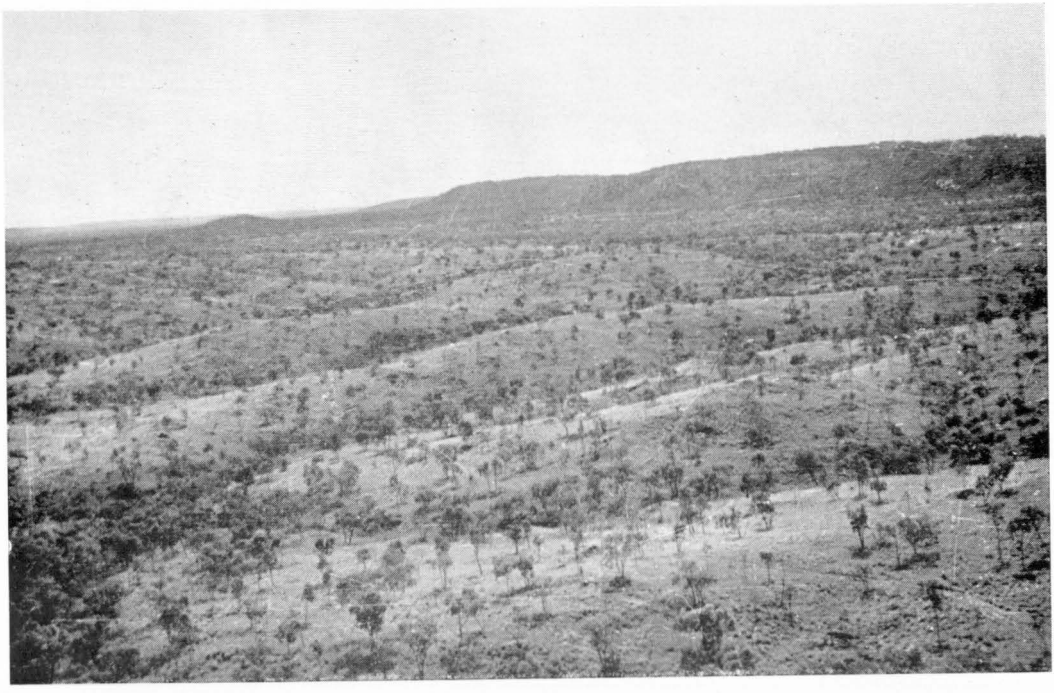


Fig. 2. Typical land surface produced by Eastern Creek Volcanics. Hills in right background are of Leander Quartzite.

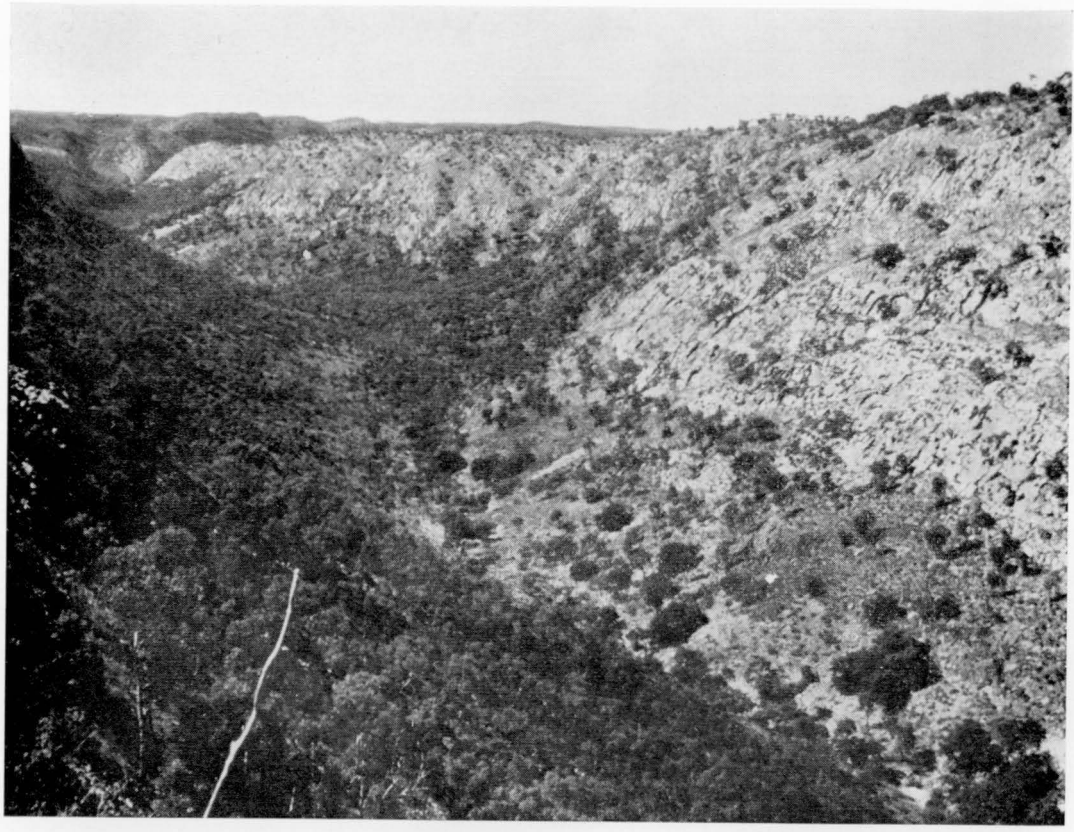


Fig. 1. Strike valley in Surprise Creek Beds, about one mile south-east of Mount Gordon copper mine. A dip slope forms the right hand wall of the valley.

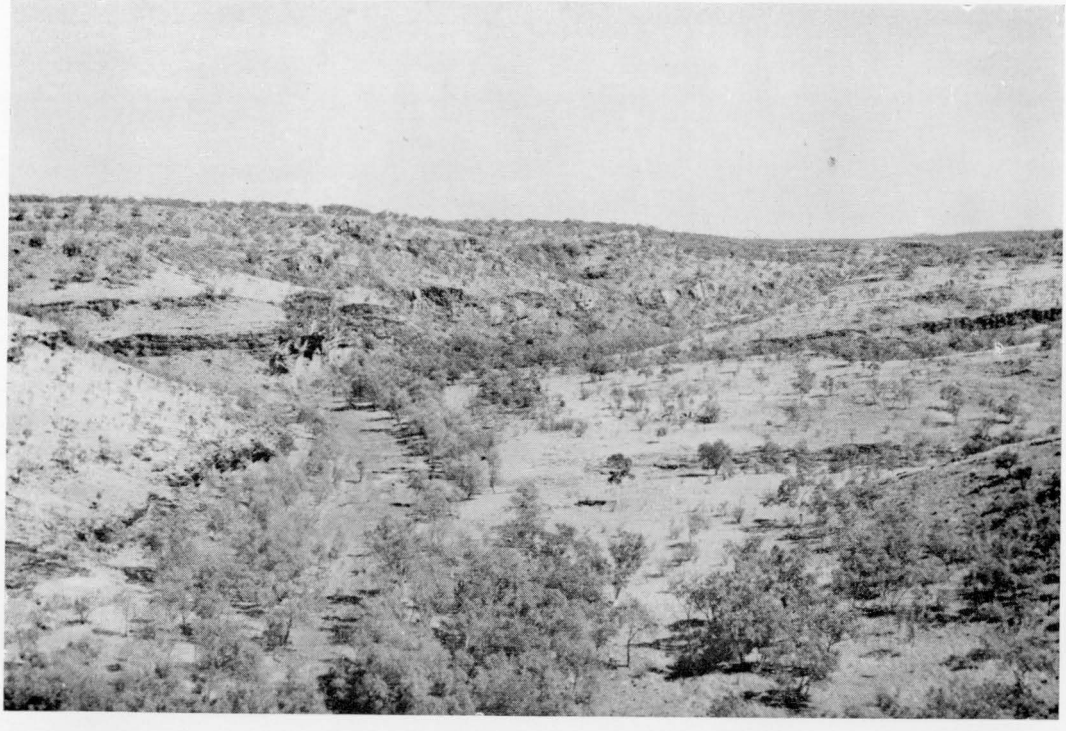


Fig. 2. Gently dipping, mainly dolomitic, strata of Paradise Creek Formation. View looking up Paradise Creek, from about 5 miles from junction with Gunpowder Creek.

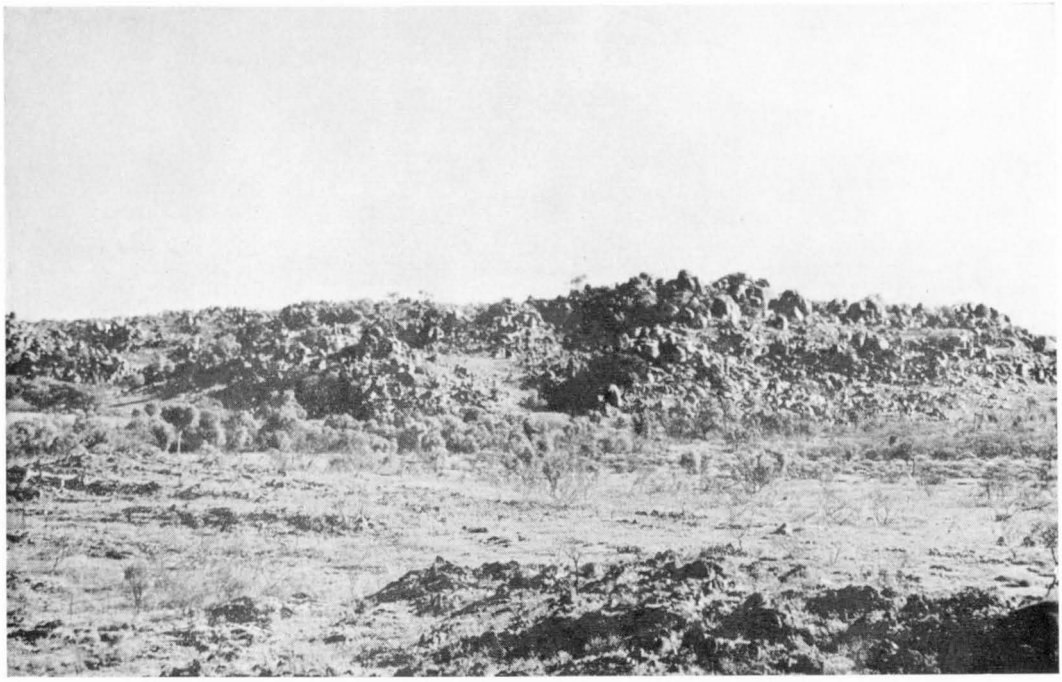


Fig. 1. Stock of Williams Granite, intruded into Kuridala Formation, about 3 miles north-east of Mount Cobalt mine.

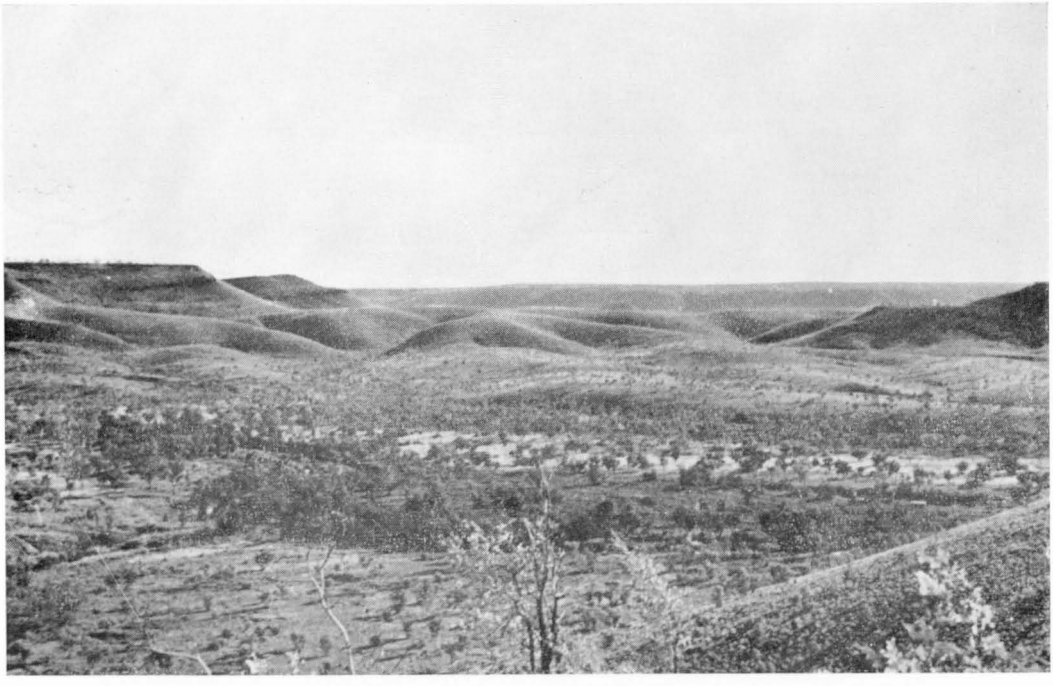


Fig. 2. Typical topographic expression of Mullera Formation; Musselbrook Creek in middle foreground. Gently dipping oolitic iron beds of the Mullera Formation appear in the left of the photograph, overlain by flat-lying Mesozoic sediments. The hills forming the skyline are of Constance Sandstone.

Fig. 1. Two beds of oolitic iron ore in the Mullera Formation, 5 miles south of Elizabeth Creek, Constance Range area. The apparent repetition of the beds in the middle distance is due to faulting. A capping of flat-lying Mesozoic sediments forms the background.

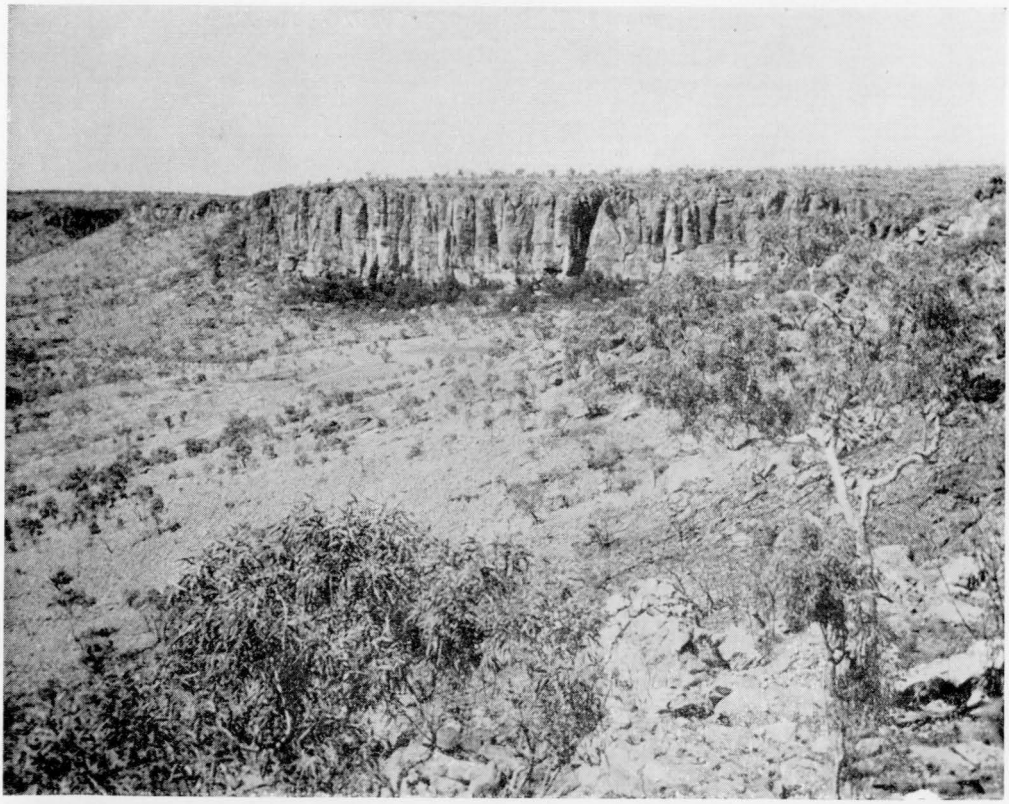


Fig. 2. Scarp of Constance Sandstone at eastern margin of Constance Range, 8 miles southwest of Lawn Hill homestead.

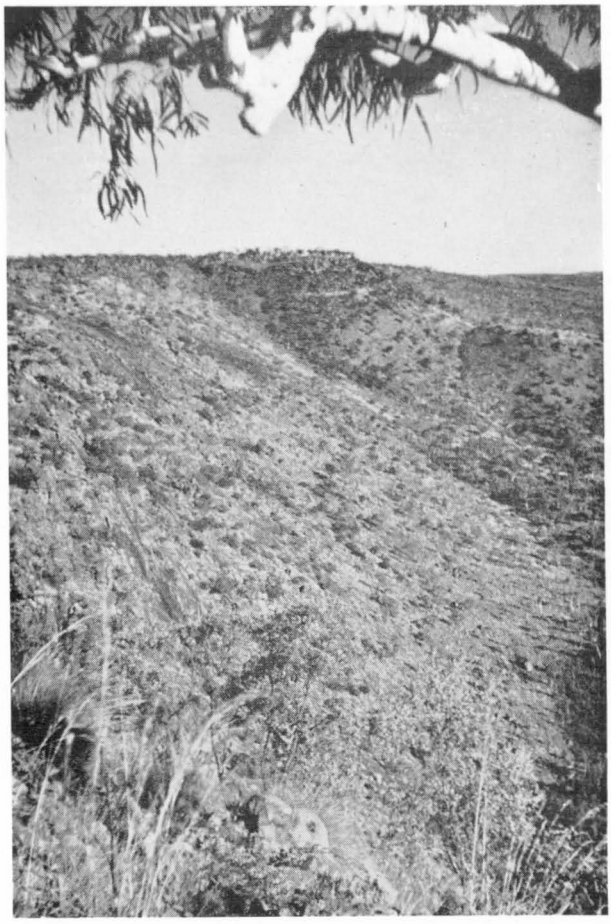
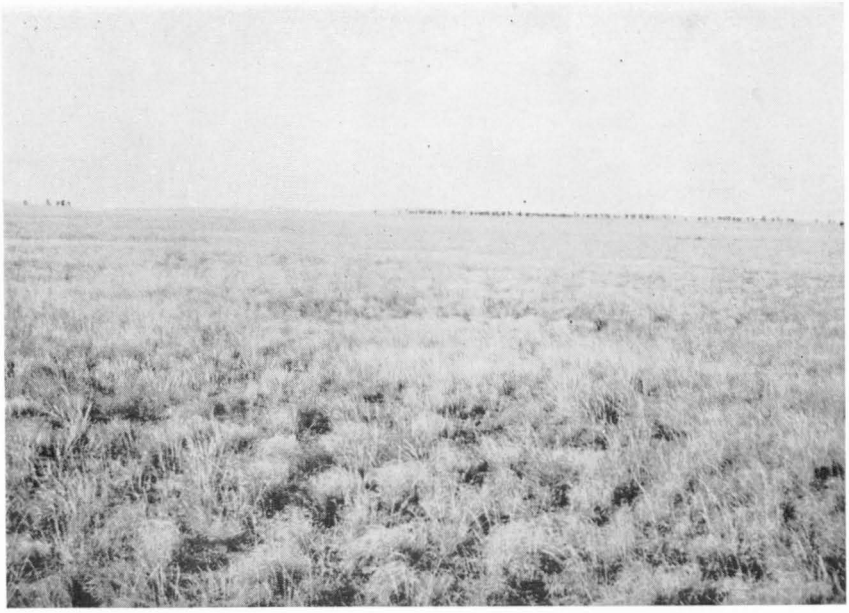


Fig. 1. Dip slope of Westmoreland Conglomerate forming southern edge of Lagoon Creek Valley, one mile west of Northern Territory border. Peters Creek Volcanics overlie the Conglomerate in the middle distance, at the right, and Mesozoic sediments form a capping in the centre.

Fig. 2. Barkly Tableland, north of Camooweal — an example of the grassy plains common in the region around the hilly Precambrian outcrop area.



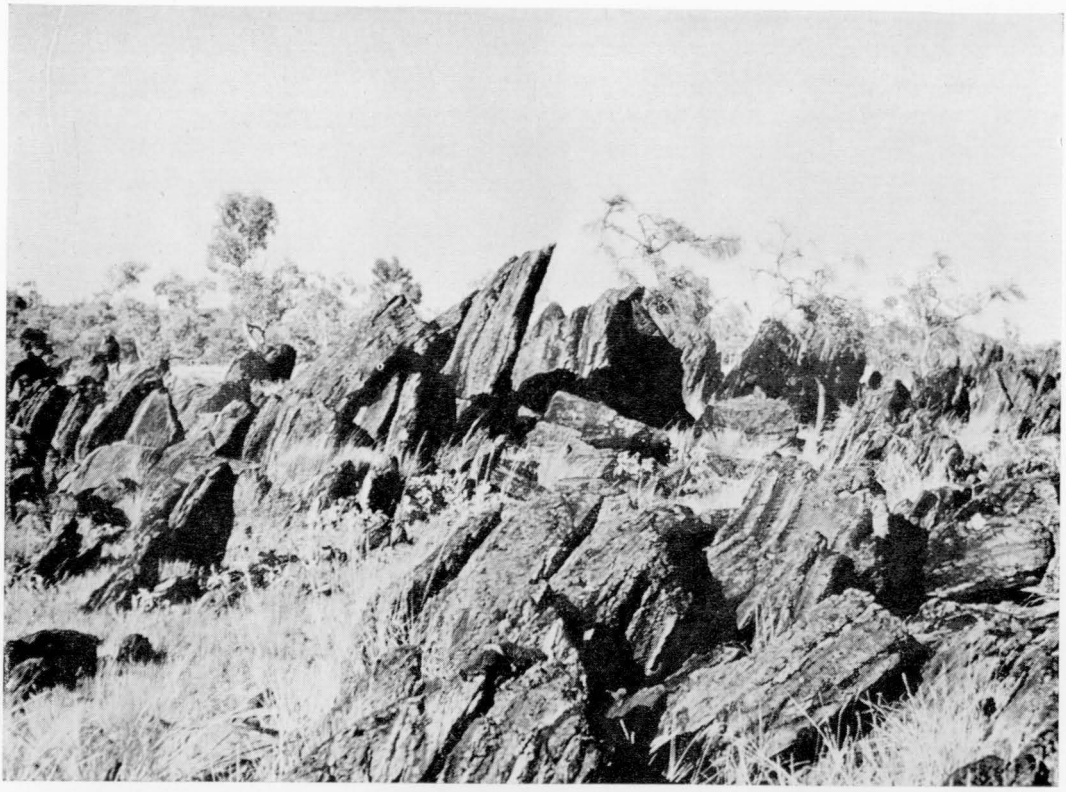


Fig. 1. Metamorphosed limestone of Staveley Formation, near Selwyn-Chatsworth Homestead track, 12 miles from Selwyn.

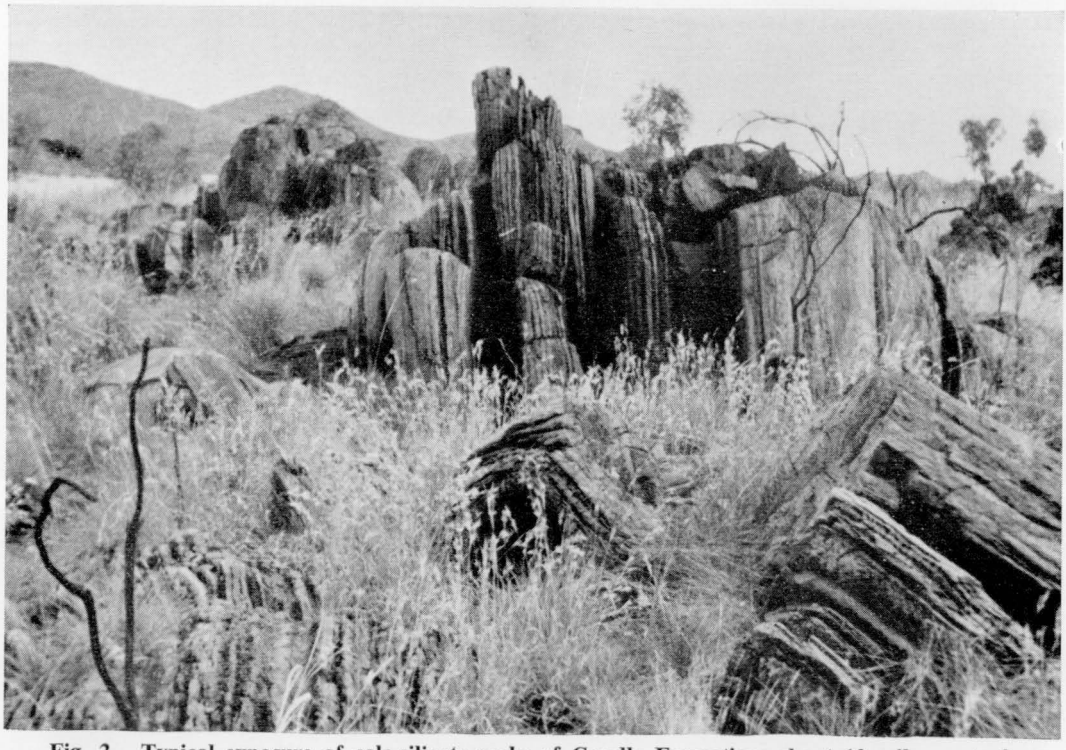


Fig. 2. Typical exposure of calc-silicate rocks of Corella Formation; about 10 miles east of Lady Fanny copper mine.

Mapping was also begun in 1956, and continued in 1957, under the leadership of J. B. Firman, in the portion of the Northern Territory adjacent to the Westmoreland 4-mile Sheet area. Results of this work, in so far as they have a bearing on the Precambrian strata in Queensland, have been included in the bulletin.

In 1958 large sedimentary iron deposits in the Constance Range area were mapped by a joint B.M.R.-G.S.Q. team, under the leadership of D. O. Zimmerman and Carter. The deposits have been tested by drilling by the Broken Hill Proprietary Company Ltd since 1957.

Authorship

Part I of this bulletin has been largely written by Carter, but the section on 'General History' was written by Brooks and that on 'Petrology' by Walker. All petrological descriptions of rocks in thin section, unless otherwise acknowledged, are based on work by Walker.

Part II was written jointly by Brooks and Carter, who also jointly compiled the Bibliography. Walker carried out the necessary laboratory work for, and wrote, Appendix I, and Brooks compiled Appendix II.

Geomorphology

Stewart (1954) described the geomorphology of the region west from longitude 139°30′E to the Stuart Highway, and from the Gulf of Carpentaria to south of Dajarra; Twidale (1956 a-c and in preparation [1 & 2]) dealt with the region east to Hughenden. The two authors treat their respective areas somewhat differently, and as the join-line passes through the area of outcropping Precambrian, the western and eastern sectors are described in different ways.

Stewart (p. 42) divides the western region into the Gulf Fall division, the Georgina Basin division, and the Barkly Basin division; in a second category of geomorphological units he divides the region into that part with an erosional land surface and that with a depositional surface. It is with portions of four of the seven subdivisions of the erosional surface that we are concerned, in the region dealt with by Stewart (p. 52 et seq.); that is: dissected country of Gulf fall, dissected country of Gulf fall with lateritic remnants, dissected country of the Georgina Basin without lateritic remnants, and dissected country of the Georgina Basin with lateritic remnants. Twidale's main divisions for the eastern sector are: The Isa Highlands, the Carpentaria and Inland Plains, and the Einasleigh Uplands. The first named division, together with two of the marginal provinces of the Plains division (the Cloncurry Plain and the Burke Plain), covers the eastern portion of the region dealt with in this bulletin. Twidale further subdivides the Isa Highlands into an immaturely dissected plateau and an immaturely dissected plateau with limited plains (Twidale, in preparation [2], fig. 26).

He recognises three earlier erosional surfaces:

(a) pre-mid-Mesozoic surface;
(b) early to mid-Tertiary surface; and
(c) late Tertiary-Quaternary surface.

These are all believed to have been peneplains and all contribute in some measure to the present configuration of the land surface. He considers that the present drainage pattern is Tertiary or later in origin and is essentially adjusted to epeirogenic movements. Only one period of mature lateritization is recognised: it is considered to be early to mid-Tertiary in age. Stewart and Twidale both recognise that differential vertical movements, in which the uplands were elevated and the coastal plains down-warped, took place in late Tertiary to Pleistocene times, thus rejuvenating the upper reaches of the present drainage system. They also agree that there has been a slight eustatic fall in sea level in Recent times. Stewart considers that this was preceded by a substantial eustatic rise in sea level in Pleistocene times, but Twidale reserves judgment. They agree that the climate has become drier since Miocene times. This has affected the rate of erosion and the type of erosional sculpture.

Within the region with which we are concerned the detail of land-form can be explained in terms of the lithology and structure of the Precambrian rocks (after allowance has been made for the youthfulness of stream channels due to sub-Recent uplift and to the influence of climate). There are two general exceptions. Within the marginal zone of dissection of the Georgina Basin, i.e. the south-west and western edge of the region, former land-surfaces are preserved in part, and these rather than the underlying Precambrian strata have shaped the drainage systems and land-forms, particularly where laterite is present. In the south-east of the area extensive remnants of horizontal Mesozoic strata have produced a characteristic topography, composed of mesas with sharp break-aways and numerous deeply indented re-entrant valleys, the result of pedimentation and headward erosion (see Pl. 2, and Öpik, 1961).

Throughout the region the effect of faulting on the topography and drainage pattern is not very pronounced except in so far as blocks of very different erosional characteristics are brought into juxtaposition by faulting.

In such cases strike-faulting tends to emphasize the 'grain' of the country and transverse faulting to destroy linear patterns. Because of the complexity of structure markedly linear patterns are, in any case, poorly developed. The extensive north-east-striking fault system on the Cloncurry 4-mile Sheet, however, appears to have exerted a considerable influence on topography in that area. In places the faults are filled with quartz (e.g. Fountain Range Fault, see Pl. 11, fig. 2) and have produced razorbacked ridges which strike across the country for many miles and provide an effective barrier through which watercourses break in narrow gorges or falls at widely spaced intervals. The Fountain Range Fault line rises more than

600 feet above the adjoining country in places. The trend of the faults is clearly picked out, even where the faults themselves have not been recognised, by such watercourses as Prospector Creek, Corella River, Tommy Creek, and Dugald River.

The sandstones and conglomerates of the Constance Range and north of the Nicholson River tend to be strongly jointed. In places the joints have been deeply eroded to give a maze of geometrically-arranged, almost vertical-sided gullies (see Pl. 25) .

Quartzite, being very resistant, generally forms the areas of greatest relief. Valleys are deeply incised and V-shaped. Where structure is not complex, main tributaries of the major streams tend to cut across the bedding strike in steep valleys and gorges and to be served by parallel subsidiary watercourses which form strike valleys (Pl. 4, fig. 1). In the west of the area, e.g. around lat. 20° 20′S, long. 139°22′E, the even-topped ridges are silicified, forming 'billy'; this apparently represents an earlier land surface.

Valleys, with extensive alluvium, are formed in shale and slate. Relief is slight. Major streams tend to occupy such belts; the West Leichhardt River follows the Mount Isa Shale belt, and the Cloncurry River, south of Cloncurry, follows the belt of the Marimo Slate. The calc-silicate rocks of the Corella Formation are generally so highly deformed that major tributaries do not conform to bedding trends. Where erosion is active, the rocks of this formation form prominent outcrops, with some high strike ridges, giving a very rough land-surface which is difficult to cross. In the more extensively soil-covered areas outcrops project boldly through the fine-textured black soil (Pl. 9, fig. 2).

The dolomite of the Ploughed Mountain and Surprise Creek Beds, and Paradise Creek Formation (Pl. 15, fig. 1) is not as resistant as the sandstone with which it is commonly associated. For this reason strike valleys tend to follow its outcrop, as they do that of the interbedded shales and siltstones of the same successions. The shale and dolomite, by their erosion, generally provide the most practicable access routes through outcropping strata with which they are associated.

The metamorphosed basaltic successions, with their generally thinly interbedded metasediments, produce low relief but rough, bouldery outcrop, difficult for travel, in which a drainage pattern showing fine detail is developed (Pl. 4, fig. 2). Where alluviation is more extensive well-grassed black or red soil plains are produced.

Where the Lower Proterozoic acid lavas are relatively slightly metamorphosed they produce a rough, boulder-strewn land-surface across which travel is very difficult (Pl. 4, fig. 1). The parts that have been strongly affected by granite or that are more deeply eroded than the remainder give open country, with numerous large, sharply-projecting outcrops. The acid and intermediate lavas of the Cliff-

dale Volcanics and Upper Proterozoic volcanic units also give a very rough, but low, topography in which the watercourses are closely controlled by a well developed joint system.

The granites of the area produce the characteristic fine dendritic drainage pattern of granites elsewhere, with fine sandy to coarse gravelly soils, which support light grasses. Where erosion is active, prominent boulders, tors, and piled masses of granite crop out (Pl. 6, fig. 1).

Regional Setting

The Precambrian of north-western Queensland, with the exception of the Camooweal Dolomite, i.e. the Cloncurrry Complex, forms part of the Australian Precambrian Shield. Though near the eastern margin of the shield, it was probably not marginal at the time of formation. The outline of its outcrop is appendiform (see Fig. 2) and is terminated in the north-west by the Northern Territory border. Beyond that point the successions of Precambrian rocks represented in Queensland by the outcrops on the Westmoreland 4-mile Sheet and of the Constance Range extend in a belt about 100 miles wide and parallel to the coastline of the Gulf of Carpentaria, to the Roper River, and there connect with the Arnhem Land Precambrian strata.

To the south-west of the region Upper Proterozoic? Camooweal Dolomite, as defined by Öpik (1956b), crops out extensively from the southern end of the Constance Range to south-east of Urandangi, and westwards into the Northern Territory. Overlying the Camooweal Dolomite are formations of Middle and Upper Cambrian age (Öpik, 1956a and b, and in preparation), which represent a Cambrian transgression which flanked the present western, south-western, and southern limits of outcropping Precambrian. The sea gradually withdrew southwards in Upper Cambrian and Ordovician times, as is indicated by Ordovician strata on Chatsworth Station about lat. 21°55′S, long. 140°02′E, and farther south, and in the Toko Range, west of the lower Georgina River.

To the north and east of the region the only strata cropping out within about 140 miles, with the exception of Mounts Fort Bowen and Brown, are Mesozoic and later sediments, both freshwater and marine. The Mesozoic outcrops also extend to the south of the Precambrian rocks, on to the Duchess, Boulia, and Glenormiston 4-mile Sheets. Mount Fort Bowen and Mount Brown are composed of folded rocks of probable Precambrian age.

Mesozoic sediments lie directly on the Precambrian strata along their eastern margin, and also form numerous flat-topped outliers. These represent the western margin of the Great Artesian Basin, whose sediments, of Triassic to Cretaceous age, have a maximum thickness of many thousand feet. In the west of the basin the basement consists of granite and metamorphics.

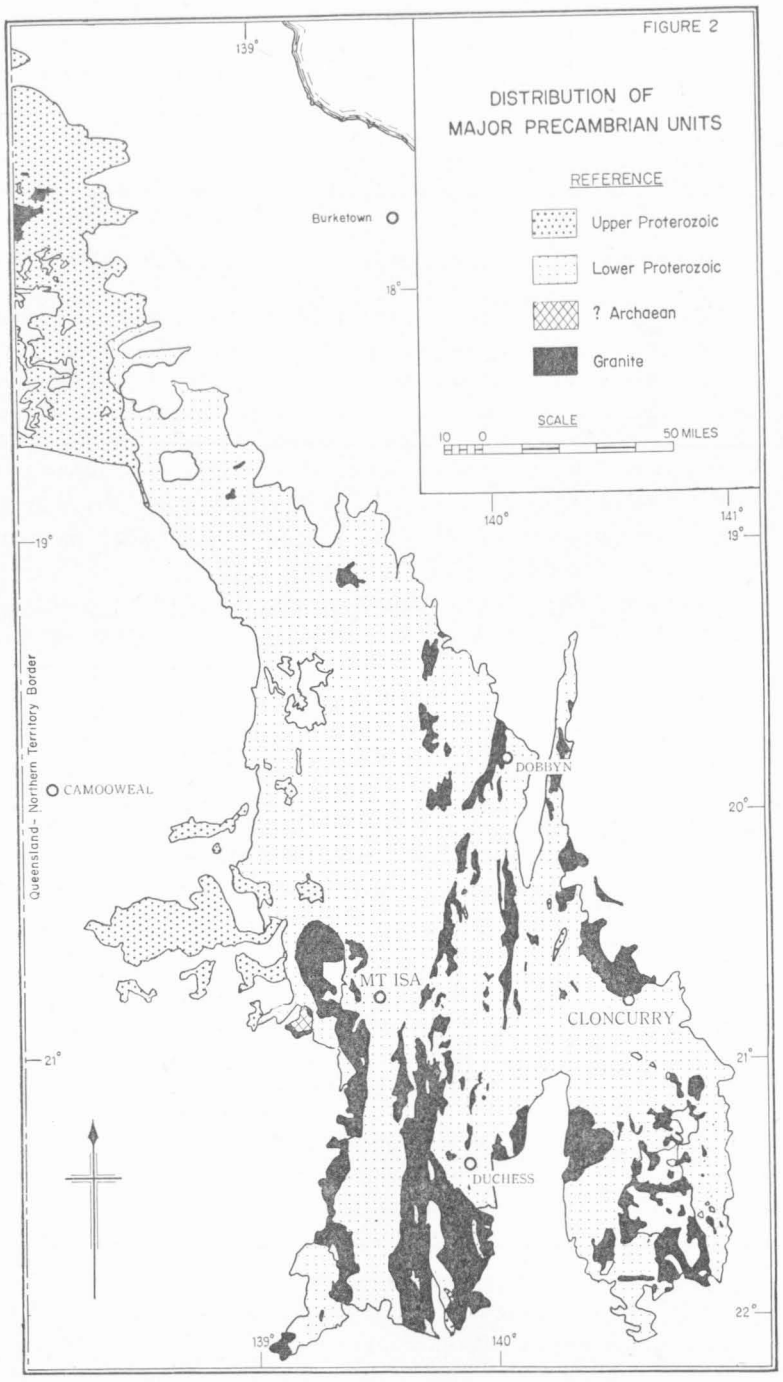


FIGURE 2
DISTRIBUTION OF
MAJOR PRECAMBRIAN UNITS
REFERENCE
Upper Proterozoic
Lower Proterozoic
? Archaean
Granite
SCALE
10 0 50 MILES
139°
140°
141°
18°
19°
20°
21°
22°
Burketown
CAMOOWEAL
DOBBYN
MT ISA
CLONCURRY
DUCHESS
Queensland - Northern Territory Border

In Tertiary times lacustrine limestone deposits formed around Urandangi and Tobermory, in a basin of internal drainage (Noakes & Traves, 1954, p. 40). Local lacustrine deposits occur near Riversleigh Homestead. The present extensive soil areas developed in this and later geological time.

Cainozoic 'black' soil and Recent alluvium cover much of the area to the north, east, and south-west of the region.

OUTLINE OF THE GEOLOGY OF THE PRECAMBRIAN

The Cloncurry Complex is believed to consist of ?Archaean, Lower Proterozoic, and Upper Proterozoic rocks, whose distribution is shown in Figure 2, and to contain granites of at least five ages.

The extent of the exposed ?Archaean crystalline rocks, probably including granite, is not accurately known. The Lower Proterozoic rocks form part of an orogenic belt. The older rocks are largely metavolcanics, acid lavas at the base, overlain by metabasalt; most of the lavas are interbedded with metasediments. The sediments accumulated in two distinct geosynclinal basins (see Fig. 4). Sedimentation continued in the western basin while diastrophism deformed the strata in the eastern belt. The orogenic forces brought about folding on meridional axes, and extensive faulting, of the strata in the eastern basin. They were probably accompanied by granite which metamorphosed and metasomatized the country rocks. During a second orogenic phase, accompanied by granite intrusion and uplift, the whole region was deformed and Lower Proterozoic sedimentation ceased.

The Upper Proterozoic consists of both lavas and shallow-water sediments; the lavas are confined to the extreme north-west of the region. Both lavas and sediments are more extensively developed in the Northern Territory. High-level granite intrudes the oldest of the lavas (which may be older than Upper Proterozoic) but is overlain by later formations. Moderate folding, on west to north-west axes, and faulting have deformed the Upper Proterozoic strata.

A brief description of the stratigraphical units of the region is given in Tables II and III. Their mutual relationships are indicated in Figures 3 and 8, and a series of stratigraphical columns show superpositional relationships in Figure 9. The units are defined, described and discussed at length on pp. 56-125.

Structure

Major unconformities are believed to occur at the base and top of the Lower Proterozoic. A strong unconformity also occurs at the base of the Deighton Quartzite, and a slight angular unconformity, of considerable regional importance, at the base of the Corella Formation. These last two unconformities are poorly represented in the west of the Lower Proterozoic outcrop area. An unconformity

TABLE II — SUMMARY OF UPPER PROTEROZOIC STRATIGRAPHY

Age	Unit	Lithology	Thickness (in Feet)	Distribution (4-mile Sheets) & Area of Outcrop	Relationships to Other Units	Remarks
UPPER PROTEROZOIC OR PALAEOZOIC	Quamby Conglomerate	Conglomerate, arkosic greywacke, sandstone.	1,000?	Cloncurry. 9 sq. miles.	Uncomformably over Corella F.	
	Makbat Sandstone	Quartzitic sandstone, some conglomerate & shale.	1,000+	Duchess, Boulia. 14 sq. miles.	Unconformably over Argylla F. & Kalkadoon Granite.	May be equivalent to Mt Birnie Beds, which are L. Cambrian.
UPPER PROTEROZOIC OR CAMBRIAN	Camooweal Dolomite	Dolomite; sandy interbeds near base.	800	Lawn Hill, Camooweal, Mt Isa, Urandangi, & others.	Unconformably below M. Cambrian sediments. Uncomformably over Pilpah Sdst. & L. Proterozoic.	Mapped by Öpik (Öpik, 1956a & b; Noakes, 1956).
	Riversdale Formation	Conglomerate, red sandy dolomite & sandstone.	150	Urandangi. 1 sq. mile.	Unconformably over Eastern Creek Volcs.; unconformably overlain by M. Cambrian.	May be equivalent to Camooweal Dol. or L. Cambrian formations.
	Colless Volcanics	Basalt and other lavas.	200?	Lawn Hill. 10 sq. miles.	Unconformably overlies Mullera F., possibly overlain by Camooweal Dol.	
UPPER PROTEROZOIC	Pilpah Sandstone	Sandstone, some conglomerate.	1,000?	Mt Isa, Camooweal. 650 sq. miles.	Unconformably over Paradise Creek F.; unconformably overlain by Camooweal Dol. & M. Cambrian.	
	Gold Creek Volcanics	Acid & intermediate lavas, agglomerate; some sediments.	300+	Westmoreland. 3 sq. miles in Queensland.	Overlies Constance Sdst.	Main occurrence in N.T. where it probably also overlies Mullera F.
	Mullera Formation	Siltstone, shale, fine sandstone; ferruginous sandstone; & siltstone.	7,000	Lawn Hill. 340 sq. miles.	Overlies Constance Sdst. conformably.	Also occurs in N.T.
	Constance Sandstone	Generally medium to coarse sandstone; some fine silty sandstone & conglomerate.	3,600	Westmoreland, Lawn Hill. 900 sq. miles.	Underlain by Lawn Hill F. with major unconformity, by Wollogorang F. disconformably(?). Conformably overlain by Mullera F.	Also occurs in N.T.
	Wollogorang Formation	Dolomite, siltstone, sandstone & chert.	500+	Westmoreland. 120 sq. miles.	Underlain by Peters Creek Volcs.; overlain, probably disconformably, by Constance Sdst.	Also occurs extensively in N.T. Type area in N.T.
	Peters Creek Volcanics	Altered intermediate & basic lavas, tuff, & agglomerate, with interbedded sediments.	1,000+	Westmoreland. 150 sq. miles.	Underlain unconformably, by Cliffdale Volcs & possibly disconformably by Westmoreland Cong. Overlain by Wollogorang F.	Also occurs in N.T.
	Westmoreland Conglomerate	Conglomerate, pebble beds, coarse to medium sandstone.	1,500 to 4,000	Westmoreland. 180 sq. miles.	Overlain, possibly disconformably, by Peters Creek Volcs. Underlain unconformably by Cliffdale Volcs.	Also in N.T. It lies on an erosional surface of Cliffdale Volcs. and Nicholson Granite.
?Upper Proterozoic	Cliffdale Volcanics	Altered acid to intermediate lavas, tuff, agglomerate.	1,000?	Westmoreland. 150 sq. miles.	Overlain unconformably by Westmoreland Cong.	Also in N.T. Intruded by Nicholson Granite. Probably L. Proterozoic.

TABLE III — SUMMARY OF LOWER PROTEROZOIC AND ?ARCHAEAN STRATIGRAPHY.

Age	Unit	Lithology	Thickness (in Feet)	Distribution (4-Mile Sheets) & Area of Outcrop	Relationships to Other Units	Remarks
LOWER PROTEROZOIC	Lawn Hill Formation	Sandstone, siltstone, shale, aphanitic volcanics.	2,000 to 5,000?	Lawn Hill. 180 sq. miles.	Conformably underlain by Ploughed Mt Beds. Overlain, with major unconformity, by Constance Sdst.	Cliffdale Volcs may be roughly contemporaneous.
	Mount Isa Shale	Shale, dolomitic shale, siltstone, sandstone.	10,000+	Mt Isa, Cloncurry, Urandangi. 140 sq. miles.	Locally unconformably underlain by Eastern Ck Volcs & by Myally Beds, otherwise conformable or disconformable.	?Contemporaneous with Gunpowder Ck F. & part of Paradise Ck F. (which see).
	Mingera Beds	Conglomerate, quartzite, sandstone, shale.	5,000?	Mt Isa. 80 sq. miles.	Conformably underlain by Judenan Beds, & overlain by Paradise Ck F.; unconformably overlain by Pilpah Sdst.	Contemporaneous with Gunpowder Ck F.
	Ploughed Mountain Beds	Sandstone, dolomite, siltstone, quartz greywacke.	10,000 to 15,000	Lawn Hill, Camooweal, Dobbyn, 1,550 sq. miles.	Underlain, with local unconformities, by Myally Beds. Conformably overlain by Lawn Hill F.	Penecontemporaneous with Surprise Ck Beds & with Paradise Ck and Gunpowder Ck Fs. jointly.
	Surprise Creek Beds	Sandstone, dolomite, siltstone, carbonaceous siltstone, conglomerate.	20,000?	Dobbyn, Cloncurry, Camooweal. 470 sq. miles.	Apparently conformably underlain by Myally Beds, unconformably underlain by Argylla & Leichhardt Meta.	Penecontemporaneous with Ploughed Mt Beds, with Paradise Ck and Gunpowder Ck Fs jointly & in part with Mt Isa Shale & Mingera Beds.
	Paradise Creek Formation	Dolomite, siltstone, sandstone.	10,000 to 15,000?	Camooweal, Mt Isa. 400 sq. miles.	Conformably underlain by Gunpowder Ck F. & Mingera Beds. Unconformably overlain by Pilpah Sdst.	Jointly penecontemporaneous with Ploughed Mt and Surprise Ck Beds.
	Gunpowder Creek Formation	Siltstone, shale, sandstone; some dolomite.	2,000?	Camooweal, Mt Isa. 200 sq. miles.	Generally conformable with underlying Judenan & Myally Beds; probable local unconformity. Conformably overlain by Paradise Ck F.; unconformably by Pilpah Sdst.	
	Judenan Beds	Sandstone, siltstone, & shale; some conglomerate, rhyolite, & basalt.	6,000 +?	Camooweal, Mt Isa, Urandangi. 550 sq. miles.	Conformable with underlying Eastern Ck Volcs. See also Gunpowder Ck F. and Pilpah Sdst.	Penecontemporaneous with Myally Beds.
	Myally Beds	Quartzite, sandstone, conglomerate, some siltstone; acid to basic lavas & agglomerate.	20,000+	Lawn Hill, Camooweal, Dobbyn, Cloncurry. 1630 sq. miles.	Part conformably, part unconformably, underlain by Eastern Ck Volcs. Unconformably underlain by Argylla F.	See also Ploughed Mt Beds, Surprise Ck Beds, Mt Isa Shale. Penecontemporaneous with Judenan Beds.
	Deighton Quartzite	Quartzite; some conglomerate.	7,000	Cloncurry, Duchess. 35 sq. miles.	Unconformably overlies Leichhardt Meta, Argylla F., Ballara Qte, Corella F.	Probably of about same age as Surprise Ck Beds.
	Chumvale Breccia	Ferruginous breccia, quartz-sericite schist, quartzite.	1,000?	Cloncurry. 4 sq. miles.	Underlain, probably unconformably, by Corella F.	Stratigraphic relationships to other units not known.
	Knapdale Quartzite	Quartzite, some calcareous near base.	6,000?	Cloncurry. 11 sq. miles.	Probably conformably over Corella F.; relationship obscured by faulting.	
	Roxmere Quartzite	Quartzite.	3,000 to 4,000?	Cloncurry. Duchess. 10 sq. miles.	Overlies Corella F. possibly disconformably.	
	Charley Creek Formation	Thickly interbedded quartzite and calc-silicate rocks.	4,000?	Cloncurry. 15 sq. miles.	Underlain, probably unconformably, by Argylla F.	Probably equivalent to, or slightly younger than, upper Corella F. Possibly equivalent to Deighton Qte.
	Corella Formation	Thin-bedded calc-silicates, schist, slate, gneiss, quartzite, hornfels, granulite; calc-silicate breccia.	10,000?	Dobbyn, Cloncurry, Duchess. 1,930 sq. miles.	Unconformably overlies Argylla F., Soldiers Cap F., Contemporaneous with part of Marimo Slate & probably with Staveley F. For relationships to other units see p. 88.	
	Mount Philp Agglomerate	Metamorphosed & metasomatized agglomerate, basalt, quartzite, & calc-silicate rocks.	?	Cloncurry, Duchess. 10 sq. miles.	Probably equivalent to basal Corella F.	Base not exposed.
	Marimo Slate	Sandy slate, quartz greywacke, siltstone, calc-silicate rocks; some metabasalt & tuff.	8,000+?	Cloncurry, Duchess. 500 sq. miles.	Contemporaneous in part with Corella F. Conformably overlies Mitakoodi Qte.	Contemporaneous, in part at least, with Answer Slate, Staveley F. & Kuridala F.
	Kuridala Formation	Quartzite, quartz-mica & staurolite-mica schist, black slate.	8,000	Duchess, Boulia. 280 sq. miles.	Conformably underlain by Staveley F.	Probably equivalent to upper parts of Marimo Slate & Corella F.
	Staveley Formation	Dolomite, calc-silicate rocks, siltstone, shale, calc-silicate breccia.	2,000 to 8,000+	Duchess. 110 sq. miles.	Conformably overlain by Kuridala F.; slight unconformity with underlying Answer Slate.	Probably equivalent to portions of Marimo Slate & Corella F.
	Answer Slate	Slate, siltstone, chert; some quartz-sericite schist.	2,000?	Duchess. 110 sq. miles.	Conformably overlies Mitakoodi Qte.; overlain, with slight unconformity by Staveley F.	Probably equivalent to lower part of Marimo Slate.
	Eastern Creek Volcanics	Interbedded metabasalt & metasediments; some schist & gneiss. Sediments include quartzite, slate, crystalline limestone.	20,000?	Camooweal, Dobbyn, Mt Isa, Cloncurry, Urandangi. 1540 sq. miles.	Conformably underlain by Mt Guide & Leander Qtes, probably disconformably by Argylla F. Overlain, part conformably & part unconformably by Myally Beds & Mt Isa Shale. Disconformable with overlying Surprise Ck Beds. Contemporaneous with lavas of Marraba Volcs & Soldiers Cap F.	
	Mitakoodi Quartzite	Quartzite, impure in part, some metabasalt, tuff, & schist.	4,000?	Cloncurry, Duchess. 140 sq. miles.	Conformably underlain by Marraba Volcanics. Conformably overlain by Marimo Slate, Answer Slate & ?Corella F.	
	Marraba Volcanics	Metabasalt & tuff; quartzite, slate, schist, crystalline limestone.	10,000+?	Cloncurry, Duchess. 220 sq. miles.	Conformably underlain by Argylla F., conformably overlain by Mitakoodi Qte.	Contemporaneous with Eastern Ck Volcs & lavas of Soldiers Cap F.
	Soldiers Cap Formation	Mica schists, including andalusite-garnet-mica schist; metabasalt, quartzite, slate, & chert.	25,000+	Cloncurry, Duchess. 780 sq. miles.	Unconformably overlain by Corella F.	Base not exposed.
	Ballara Quartzite	Quartzite, some conglomerate.	2,000+	Cloncurry, Duchess. 40 sq. miles.	Conformably over Argylla F.; overlain (?)unconformably by Corella F. & unconformably by Deighton Qte.	Probably contemporaneous with Mt Guide & Leander Qtes.
	Mount Guide Quartzite	Quartzite, feldspathic in part; conglomerate; some metabasalt.	4,000 to 8,000+	Mt Isa, Cloncurry, Urandangi, Duchess. 400 sq. miles.	Probably overlies Leichhardt Meta. unconformably and Argylla F. disconformably. Conformably overlain by Eastern Ck Volcs.	Equivalent to Leander Qte & probably to Ballara Qte.
	Leander Quartzite	Quartzite, some metabasalt & tuff.	5,000+ Base not exposed.	Mt Isa, Cloncurry. 90 sq. miles.	Conformably overlain by Eastern Ck Volcs.	Equivalent to Mt Guide Qte & probably to Ballara Qte.
	Argylla Formation	Metarhyolite, metadacite; some metabasalt & pyroclastics; interbedded metasediments, altered in part to schist, gneiss & migmatite.	10,000?	Dobbyn, Cloncurry, Duchess, Boulia. 800 sq. miles.	Underlain, probably conformably, by Leichhardt Mets. Overlain, conformably by Marraba Volcs & Ballara Qte, probably disconformably by Mt Guide Qte & Eastern Ck Volcs, unconformably by Corella F., Deighton Qte, Myally Beds, & Surprise Ck Beds.	
	Leichhardt Metamorphics	Migmatite, gneiss, schist, recrystallized acid lavas, & amphibolite; some metasediments.	? Base not exposed.	Dobbyn, Cloncurry, Duchess. 430 sq. miles.	Overlain ?conformably by Argylla F.; clearly unconformably by Myally & Surprise Ck Beds.	
?ARCHAEAN	Yaringa Metamorphics	Migmatite, gneiss, schist, quartzite, conglomerate.	?	Mt Isa. 25 sq. miles.	Not in contact with any other formation. Age inferred from grade of metamorphism.	

TIME RELATIONSHIPS OF PRECAMBRIAN UNITS
NORTH - WEST QUEENSLAND

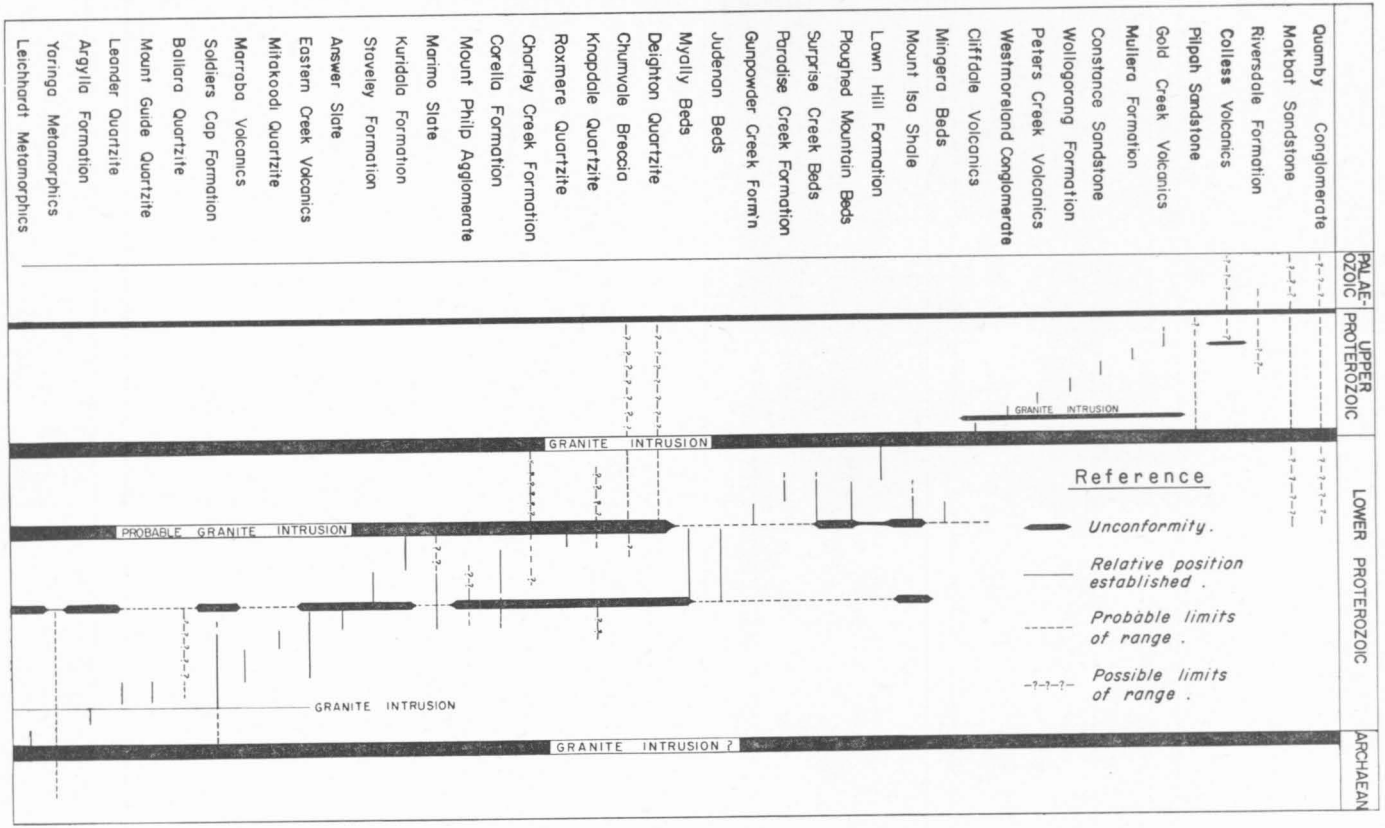


Fig. 3.

Notes :

1. The metabasalts in the Eastern Creek Volcanics, Marraba Volcanics, and Soldiers Cap Formation are assumed to be contemporaneous.
2. Lines representing deposition of Formations are not to scale.
3. The probable importance of unconformities (in terms of degree of angular unconformity or time break represented) is indicated schematically by the thickness of the symbol.
4. Distribution of the unconformities which do not extend throughout the region is largely interpretative: an attempt has been made to show the geographical distribution by reference to outcropping units.
5. An unconformity separates Middle from Lower Cambrian; and there may be several in the late Upper Proterozoic.

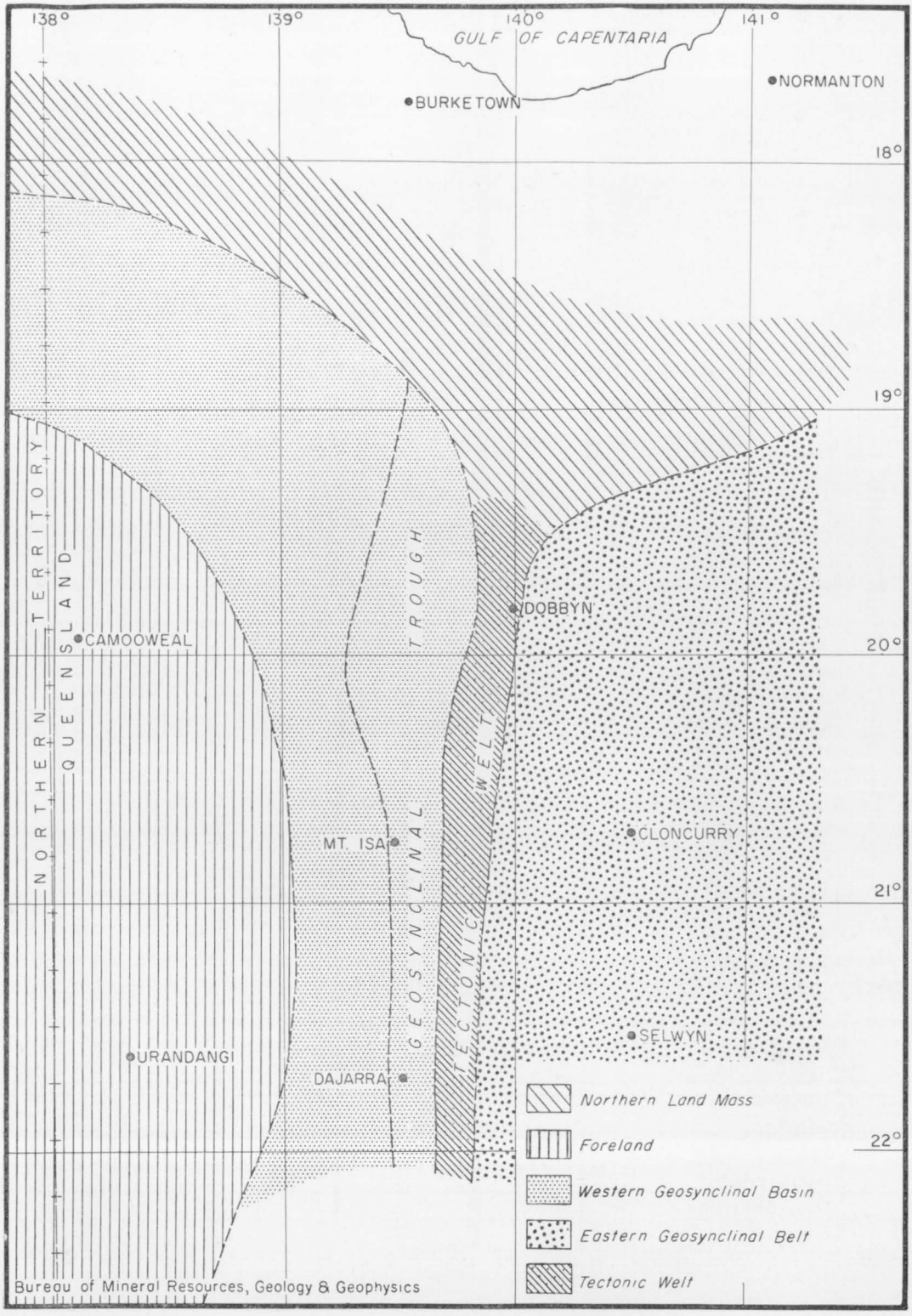


Fig. 4. Lower Proterozoic tectonic elements.

occurs between the ?Lower Proterozoic Cliffdale Volcanics and the Westmoreland Conglomerate of Upper Proterozoic age. Unconformities also occur at the base of the Colless Volcanics and the Camooweal Dolomite (which is not dealt with in this bulletin).

The structure of the Yaringa Metamorphics, which are possibly Archaean, has not been worked out. They have been extensively affected by plastic deformation, but the foliation of migmatite and gneiss tends to strike between 040° and 140°.

The Lower Proterozoic strata in the eastern basin (other than the Deighton Quartzite) are generally strongly folded on near-meridional axes. Major fold axes are shown in Figure 14. South-west of Cloncurry a major anticline pitches to the north-east, and in the latitude of Cloncurry east-west trends are locally dominant (see Pl. 26, fig. 1). Superimposed on the major structures of the region are lesser folds up to 5 miles from crest to crest. The axes of these folds dip east from the eastern margin of outcrop to about 20 miles west of Cloncurry. West of this point they tend to dip west. The main fault system is a conjugate strike-slip system whose components strike about 030°-045° and 130°-150°. The north-east-striking faults are the best developed. Many of them form impressive topographic features (see Pl. 25). Strike faulting is also very common; probably many more strike faults with extensive displacement occur than have been mapped. South of Cloncurry are several east-dipping high-angle reverse faults; they include the 'Cloncurry Overthrust' of Honman (1938). Movement on these faults appears to have been small. The Deighton Quartzite, which overlies the older strata with a major unconformity, is preserved only in basin structures, and has dips up to 70°.

West of the line of outcropping Leichhardt Metamorphics (which formed tectonic land through much of Lower Proterozoic time) several minor unconformities occur. The Eastern Creek Volcanics are more strongly fractured than the overlying strata, but folding throughout the succession is roughly of the same degree. However, the type of folding differs markedly on either side of the Mount Gordon Fault-zone. To the east, folds are generally linear, but open, with dips up to 80° (see Pl. 26, fig. 1)—in a few localities folds are overturned, notably west of the Mount Isa Fault; synclines are generally more tightly folded than anticlines; most folds pitch north at high angles, and fold axes generally strike north to north-north-east (west of Dobbyn some fold axes strike north-west). West of the Mount Gordon Fault-zone, folding in the Lower Proterozoic strata is commonly of the basin-and-dome type and fold axes strike in many directions; average dip of beds is 30°-40°; two major domes dominate the structure: one centred north-west of the Mount Oxide copper mine and the other between Archie Creek and the Gregory River (see Fig. 15). There are some linear fold structures, with axes striking north-north-east to north-east.

Faults west of the Leichhardt Metamorphics are of four kinds: conjugate strike-slip faults, which strike about 045° and 130°; east-west-striking normal

faults which have resulted in considerable repetition of units; high-angle faults which strike north-north-east and are believed to have been very long-lived, and to have operated during the formation of the western trough; and the Mount Isa Fault—a high-angle, west-dipping reverse fault, on which there has probably been considerable transcurrent movement. Strike faulting has probably been important throughout.

The Upper Proterozoic strata are moderately folded into clearly defined basins and domes: dips greater than 40° are uncommon, except in fault zones; in the extreme north-west dips are generally less than 20°. In the Westmoreland and Lawn Hill Sheet areas the major axes strike east-west. The fold axes in the Pilpah Sandstone, west of Mount Isa, are less regular, but tend to strike north-west. The Quamby Conglomerate is largely confined to fault blocks, and folding may have been controlled by fault movement. Upper Proterozoic rocks are strongly faulted; some faults have throws of several thousand feet.

Sedimentation

During Lower Proterozoic time sediments are believed to have come first from a foreland to the west and south-west of the accumulation area and from a northern landmass, and later also from the tectonic land, which shed to east and west (see Figs. 4 and 5).

Sediments were dominantly arenaceous and dolomitic; shale formed a smaller part of the sedimentary record than is usual in orogenic belts. Greywacke was also poorly represented, although most sediments were not well sorted. Most of the sediments were laid down in shallow water, but parts of the Corella Formation may have been deposited in deeper water.

The Upper Proterozoic Westmoreland Conglomerate may be terrestrial but later sediments were shallow-water marine. Apparently strong epeiric movements during Upper Proterozoic time resulted in considerable fluctuation of the strandline.

Stromatolitic fossils have been found in the Upper Proterozoic Wollogorang Formation and in the Lower Proterozoic Paradise Creek Formation (see Pls. 22 and 23). Possible algal remains have also been found in the Corella Formation. All occur in dolomitic, or altered dolomitic, strata.

Igneous Activity

There is a long history of volcanic activity in the region. The Lower Proterozoic succession starts with very extensive metadacite and metarhyolite, with some basalt and pyroclastics. After an interval with little vulcanicity a prodigious volume of basalt was extruded. Acid, intermediate, and basic lavas form a few hundred feet of the succession at the top of the Myally and Judenan Beds. Acid and intermediate lavas and pyroclastics, with some basalt, also occur in the

Upper Proterozoic in the extreme north-west of the region. There is a small occurrence of basic lavas, the Colless Volcanics, south of the Constance Range, near the Northern Territory border. These lavas are probably Upper Proterozoic, but may be Cambrian.

Granite crops out widely in the eastern belt (Figs. 4 and 13) and in the older strata west and south of Mount Isa, but is not common in the western belt north of the Barkly Highway. The Cliffdale Volcanics, north of the Nicholson River, are intruded by two granites, but the overlying Upper Proterozoic units are younger than the granites.

The granites have been grouped into nine named bodies, by geographical distribution (Fig. 13). Many of the named granite bodies are probably composite and contain intrusions of more than one age.

The granites that invaded the Precambrian rocks may be of five different ages. Field and petrological evidence shows the existence of

1. A probably Archaean granite, evidenced by arkose and granite pebbles in the older Lower Proterozoic units. Parts of the Sybella Granite may be Archaean.
2. The Ewen Granite, which intrudes the Argylla Formation but is overlain by Eastern Creek Volcanics. The granodiorite which forms the bulk of the Kalkadoon Granite, and which is overlain by the Surprise Creek Beds at Sunday Gully, may be of similar age.
3. Coarse to medium-fine-grained, porphyritic, commonly foliated, granite and adamellite which intrudes the Corella Formation and contemporaneous units. This granite is cut by finer-grained granite which may be an aplitic phase or may represent a later intrusion.
4. The Weberra Granite, muscovite-rich in part, which intrudes the Ploughed Mountain Beds, and is petrologically different from the other Lower Proterozoic granites.
5. The Nicholson Granite, with its two phases whose mutual relationships are unknown.

Petrological work (Joplin & Walker, in press) has shown that, despite the diversity referred to above, most of the granitic material included within each named body is of fairly uniform modal composition. In the brief description that follows reference to a named body therefore is to the main constituent of the body.

The main granitic type in the Kalkadoon Granite is granodiorite; many of the early granites, however, are fairly soda-rich and the Wimberu and Naraku Granites are adamellites. Some of the later granites, for example the Sybella and particularly the Wonga, are potash-rich granites. The dark mineral in most of the granites is biotite, but some, particularly the Wonga Granite, contain hornblende. In the Ewen Granite the dark mineral is now mainly chlorite. Texturally the granites range from coarse porphyroblastic gneiss (Pl. 20, fig. 1) to

fine even-grained microgranite. The contact effects also differ greatly; some granites display extensive relict structures (Pl. 21) and undoubtedly result from the granitization of the pre-existing rocks, locally at least. Others have narrow contact zones and de-oriented xenoliths (Pl. 19) and were magmatic.

Small bodies of albitite and soda aplite occur widely, generally as intrusives into the granite masses. Aplite and pegmatite similarly are widespread. Most muscovite pegmatite is marginal to the main metamorphic belt, south of the latitude of Mount Isa.

Field and petrological investigations have shown that there are at least five age groups of dolerite in the Lower Proterozoic rocks. They are:—

1. Amphibolite, either dykes or flows, affected by the granodiorite in the Kalkadoon Granite.
2. Early metadolerite dykes, older than the first main Lower Proterozoic orogenic deformation. These form dyke swarms (Pl. 18) and may be genetically related to the Eastern Creek and contemporaneous basic vulcanicity.
3. Metadolerite dykes that were emplaced after the deposition of the Corella Formation but before the first deformation.
4. Dolerite and metadolerite which post-date the first orogenic deformation. These occupy structural traps, such as fault lines and noses of folds.
5. Practically unaltered dolerite that forms dykes, and in places cuts major granite bodies. It appears to fall into two compositional groups, which may be of different ages.

Within these five broad groups, some further sub-division may be possible (see Table V); there may also be some Archaean basic intrusives. Some dolerite dykes also occur in the Upper Proterozoic strata north of the Nicholson River.

Metamorphism and Metasomatism

The Upper Proterozoic strata of the region are practically unmetamorphosed, and the Lower Proterozoic rocks which have been involved only in the second orogeny show, at most, slaty cleavage. Contact metamorphism is confined to narrow aureoles around intrusive granite.

The older Lower Proterozoic strata, however, display a wide range of metamorphic products. Fracture cleavage, slaty cleavage, schistosity, gneissose foliation, and migmatite may all be seen. The overall regional metamorphic grade appears to be that of the greenschist facies, but the amphibolite facies has been reached over wide areas; locally the cordierite-anthophyllite, and comparable, sub-facies of the amphibolite facies have developed. The regional metamorphism appears to have had a large thermal component.

Metasomatism, on a regional scale, has affected a large part of the eastern geosynclinal belt. Its effects are clearest in the Corella Formation, where soda-

chlorine metasomatism, combined with regional and contact metamorphism, has produced gneisses and granulites rich in scapolite, albite, pyroxene, and amphibole. Potash metasomatism, with consequent feldspathization and granitization, also affected wide areas.

Geological History

Very little is known of the history of the rocks which formed the basement to the Lower Proterozoic orogenic belt. The presence of granite pebbles and of arkose in the older Lower Proterozoic units shows that a granitic terrain provided a source of sediments. The Yaringa Metamorphics and part of the Sybella Granite may be older than the Leichhardt Metamorphics—which is probably the oldest formation in the established Lower Proterozoic succession—and may have supplied detritus. Inliers of high-grade metamorphic rocks west and south of Mount Isa may also be Archaean (see pp. 59, 60).

A study of cross-bedding and current ripple marks has shown that a source of sediment for the Lower Proterozoic orogenic belt persisted to the north of the present outcrop area through much, or all, of the history of the belt (see Fig. 4). The only pebbles from this source are of quartzite. An Archaean metasediment succession may therefore have lain to the north of the Lower Proterozoic orogenic belt.

Lower Proterozoic

The Leichhardt Metamorphics, of metadacite and metarhyolite, with amphibolites, schists, gneiss and migmatite near the top of the succession, show that one of the earliest events in the history of the Lower Proterozoic orogenic belt was acid vulcanicity. The history and palaeogeography of this event cannot be deciphered on the evidence obtained so far, but the record of the next event is fairly clear.

Acid lavas, both rhyolite and dacite (Argylla Formation), were poured out on a land surface probably from fissures, in a north-south belt immediately east of the outcropping Leichhardt Metamorphics. At this time the sea lay not far to the east, and lava flowed into it to produce interbedded rhyolite and sediment (Argylla Formation in the Duck Creek-Malbon River and Limestone Creek areas). Acid lavas have not been recorded in the base of the Soldiers Cap Formation. The explanation offered is that the lava did not extend so far east, as the basal Soldiers Cap Formation strata are thought to have been roughly contemporaneous with those of the Argylla Formation.

As the vulcanicity continued the sea advanced to the west, and interbedded lavas and sediments constitute practically the whole of the upper part of the Argylla Formation. The sea may not have covered the north of the region (see Figs. 5A and 6A). The late stages of this volcanic cycle were accompanied

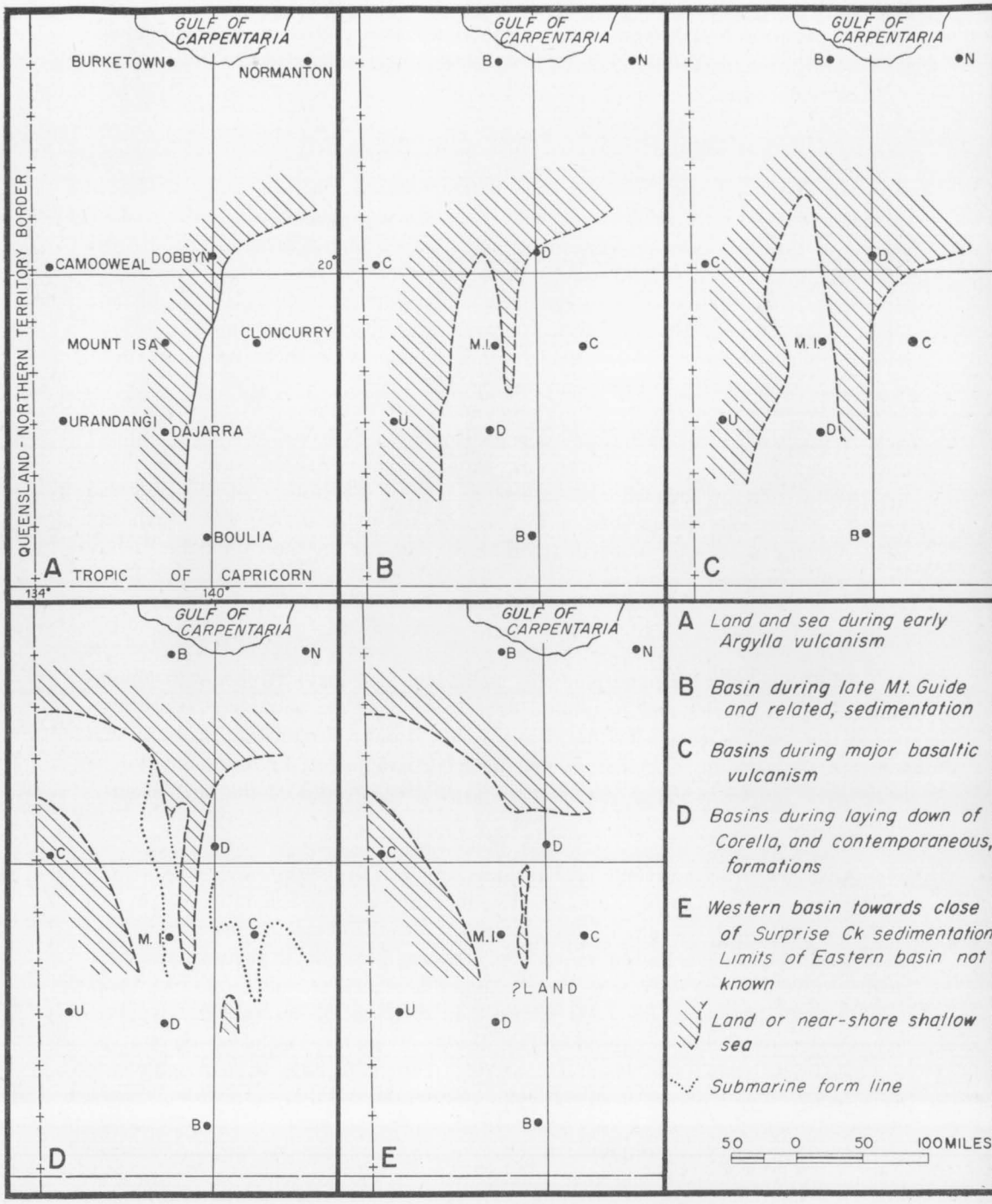


Fig. 5. Evolution of the Lower Proterozoic orogenic belt.

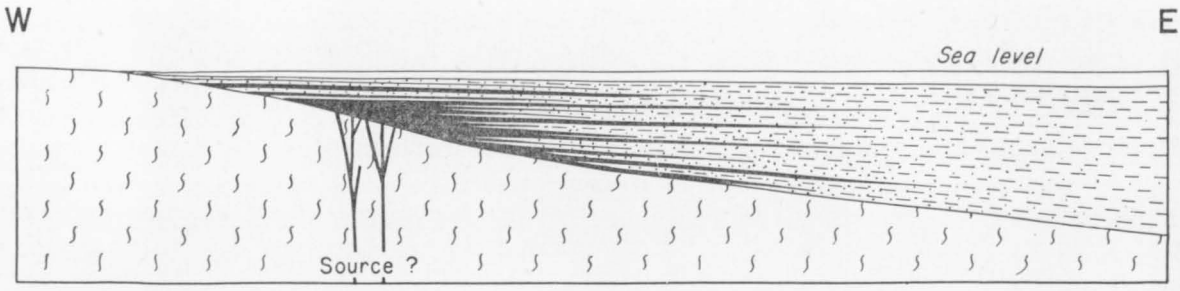
by extensive eruption of pyroclastics and by the extrusion of several flows of basalt. How far west the acid lavas extended is not known.

Towards the close of the acid vulcanicity a high-level granite petrologically similar to, and probably co-magmatic with, the rhyolite of the Argylla Formation was intruded into the Argylla Formation. This is the Ewen Granite, which is overlain by the Eastern Creek Volcanics. The granodiorite of the Kalkadoon Granite, which is older than the Surprise Creek Beds, and is considered by Joplin & Walker (in press) to be petrologically similar to, and probably co-magmatic with, the dacite of the Leichhardt Metamorphics, was probably also intruded about the same time; its emplacement cannot be dated as accurately as that of the Ewen Granite.

The acid vulcanicity was succeeded by a period with very little volcanic activity, in the course of which a sheet of sand was deposited over nearly all the region. This is preserved as the Mount Guide Quartzite, Leander Quartzite, Ballara Quartzite, and undifferentiated quartzite successions at the base of the Marraba Volcanics and immediately below the metabasalts of the Soldiers Cap Formation. The Mount Guide Quartzite derived its material from a nearby crystalline terrain; this is evidenced by its high feldspar content and by arkose and conglomerate at its base. A study of cross-bedding in the Mount Guide Quartzite has shown that detritus was derived mainly from the west in the lower part of the succession, but that before deposition was half complete sediments were also being received from the east and north-east. This is interpreted as indicating that the tectonic welt that divided the region in two through the whole of the subsequent orogenic history (see Fig. 4) had begun to emerge as land, probably as a peninsula projecting from the northern land mass (Fig. 5B), in the early stages of deposition of the quartzitic succession. Emergence was gradual and had little effect on the type of sediment laid down.

North of Surprise Creek the quartzitic succession is absent. The Argylla Formation and Ewen Granite north of Dynamite Creek are overlain by a thick conglomerate, with granite and rhyolite pebbles and boulders set in an arkosic matrix (Pl. 13, fig. 1). The conglomerate forms the base of the Eastern Creek Volcanics. Similar conglomerate is interbedded with basic flows nearby and in the Surprise Creek area. These conglomerates indicate that the Ewen Granite and Argylla Formation provided detritus during the period of basic vulcanicity that followed the laying down of the quartzitic succession elsewhere. As the uneroded part of the Argylla Formation north of Surprise Creek contains very little sediment and the formation was subjected to erosion during, and immediately preceding, the basic vulcanicity, it is probable that erosion continued in the intervening period—the time when the Leander and Mount Guide Formations, and contemporaneous arenaceous successions, were laid down.

Some arkosic beds in the Soldiers Cap area appear to have required a local source of material.

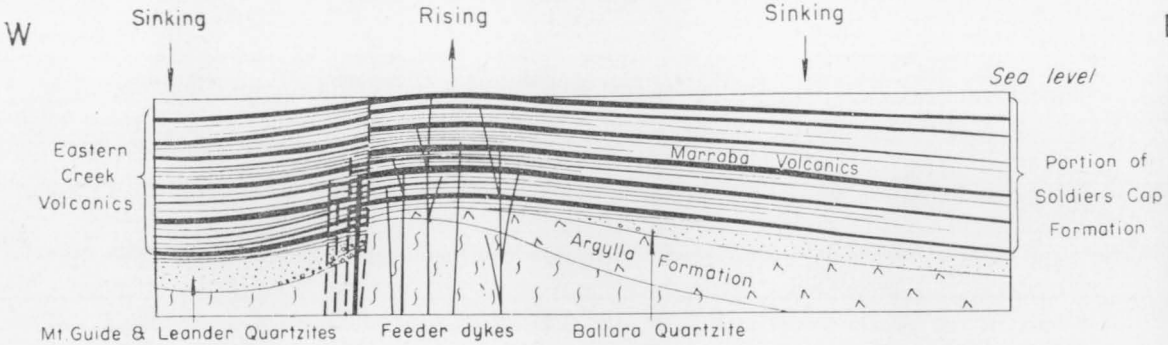


Acid lavas.

Sandy and argillaceous sediments.

? Archaean crystalline basement.

A. Late stage of acid vulcanicity that produced Argylla Formation. Distance across section about 100 miles.



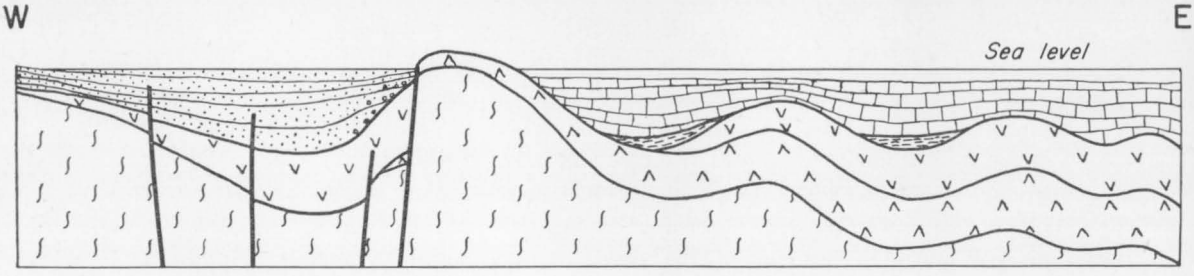
Basalt and interbedded sediments.

Arenaceous sediments.

Acid lavas of Argylla Formation.

? Archaean basement.

B. Extrusion of Eastern Creek, and contemporaneous, Volcanics. Distance across section about 140 miles.



Sandstone of Myally Beds.

Dolomite, etc., of Corella Formation.

Shale of Marimo Slate and Corella Formation.

Fault

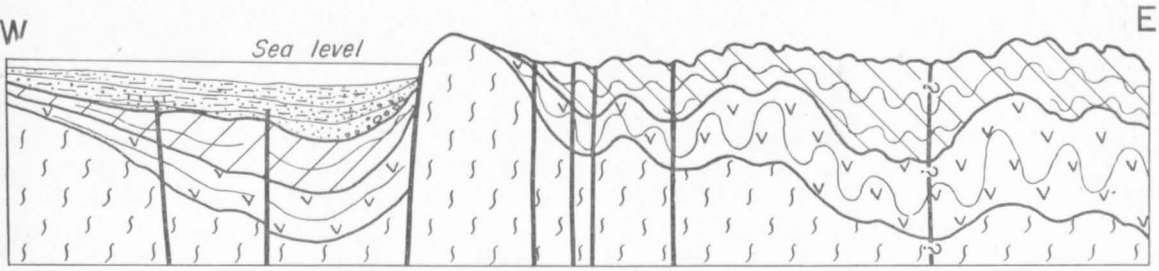
Basalt and associated sediments.

Acid lavas and associated sediments.

? Archaean basement.

C. Late stage of Corella, and contemporaneous, sedimentation. Distance across section about 160 miles.

Fig. 6. Schematic sections showing development of Lower Proterozoic orogenic belt. Continued in Figure 7.



Conglomerate, sandstone, siltstone and dolomite of Lower Surprise Creek Beds and contemporaneous units.

Myally Beds.

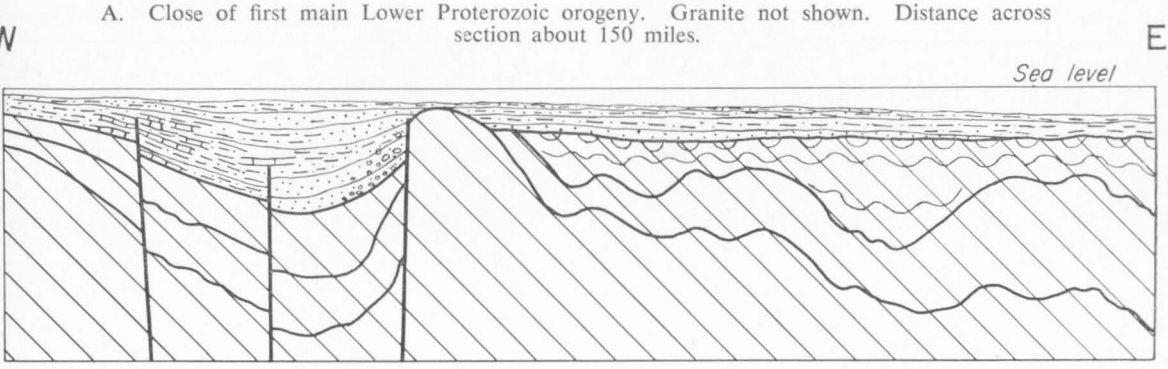
Fault

Corella Formation, Roxmere Quartzite and contemporaneous units.

Lower Proterozoic volcanics and associated sediments.

? Archaean basement.

A. Close of first main Lower Proterozoic orogeny. Granite not shown. Distance across section about 150 miles.

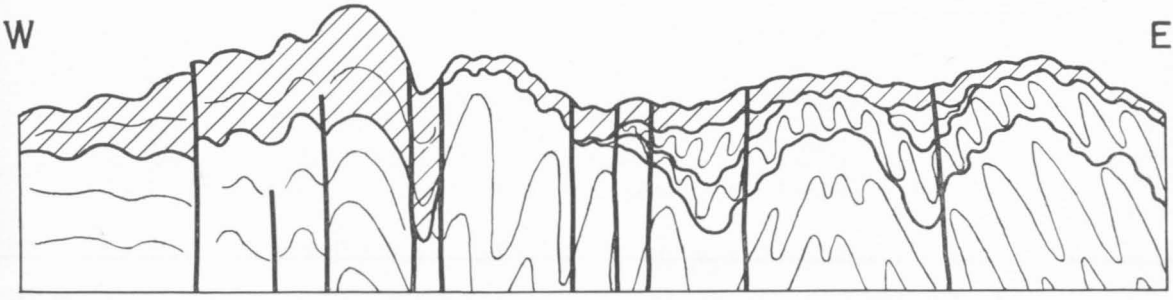


Dolomite, siltstone, sandstone and conglomerate deposited after first Lower Proterozoic orogenic deformation.

Lower Proterozoic and ?Archaean strata deformed in first Lower Proterozoic orogenic phase.

Fault

B. Towards close of Surprise Creek, and related, sedimentation. Distance across about 150 miles.



Previously unfolded strata.

Previously folded strata.

Fault

C. Final Lower Proterozoic orogenic deformation. Granite not shown. Distance across section about 130 miles.

Fig. 7. Schematic sections showing development of Lower Proterozoic orogenic belt. Continued from Figure 6.

Basalt was next poured out over a vast area. The vulcanicity was centred along the tectonic welt. The meridional basin or geosyncline west of the welt became larger; and interbedded basalts and sediments accumulated to a maximum thickness of more than 20,000 feet (the Eastern Creek Volcanics). Subsidence of the basin was accompanied by normal faulting. Meanwhile basalt also poured eastward from the welt in submarine flows to produce the Marraba Volcanics and the volcanic portion of the Soldiers Cap Formation (see Fig. 6B). Throughout the pre-basaltic formations, and, to a lesser extent, in the basaltic successions themselves, numerous metadolerite dykes occur (Pl. 18; see also Atlas, Pls. 7-9). They are almost absent from the younger formations (those in the younger formations may belong to another group—see p. 133) and are therefore considered to have been related to the basaltic vulcanicity. The dykes are most common in the Leichhardt Metamorphics and Argylla Formation, along the line of the welt; they may represent, in part, feeders to the flows. Some of the dykes in the Marraba Volcanics may also have served as feeders.

As the basic vulcanicity progressed the median ridge continued to rise above sea-level and was constantly eroded. The ridge was probably a broad feature, perhaps 30 or 40 miles across (Fig. 5C), but it is not known whether the two depositional basins were linked. Intensity of vulcanicity and of sedimentation varied considerably from place to place; this is indicated by the variations in thickness of basalts, and of the proportion of lava to sediment. South of Dajarra the onset of intense vulcanicity was more gradual than elsewhere, and the division between Mount Guide Quartzite and the Eastern Creek Volcanics is not easy to determine. In places in the Eastern Creek Volcanics the proportion of lava to sediment probably exceeds 4:1, but in most places it is nearer to 1:1; the associated sediments are generally shallow-water types. Some of the lavas may have been extruded on land or in a littoral environment, but generally the portions of the succession still preserved were formed under water— presumably the sea. The Marraba Volcanics and Soldiers Cap Formation were certainly submarine in origin; apparently open sea extended to the east as there is no record of sedimentation from that direction; however, the arkosic material referred to on p. 47 required a nearby source.

Towards the top of the Eastern Creek Volcanics the proportion of sediment to lava increases markedly. Sharply lensing beds of quartzite attain thicknesses of 2,000 feet. By the time basic vulcanicity had ended the Eastern Creek Volcanics had been down-faulted many thousand feet along a line just east of Gorge Creek.

Basic vulcanicity was almost spent by the time the first sediments of the Mitakoodi Quartzite were deposited. A few basalt flows and tuff in this succession and in the lower part of the overlying Marimo Slate show that weak volcanic activity continued for some time, or was renewed. The final phase was probably the building up of an agglomeratic cone, with some basalt, in the Ballara area. This took place in the early stages of deposition of the Corella Formation.

Vertical movement in the crust appears to have become more complex as vulcanicity diminished. The single broad arch was replaced by three smaller anticlinal structures which were reflected in the configuration of the sea-floor and land surface. The most westerly had its axis roughly along the present main line of outcrop of the Leichhardt Metamorphics. The two more easterly ridges show up in the present-day north-pitching anticlinoria south-east and south-west of Cloncurry (see Figs. 5D and 6C). These ridges were mainly submarine, but west of Selwyn the central welt may have emerged as land at a slightly later date: in the Staveley Formation, mud cracks, flow casts, and a lateral transition from siltstone to dolomite (calc-silicate) reveal extremely shallow-water conditions and a shelving strandline, dipping away from land in the west. A minor unconformity occurs at the base of the Staveley Formation. Still later (probably late Corella times) extensive black carbonaceous shales (around Kuridala) indicate restricted circulation in the sea, possibly the result of accumulation in a trough between two ridges.

Farther north the Marimo Slate shows a similarly diverse lithology. An unconformity between the Soldiers Cap Formation and the Corella Formation, east of Cloncurry, and extensive calc-silicate breccia in the Corella Formation where it outlines the present-day anticlinorium south-west of Cloncurry, provide additional evidence of deformation of the sea-floor.

Meanwhile the main welt, although reduced in width, continued to separate the two depositional basins. In the west, crustal movements, contemporaneous with those referred to above, produced local unconformity and marginal conglomerate along the west flank of the tectonic land, but did not interrupt sedimentation farther west. The Myally Beds and Judenan Beds developed in the western geosyncline while the Corella Formation and Roxmere Quartzite were deposited in the eastern basin.

The limit of onlap by the sea over the foreland is not known. The foreland does not appear to have contributed much coarse material; it probably had fairly low relief and a wide shelf area. The Myally Beds consist mainly of medium-coarse, moderately well sorted, sandstone and conglomerate, forming massive to well-bedded strata. The penecontemporaneous Judenan Beds contain more siltstone than the Myally Beds.

The main accumulation of sediments after the first Lower Proterozoic diastrophism appears to have been north of Mount Isa. The northerly limits of the basin are concealed beneath later sediments, but cross-bedding indicates a sediment source to the north, in addition to the foreland to the west and tectonic land to the east; the basin was clearly geosynclinal in magnitude and character. West and south-west of Mount Isa the basement apparently did not yield and sediments were much thinner than to the north. The general shape of the two basins at this time is suggested in Figure 5D.

The basin probably subsided, in part at least, by movement along a series of near-meridional normal faults which formed the limits of the most deeply subsiding portion of the trough. The Mount Gordon system, the Gorge Creek-Quilalar system and its extension northwards, and the Mount Isa-Leichhardt system of faults may all have been active during subsidence. North of latitude 20°30′S a number of approximately east-west faults, which are restricted to the belt between the meridional faults, may also have played a part in the deepening of the basin. Some of them were hinge faults.

In the eastern geosynclinal belt, contemporaneous with the laying down of the Myally and Judenan Beds in the west, sediments of the Corella Formation gradually extended westwards on to the main welt as the sea transgressed over it, cutting across successively older rocks as the sea advanced.

A thick sheet of sandstone or other sediment may have been deposited over the Corella Formation before an orogenic phase deformed the eastern basin: the Roxmere Quartzite, and probably the Knapdale Quartzite, may be remnants of it. The degree of deformation and metamorphism and the extent of granite exposure in the underlying rocks denote a thick cover at the time of granite emplacement, but it is not surely known how much of the metamorphism and granite emplacement took place during the first Lower Proterozoic orogenic deformation. Later strata would probably have provided adequate cover during the second orogenic deformation and granite emplacement.

Sedimentation in the eastern basin was interrupted by tectonic movements, with east-west compression, in the course of which strata were moderately to strongly folded on meridional axes and were extensively faulted. Transcurrent strike-slip faults formed extensively in the eastern belt. Petrological evidence of grade of metamorphism and magmatic trends (see p. 156) indicates that the deformation was probably accompanied, or followed, by granite emplacement, but throughout much of the area it is not possible to assign outcrops of granite to the first or the second Lower Proterozoic orogenic phase. The very widespread scapolitization (which is confined to the strata in the eastern geosynclinal belt, and has not affected the Deighton Quartzite) may have been related to the granite emplaced about this time.

The orogenic deformation was centred in the eastern basin, but produced minor effects in the western geosyncline. These include a strong, but local, unconformity between the Myally Beds and the Ploughed Mountain Beds, an unconformity at the base of the Mount Isa Shale, and extensive conglomerate at the base of the Surprise Creek Beds. The lavas at the top of the Myally and Judenan Beds may also be related to this orogenic phase.

The deformation of the strata in the eastern basin was accompanied, or succeeded, by uplift and a period of erosion of sufficient duration to have produced a surface with strong topographic relief before sedimentation began again.

Widespread intrusions of dolerite and gabbro were emplaced in structural traps such as faults and the crests of folds. As the intrusions have been affected by granite they can be dated as younger than the earliest diastrophism and older than the youngest Lower Proterozoic granite; but it is not known whether they pre-date the earlier granite.

After the crustal movements and volcanic extrusion, sedimentation in the western geosyncline appears to have been less rapid than previously, but in places at least 20,000 feet of sediments accumulated. Dolomite, siltstone, shale, and fine sandstone, generally impure, form a large proportion of the successions. The dolomitic beds are best developed in the Ploughed Mountain Beds, in the north, the Paradise Creek Formation immediately west of the Mount Gordon Fault-zone, and the Mount Isa Shale. Biostromal algae grew in association with the dolomitic strata along, and west of, a line which probably closely marked the break-of-slope at the scarp of the Mount Gordon Fault-zone.

The Mount Isa Shale appears to have occupied a special tectonic position as a trough or foredeep between the old foreland on the west and the tectonic land to the east, in which shale and dolomite accumulated deeply. The few cross-beds, mainly in the dolomitic strata, that have been measured, indicate sediment sources to the west and east. Some large slumped masses of sedimentary breccia in the dolomitic strata also indicate an appreciable off-shore slope. The Mount Isa and Leichhardt Faults were probably active during the laying down of the Mount Isa Shale—a continuation of earlier normal faulting evidenced by the proximity of the Leander Quartzite and the Myally Beds near the northern limit of outcrop of the Mount Isa Shale.

The Mount Isa Shale is probably the same age as the Surprise Creek Beds, or the lower portion of them, but conglomerate in places indicates that possibly the Mount Isa Shale and the Myally Beds are separated by an erosional break.

The Mingera Beds, which underlie the Paradise Creek Beds, were apparently near-shore deposits as beds lens sharply and contain extensive boulder conglomerate.

Cross-bedding, sediment types, and the lensing of beds all show that the tectonic land, the northern land mass, and the foreland all contributed detritus to the western basin after the first main Lower Proterozoic orogenic deformation; but the tectonic land may have become progressively less important (see Figs. 7A and B, and Fig. 5E).

A few tuffs, and probably rhyolite, in the Lawn Hill Formation indicate a brief and local volcanic episode late in the history of sedimentation of the western geosyncline. The Cliffdale Volcanics may also have been extruded at the same time.

After the Lawn Hill Formation was laid down, the history of the closing stages of sedimentation of the western geosyncline is not very clear. The uppermost strata have probably been eroded away.

East of the tectonic land the Deighton Quartzite is believed to be of Lower Proterozoic age because of the degree of folding. It has probably also been intruded by a pegmatite, and no Upper Proterozoic, or younger, igneous activity is known in the locality. It is probably roughly contemporaneous with the Surprise Creek Beds and Lawn Hill Formation and was deposited on a surface with strong topographic relief. Distribution of rock types and cross-bedding indicate that sedimentation was from the west. Material was probably derived from the tectonic land and the northern land mass, but it is not known whether the basin was linked with the western geosyncline. Sedimentation in the eastern basin must have been much more widespread than the present Deighton Quartzite.

A renewal of east-west compression resulted in strong meridional folding of the eastern portion of the western geosyncline (Pl. 26, fig. 2). The north-eastern portion, in the Dobbyn 4-mile Sheet area, was folded on north-west to north-north-west axes. The reason for this is not apparent, but it may be due to some basement control. West of the Mount Gordon Fault-zone fold axes lack the strongly preferred directions to be seen farther east. West of Mount Isa the shallow rigid basement inhibited linear folding such as can be seen farther north.

The strong, basin-like, folding of the Deighton Quartzite shows that the underlying beds had not yet become rigid. The overturning of the fold axes in the older succession was probably produced by this second orogenic deformation.

Conjugate strike-slip faults, arranged symmetrically to the fold axes and with movement consistent with east-west compression, developed in both the eastern and western basins. Much of the movement in the eastern belt appears to have taken place on the pre-existing conjugate faults. Analyses have been made of all the faults that affect Precambrian, but not younger, rocks. The results are presented in Figures 15 to 18, and the faulting discussed on pp. 184-5, where it is concluded that the difference in the dihedral angles between the conjugate faults in the eastern and western belts may be due to a change in the attitude of the pre-existing faults in the eastern belt as a result of the second compressive phase, and about 30% shortening of the eastern belt may have resulted from the second orogeny. Movement on the strike-slip faults may also have been responsible for the unusual basin-like folding of the Deighton Quartzite.

In addition to the conjugate faults produced by the second compressive phase, high angle reverse faulting also took place on the 'Cloncurry Overthrust' and the Mount Isa Fault. Movement was probably slight on the Cloncurry and related faults, but was large on the Mount Isa Fault. Although the fault movement had a vertical component the faults may have been essentially shear or transcurrent faults.

Granite emplacement accompanied, or followed, the final Lower Proterozoic diastrophism. It cannot be proved that granite intrusion accompanied the earlier orogeny, but the most probable history of granitic events is that proposed in Table VI. Although metamorphism is extensive (but varied) and can reach a moderately

high grade in the older beds in the eastern basin, regional metamorphism in the younger sediments of the western geosyncline is very slight and contact effects are generally restricted to within a few hundred feet of the intrusion.

Widespread but sparse, generally east-striking, dolerite dykes cut through granite and country rock in the eastern basin. East-striking dykes also occur in the Mount Isa Shale and farther north.

Uplift completed the evolution of the Lower Proterozoic orogenic belt (see Fig. 7C). A prolonged period of erosion ensued.

Upper Proterozoic

In the north-west of the region the succession now exposed began with the outpouring of a considerable thickness of red, porphyritic, acid to intermediate lavas, the Cliffdale Volcanics. They were extruded on a land surface in an east-west belt north of latitude 18° S, and ended with considerable tuff and agglomerate. They were then intruded by two granitic magmas (both mapped as Nicholson Granite). One is a coarse, red, porphyritic, ferro-magnesian-poor dioritic rock, very similar in appearance, except for its granitic texture, to the lavas it intrudes. The other is a coarsely porphyritic biotite granite. The mutual relationships of the two intrusives are not known. The intrusion probably caused the land surface to arch along the line of intrusion, and erosion exposed the Nicholson Granite. The Cliffdale Volcanics and Nicholson Granite are shown in Plates 1 and 2 of the Atlas as Upper Proterozoic, but they are probably older (see footnote, p. 114).

The coarse-grained Westmoreland Conglomerate was deposited on the Cliffdale Volcanics and the Nicholson Granite after a period of erosion. It may be derived from high land to the east, but contains considerable locally-derived detritus.

A second period of vulcanicity produced the Peters Creek Volcanics, of acid to basic, but generally intermediate, lavas, tuff, and interbedded sediments. This was followed by the dolomite, siltstone, and sandstone of the Wollogorang Formation; *Collenia* occurs in the dolomite. None of the units so far referred to crop out south of the Nicholson River.

A topographic basin gradually developed south of latitude 18° S. In this the Constance Sandstone accumulated to a maximum thickness of about 4,000 feet. Sediments are medium to coarse-grained—mostly coarse in the north. In the main outcrop area the Constance Sandstone was deposited with major unconformity on the Lower Proterozoic Lawn Hill Formation. In the north it lapped over the Wollogorang Formation, possibly on to an erosional surface. The southern limit of the basin is not known.

The Constance Sandstone was followed conformably by the Mullera Formation, of siltstone, shale, ironstone, and fine sandstone, all of which abound in shallow-water sedimentary structures. It was deposited over a smaller area than the Constance Sandstone and does not crop out in Queensland north of the Nicholson River.

Further vulcanicity is recorded in the extreme north in a small outcrop of Gold Creek Volcanics—acid to intermediate lavas and some interbedded sediments.

At this point it overlies Constance Sandstone, but in the Northern Territory has been seen to overlie the northern margin of the Mullera Formation. The Colless Volcanics, which occur along the fault-line that marks the southern limit of outcrop of the Constance Sandstone and Mullera Formation, are believed to be of Upper Proterozoic or Cambrian age.

The strata were folded on east-west axes, probably before the Colless Volcanics were extruded. North of latitude 18°S folds are markedly linear (this linearity does not persist far into the Northern Territory), but dips are generally not greater than 20°, except on faults. Folding was probably controlled by the granite-cored Proterozoic basement. South of latitude 18°S basins and domes, with dips up to 40°, developed. The major axes are east-west. Extensive faulting succeeded, or accompanied, the folding.

West of Mount Isa the Pilpah Sandstone was laid down in Upper Proterozoic time. The material was derived from the high land which had risen in the east as a result of the final Lower Proterozoic diastrophism. It was subsequently folded, to produce basin and dome structures, with the major axes north-west. The time relationship of the Pilpah Sandstone and the formations to the north-west is not known, but the Constance Sandstone and Pilpah Sandstone are possibly about the same age.

Of the remaining units mapped as Upper Proterozoic, the Riversdale Formation is overlain by Middle Cambrian sediments; it is possibly equivalent to the Camooweal Dolomite. The Makbat Sandstone may be equivalent to the Lower Cambrian Mount Birnie Beds; and it has not been possible to date the Quamby Conglomerate and undifferentiated outcrops.

The Camooweal Dolomite formed a sheet, probably one thousand feet thick in places, over a wide area west and south-west of the Lower Proterozoic strata, which at the time of deposition formed land in much the same position as today. It also overlapped the Upper Proterozoic sediments. It is Upper Proterozoic or Lower Cambrian and probably formed in an intra-continental sea (Öpik 1956a, b; Noakes, 1956).

The post-Precambrian history of the region is given on pp. 33 and 36.

STRATIGRAPHY AND LITHOLOGY

The Precambrian strata can now be subdivided with much greater precision and in much greater detail than has hitherto been possible. This sub-division has required the redefinition, modification, and, in some cases, abandonment of some previously published stratigraphical names. For this reason a list of published names, together with selected references and a statement of proposed usage, is included here (Table IV). The historical background of most of these names is to be found in Bryan & Jones (1944). A review has also been submitted to the

TABLE IV — PREVIOUSLY PUBLISHED STRATIGRAPHIC NAMES IN ORDER OF FIRST USE.

Name	Selected Reference	Comment	Proposed Usage
Cloncurry Series	Dunstan (1913)		Preserved as Cloncurry Complex.
Lawn Hill Series	Dunstan (1913, p. 121) Shepherd (1932, p. 377) Jensen (1941, p. 7)	Dunstan and Shepherd apply the name to different (in part) rock masses. Those to which Dunstan applied the name contain an unconformity and do not include the Lawn Hill mineral-bearing rocks.	Modified and redefined as 'Lawn Hill Formation', largely containing rocks to which Shepherd & Jensen applied the name.
Quamby Conglomerates Mount Quamby Series	Ball (1921, p. 10) A.G.G.S.N.A. (1936a, p. 50)		Ball's name & type area preserved ('s' deleted).
Mount Isa Series Mount Isa Shales	Saint-Smith (1924, p. 411) Shepherd (1932, p. 377) A.G.G.S.N.A. (1937a, pl. 4) David (1932, p. 29)	Used in different senses by these and other authors. David's Mount Isa Shales are the same as Shepherd's Mount Isa Series.	Preserved as Mount Isa Shale in sense apparently used by Shepherd and by Blanchard & Hall (1937).
Spring Creek Series Spring Creek Basalts Spring Creek Volcanics	Shepherd (1931, p. 225) Shepherd (1946, p. 146) David (1932, p. 30) Shepherd (1953, p. 386)	This name is not favoured because of the multiplicity of 'Spring Creeks' in this and other areas.	Abandoned. Replaced by 'Eastern Creek Volcanics.'
Argylla series Kalkadoon series Leichhardt series	David (1932, p. 29) A.G.G.S.N.A. (1936a & 1937a) Nye & Rayner, (1940, pl. 1) Shepherd (1946, p. 146)	Owing to inadequate structural and stratigraphical information considerable confusion, including duplication and inconsistent usage, has arisen over these names.	Argylla series — redefined and used as Formation — Argylla Formation. Kalkadoon series — redefined as Kalkadoon Granite. Leichhardt series — redefined as Leichhardt Metamorphics.
Corella Limestone Corella Series	David (1932, p. 29) Shepherd (1946, p. 146)		Redefined as Corella Formation.
Wonga Granites Wonga Series	David (1932, p. 31) Shepherd (1946, p. 146)		Preserved as Wonga Granite.
Templeton Granite	Shepherd (1932, p. 377)	The use of Templeton in the name 'Templeton Series,' applied by Whitehouse (1930) to nearby Cambrian strata, has priority.	Abandoned. Replaced by Sybella Granite.
Black Star Group Black Rock Group Rio Grande Group	Shepherd (1933, pp. 314-6)	These have the status of members within the Mount Isa Shale formation.	Not used in this publication as they are not of regional significance. Should be redefined as 'members.'
Soldiers Cap series	A.G.G.S.N.A. (1936a, p. 49) Honman (1937a)		Redefined and preserved as 'Soldiers Cap Formation'.
Wollogorang series	A.G.G.S.N.A. (1940a, p. 29 & 35)	Succession in Northern Territory given this name; extends into Queensland.	Wollogorang Formation.
Constance Range series	A.G.G.S.N.A. (1940a, p. 23) Jensen (1941, p. 9)	The succession as defined by Jensen contains an unconformity & does not contain the strata which comprise the bulk of the Constance Range.	The name Constance Sandstone is applied to a sandstone succession in the Constance Range, roughly that which Cameron (1901) referred to as 'sandstones of the Constance Range.'
Cloncurry Granite	Jones (1953, p. 350)	Name pre-empted by Cloncurry Series.	Abandoned.
Cloncurry Complex	Geological map of Queensland Scale 1" : 40 miles (1953)	This name is applied essentially to the same rocks as those to which 'Cloncurry Series' was first applied but avoids the confusing use of the word 'Series.'	Preserved.
Carpentaria Complex	Noakes & Traves (1954, p. 35)	This name applies to the same rocks as those covered by Cloncurry Complex together with their extension into the Northern Territory. Cloncurry Complex has priority.	Abandoned.
Pilpah Sandstone	Noakes & Traves (1954, p. 36)		Preserved as defined. Redescribed.

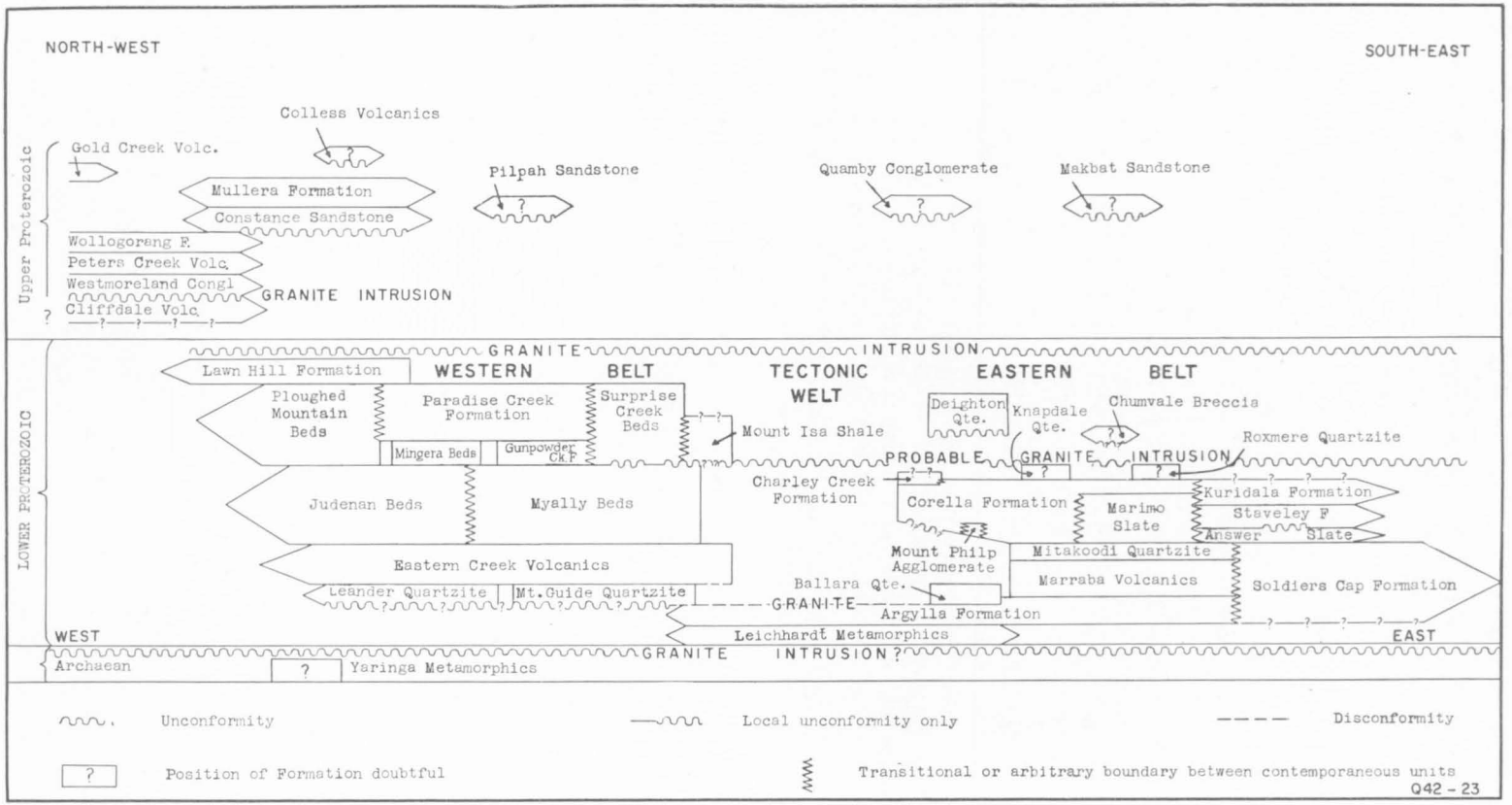


Fig. 8 : Schematic representation of relationships of Precambrian stratigraphic units. Lower Proterozoic units are generally arranged from west to east across figure; Upper Proterozoic units are arranged from north-west to south-east across figure. Not all units that are in contact are so shown in the figure.

Queensland Stratigraphic Nomenclature Committee (Carter, 1956, unpubl.). New and revised formal names conform with the Australian code of stratigraphic nomenclature (see Raggatt, 1959, pp. 63-70). However, in such a complex metamorphic belt as is to be found in this region it has not been practicable to delineate units which differ from one another in grade of metamorphism only. The criteria used to identify units include inferred original lithology, stratigraphical position, and continuity along the strike. All names used have been approved by the Queensland Stratigraphic Nomenclature Committee.

The informal term 'beds' has been used in preference to 'formations' for some units. The reason is that, although type areas and even considerable areas elsewhere are adequately known, the distribution, overall lithology, and relationships to other units have not been satisfactorily determined. Subsequent mapping may well produce extensive changes in the sub-divisions proposed here.

Type sections or areas have rarely been given for the previously-named units; these are provided in the definitions below. In Figure 3 an attempt is made to show schematically the time relationships of the various stratigraphical units; in Figure 8 the tectonic and superpositional relationships of the units are shown, and in Figure 9 twenty-seven stratigraphic columns showing stratigraphical relationships are presented. Tables II and III contain a summary of Upper Proterozoic and Lower Proterozoic stratigraphy.

Precambrian

Cloncurry Complex

The name Cloncurry Complex was first used in the geological map of Queensland, published by the Queensland Department of Mines in 1953. It supersedes 'Cloncurry Series.' As used in the map it includes all the Precambrian rocks of north-western Queensland, including the Upper Proterozoic sediments and lavas of the Constance Range and Nicholson River areas, but excluding the Upper Proterozoic Camooweal Dolomite (which at that time was placed in the Cambrian).

The extension of the Cloncurry Complex into the Northern Territory is, of course, not shown, but the strata of the Constance Range/Nicholson River region appear to extend westwards to the Arnhem Land plateau. In the light of existing knowledge a more natural grouping for the Cloncurry Complex seems to be to include only the Lower Proterozoic and Archaean successions and to form a separate division for the Upper Proterozoic rocks of the Northern Territory and the extreme north-west of Queensland.

Yaringa Metamorphics

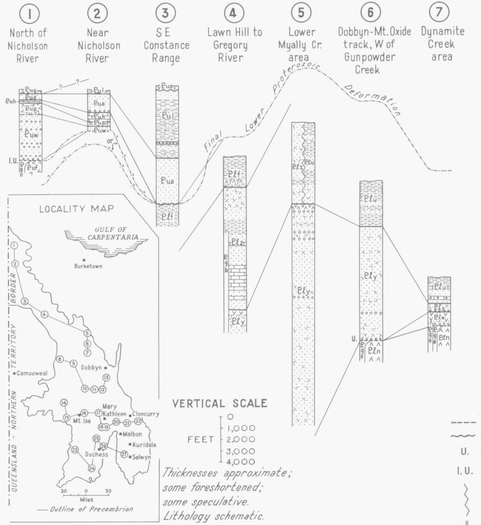
Definition. Derivation of name: Yaringa Creek (or Little Templeton River).

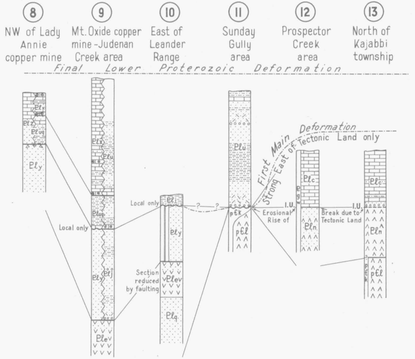
Map reference: Mount Isa 4-mile Sheet (Atlas, Pl. 5).

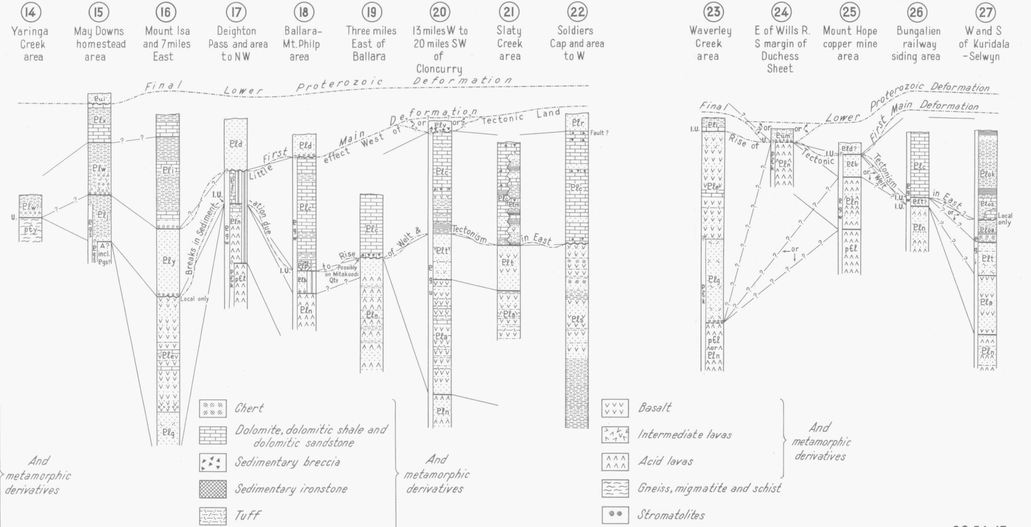
Distribution: Entirely west of Gap Bore, in an area of about 25 square miles, north and south of Yaringa Creek, bounded in the north and west by alluvium and in the south by Sybella Granite. In places outcrop is sparse.

SUPERPOSITIONAL RELATIONSHIPS OF PRECAMBRIAN STRATIGRAPHIC UNITS

FIGURE 9







REFERENCE

- Observed erosional break
- Observed angular unconformity
- U. Unconformity inferred from local evidence
- I.U. Unconformity inferred from evidence elsewhere
- Lateral transition, or arbitrary boundary, between contemporaneous units
- Joined units in contact but time interval between deposition

- Shale
- Carbonaceous shale and siltstone
- Siltstone, or interbedded shale, siltstone and sandstone
- Sandstone
- Feldspathic sediments, including arkose
- Conglomerate

} And metamorphic derivatives

- Chert
- Dolomite, dolomitic shale and dolomitic sandstone
- Sedimentary breccia
- Sedimentary ironstone
- Tuff
- Agglomerate

} And metamorphic derivatives

- Basalt
- Intermediate lavas
- Acid lavas
- Gneiss, migmatite and schist
- Stromatolites

} And metamorphic derivatives

QG 34-17
G.M.

Lithology: Dominantly migmatite, gneiss, mica schist, quartz-mica schist, and sericite schist; some quartzite and schisted conglomerate. Some basic igneous rocks occur, but they are probably intrusive.

The lithology of the succession is typically developed and best exposed north of Yaringa Creek, from 2 miles north-west of Gap Bore. The migmatites are well shown south of Yaringa Creek at lat. 20°50′55″S, long. 139°09′45″E.

Thickness: Unknown.

Age: Precambrian, possibly Archaean (see below, also, p. 129).

Contacts: Intruded by Sybella Granite; by a quartz-feldspar porphyry with white euhedral orthoclase crystals and a grey groundmass (see p. 132); and probably by granite-altered metadolerite. The succession is not in contact with any other metamorphic or sedimentary unit, but sediments, probably of the Mingera Beds, crop out within 1,500 feet of the eastern margin. A marked difference in metamorphic grade distinguishes the Yaringa Metamorphics from the ?Mingera Beds.

Description and Comment. The Yaringa Metamorphics differ from other Lower Proterozoic metamorphics in several respects. Migmatites and coarse mica schists are much more abundant than elsewhere in the region, although local developments in other places are known, particularly, but not entirely, in the Leichhardt Metamorphics. Joplin (1955, p. 38) has described some of the rocks of the Yaringa Metamorphics.

South of Yaringa Creek the granite was found to be typical coarse-grained foliated Sybella Granite. The abundance of migmatite and coarse schists at its margin may therefore be due to local concentration of fluids associated with the Sybella Granite, rather than an earlier period of metamorphism.

No attempt was made to ascertain the structure of the Yaringa Metamorphics, as plastic deformation has produced a very complex pattern. Numerous readings of bedding, schistosity, and migmatite-banding directions showed a preponderance of trends between 040° and 140°. This contrasts with the major trend directions for other units.

The intrusive quartz-feldspar porphyry, which has a very distinctive appearance in hand-specimen, has not been observed in any other part of the region. Under the microscope it is seen to be little metamorphosed.

The differences between the Yaringa Metamorphics and the Lower Proterozoic metamorphic units of the region are sufficient to suggest that the former may belong to an older system, particularly as the type of sediments farther east and the sedimentational pattern in general require a granitic source to the west. The pebbles contained in the conglomerate within the succession are not of diagnostic value as they consist only of quartz-sericite schist, quartzite, slate, and quartz.

As far as can be judged from the very little petrological work carried out, the grade of metamorphism of the Yaringa Metamorphics is comparable to that of the Leichhardt Metamorphics. However, in view of the very great range in metamorphism in some of the Lower Proterozoic strata grade of metamorphism appears to be very unsure ground for correlation.

The original sediments of the Yaringa Metamorphics were probably siltstone, argillaceous sandstone, quartz sandstone, and a thin pebble conglomerate.

Other ?Archaean Rocks

Joplin (1955) has described specimens of metamorphics of apparently anomalously high grade from west of Mount Isa, at lat. 20°37′50″S, long. 139°24′30″E; from near McKellars Well, at lat. 20°58′S, long. 139°24′E; and from a point

8 miles north-west of Sulieman Bore, at lat. 21°36′20″S, long. 139°18′E. On field evidence no grounds could be found for differentiating between the strata from which the specimens were collected and some highly altered portions of the Eastern Creek Volcanics; the high-grade metamorphic rocks described by Joplin are possibly the product of local stress conditions or the reinforcing effect of more than one granite. Nevertheless, the possibility exists that these and other areas of high-grade metamorphic rocks represent small discontinuous inliers of 'basement' projecting through the surrounding younger strata. As they cannot be distinguished on field evidence as mappable entities at the present density of mapping, the creation of separate stratigraphic units cannot be justified.

On the other hand it is quite possible that the Sybella Granite, as mapped, contains outcrops of Archaean granite. Arkose west of Mount Isa, which was apparently formed almost *in situ,* and was subsequently metamorphosed by the Sybella Granite, has been recognised by Joplin (p. 39). Further work has shown a granite mass in the same general area which is intruded by later masses of Sybella Granite (see p. 150). Granite boulders have been found in association with metamorphosed acid lavas, probably at the base of the Argylla Formation, in a conglomerate south-west of Rifle Creek dam (see p. 62). This evidence points to the existence of an exposed granite mass older than the recognised Lower Proterozoic units; it may reasonably be regarded as Archaean.

Leichhardt Metamorphics

Definition. Derivation of name: Leichhardt River. The name 'Leichhardt Series' was first published by David (1932, p. 29) from Shepherd's then unpublished classification (see p. 28). Subsequently, owing to inadequate knowledge of the area, considerable confusion of nomenclature arose. Officers of the Aerial, Geological and Geophysical Survey of North Australia included in the Kalkadoon-Argylla series the succession to which it is believed Shepherd intended that Leichhardt Series should apply (see A.G.G.S.N.A. 1936a, p. 49 and Pl. 1; 1937a, Pl. 4; Honman, 1937b, p. 5; Nye & Rayner, 1940, Pl. 1; Shepherd, 1946, p. 146; 1953, p. 386). Leichhardt Metamorphics, as here defined, are believed to be the lithological unit which most nearly includes the area of rocks to which Shepherd first applied the name Leichhardt Series.

Map reference: Dobbyn, Cloncurry, and Duchess 4-Mile Sheets (Atlas, Pls. 7-9). The type area is in the Cloncurry 4-mile Sheet area.

Distribution: In a meridional belt, more than 100 miles long and up to 20 miles wide about longitude 139°45′E, together with an area of 45 square miles around the Argylla (Blockade) copper mines. The total area of outcrop, as mapped, is 430 square miles.

Lithology: Essentially highly to moderately metamorphosed acid lavas, with some metamorphosed sediments, metabasalt, and rare tuff. In places the lava, for the most part originally dacite and rhyolite, is migmatized and granitized; elsewhere it has been recrystallized. Associated metamorphics include migmatite, gneiss, mica schist, quartzite, calc-silicate rocks, and hornblende schists and amphibolite which were probably mainly basic igneous intrusives originally.

The succession is typically developed along the track from the Referee copper mine west towards Glenroy homestead to the head of Doughboy Creek gorge—a distance of 5 miles. This is designated the type area. Small granite outcrops are numerous along this line, which is only a few miles south of a section described by Honman (1937b, p. 5) as representative of the Kalkadoon-Argylla succession.

Thickness: Unknown, as base not exposed and structure not determined.

Age: Probably Lower Proterozoic (see p. 129). With the possible exception of the Yaringa Metamorphics and other unnamed rocks, the Leichhardt Metamorphics are the oldest rocks known in the region.

Contacts: Overlain conformably by the Argylla Formation (but see below), and probably disconformably by Mount Guide Quartzite. Clearly unconformably overlain by the Surprise Creek and Myally Beds.

Description and Comment. The main lava in the Leichhardt Metamorphics is metadacite. It is characteristically grey, medium-grained and porphyritic. Some flow-banding, both planar and convolute, has been recorded. In hand specimen phenocrysts appear to be mainly of white euhedral feldspar and quartz crystals 1 to 3 mm. across; they are set in a fine or aphanitic ground-mass. The quartz may be conspicuous on weathered surfaces; it is commonly pale blue. The feldspar includes microcline, albite, and andesine; the first two are probably the result of alteration and addition as some of the microcline is porphyroblastic and the albite displays checker albite twinning. The main dark mineral is biotite, which is probably a pseudomorph of hornblende. The groundmass consists of a fine mosaic of quartz, feldspar, sericite, and some biotite. All the lavas show the effects of regional metamorphism, but thermal and metasomatic effects differ greatly with distance from granite: some dacites have been recrystallized, others completely migmatized. Typical dacites are described petrologically in Appendix I, p. 279. (Spec. R7219, 7220). Metarhyolite and metatoscanite also occur widely in the Leichhardt Metamorphics (see Appendix I, Spec. R7212-7214 and R3266-3268, pp. 278-9). The metarhyolite is generally porphyritic and is similar to metarhyolite in the Argylla Formation, which is described in the description of that unit.

A tuffaceous greywacke from 3 miles west of Oona railway siding is finely banded (1 mm.); it is dark grey and flinty, and breaks with a conchoidal fracture. It is composed of shards of quartz, microcline, and plagioclase, and rock fragments, in a sericitic matrix. A tuff is described in Appendix I (Spec. R6943, p. 280).

The metabasalt includes amygdaloidal flows whose amygdules are infilled with calcite, epidote, feldspar, or quartz. One amygdule contained pyrite. Some flows are in the greenschist metamorphic facies, and have a lepidoblastic fabric; constituent minerals are lathed feldspar and amphibole (about 1 mm. long), chlorite, iron oxide, and epidote. The feldspar is probably albite. Others are in the amphibolite facies, have a granoblastic fabric, and consist of porphyroblasts of plagioclase and amphibole, with some quartz and many iron oxide grains, set in a matrix of feldspar, quartz, biotite, and minor epidote, apatite, and sphene; some zircon has been recorded.

Local zones of migmatization have been recognised in two places: on the Mount Isa-Kajabbi track (lat. 20°40′10″S, long. 139°41′30″E), and 7 miles north-north-east of Rifle Creek dam, about lat. 20°54′40″S, long. 139°36′30″E; other areas of migmatite doubtless occur in the Leichhardt Metamorphics. In these places migmatites, gneiss, and schist have developed over small areas.

Metasomatic alteration or granitization of the Leichhardt Metamorphics is generally confined to narrow zones marginal to the granite. In some places, as Joplin (1955, p. 54) has pointed out, quite extensive exposures of granitized country may be due to the partial unroofing of the underlying granite. In other places, however, the lavas appear to have been extensively granitized.

Owing to the paucity of flow-lines and of interbedded metasediments detailed structure within the Leichhardt Metamorphics is not readily determinable. For this reason, also, estimates of thickness of the formation, as exposed, are likely to be so inaccurate as to be valueless. Overall, the formation forms an anticlinal structure.

The relationship of the Leichhardt Metamorphics to the Argylla Formation has not been satisfactorily established. The two formations have been differentiated because of an apparent disparity in the overall grade of metamorphism. Most of the lavas in the Argylla Formation are red-brown, rather than grey.

At lat. 20°59′S, long. 139°33′E, two miles south-west of Rifle Creek dam, a highly folded succession of hornfelsed conglomerate and acid lava has been taken to represent the base of the Argylla Formation. However, the folding is too complex to determine whether the general structure is anticlinal or synclinal, so that it is not clear whether the conglomerate marks the base of a succession containing altered acid lavas (the Argylla Formation) or the overlying Mount Guide Quartzite. Conglomerate containing acid lava boulders has also been recorded near the base of the Argylla Formation, as mapped, at about lat. 20°02′30″S, long. 139°55′E, and farther north, but it is apparently of local significance only.

A feature of the area of outcrop of the Leichhardt Metamorphics is the abundance of metadolerite and amphibolite dykes (and possibly sills). These form impressive dyke swarms in places (see Pl. 18). They have been altered by granite, some of them very strongly; some also cut older granite. Differences in grade of metamorphism observed in dolerites lying close together indicate that there may be at least two ages of basic intrusives. The fresher of these may be related to the Eastern Creek and associated vulcanicity.

Argylla Formation

Definition. Derivation of name: Argylla Creek (see also Table IV, and Leichhardt Metamorphics, Derivation of name).

Map reference: Dobbyn, Cloncurry, Duchess, and Boulia 4-mile Sheets (Atlas, Pls. 1, 7 to 9). The type area is in the Cloncurry Sheet area along the Cloncurry-Mount Isa road (see footnote p. 16), from 22 to 24 miles east of Mount Isa, i.e. west of long. 139°50′20″E.

Distribution: As mapped the Argylla Formation crops out in several discrete areas. The main belt extends for 190 miles from lat. 19°20′S, long. 139°44′30″E, 17 miles west-south-west of the junction of the Leichhardt River and Gunpowder Creek, to lat. 22°04′S, long. 139°43′40″E, 2 miles north-west of Buckingham Downs homestead, in the south. The belt is up to 20 miles wide and outcrops are discontinuous. The second area of outcrop, of 120 square miles, is in the Duck Creek/Malbon River area, centred around lat. 21°03′S, long. 140°04′E. The third area forms a meridional belt, 17 miles long, and one to four miles wide, north and south of Limestone Creek. It is an extension, south of Wimberu Granite, of the Duck Creek/Malbon River occurrence. Several smaller bodies crop out in a belt from the abandoned township of Ballara north to the Dugald River. The Argylla Formation is also exposed in a dome 12 miles long by 2 miles wide, east of Prospector Creek about lat. 20°17′S, long. 139°56′E. The total area of outcrop of the unit, as mapped, is 800 square miles.

Lithology: Metamorphosed rhyolite and metadacite, with smaller quantities of metabasalt, tuff and agglomerate; quartzite, arkose, calc-silicate rocks, conglomerate, slate, schist, and gneiss. The grade and type of metamorphism differs considerably from place to place.

Thickness: Approximately 10,000 feet. The thickness of the formation probably varies widely in the different outcrop areas.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Underlain, generally conformably, by Leichhardt Metamorphics (see p. 63). Overlain, conformably by Marraba Volcanics and Ballara Quartzite, disconformably by Mount Guide Quartzite and Eastern Creek Volcanics, probably unconformably by Corella Formation and clearly unconformably by Deighton Quartzite, Myally Beds and Surprise Creek Beds.

Description and Comment. The main lava is typically coarsely porphyritic, with euhedral pink feldspar phenocrysts which in some flows are more than 2 cm. long, and a granoblastic to aphanitic, red-brown to almost black, groundmass. Quartz phenocrysts are numerous; some are blue, and most of the others are colourless. Most such lavas are of metarhyolite (see Appendix I, p. 280, Spec. R6940 and R7224, also Joplin, 1955, pp. 45-47). Both microcline and albite form phenocrysts; the albite commonly displays checker twinning. Ferromagnesian minerals are not common, but some biotite occurs in the flows with a dark groundmass. Iron oxide grains, of average size 0.5 mm., are evenly distributed through the red-brown flows. The groundmass consists mainly of fine quartz, but microcline abounds in some specimens. Many of the flows are porphyritic, and some are several hundred feet thick, which led earlier workers to describe them as porphyry and to regard them as intrusive (see below). Flow-lines are not abundant; where observed they are generally straight, but some intricate flow-lines indicate viscous flow. In places (e.g. in the flow immediately west of the quartzite ridge which the Mount Isa-Cloncurry road crosses 25 miles from Mount Isa, at lat. 20°41′15″S, long. 139°50′25″E, and at the Crusader copper mine) rounded rhyolitic and other pebbles may be seen in the flows. Rude columnar jointing occurs near the Edna May copper mine. Some vesicular red-brown acid lavas have been observed. Where recrystallization or local granitization has profoundly altered their appearance the lavas may no longer be readily recognisable as such in the field. Some of the wider concordant bodies may be sills. In addition to the concordant porphyritic bodies some clearly transgressive granite porphyry and quartz-feldspar porphyry occurs in the Argylla Formation in the Dobbyn 4-mile Sheet area, generally as a marginal phase of the Ewen Granite; some bodies are dyke-like.

Not only are some of the highly altered lavas difficult to recognise in the field, but the growth of feldspar porphyroblasts in metasediments has produced some rocks which closely resemble some of the altered porphyritic lavas. The problem is most pronounced near the Wonga Granite, which apparently produced extensive potash metasomatism, and is not confined to the Argylla Formation (see Appendix I, pp. 283-4).

The metadacite appears to have been similar, before metamorphism, to the dacite of the Leichhardt Metamorphics. (See Appendix I, pp. 278-283, Spec. R5703, R5791, R6940-1, R7221-2, R7229-30). Interbedding of metadacites and metarhyolites has been observed. Throughout the area of outcrop metabasalts (possibly including andesites) occur in the upper part of the succession. They are a minor constituent only, but may form an important part of the upper part of the succession east of Dajarra. Vesicular and amygdaloidal basalts have been recorded, the amygdules being filled with feldspar, calcite, or quartz. Tuff and agglomerate are also more plentiful in the upper part of the formation than in the lower part. Beds of agglomerate up to 15 feet thick, and with angular fragments exceeding one foot, have been observed.

The metamorphosed sediments of the Argylla Formation include conglomerate; cross-bedded quartzite; epidote quartzite; arkose and feldspathic quartzite; chloritic, quartz-sericite and sericite schists and slates; mica schist, including dark red-brown mica schist; crystalline limestone and calc-silicate rocks. The metasediments are well exposed in an ?in-faulted block of the Argylla Formation east of the Razorback Mountain; they are poorly developed in the type area.

In the outcropping bodies in the Duck Creek/Malbon River area and south of the Wimberu Granite (Limestone Creek area), on the other hand, the acid lavas are interbedded with extensive metasediments and form the lesser part of the succession. Exposure is poor, but the metasediments appear to be dominantly quartzite, schist, and slate. Acid flows are thin; metabasalts occur in the upper part of the succession. Immediately south of the Wimberu Granite the original rocks have been so altered by thermal metamorphism, metasomatism, and profound weathering (see p. 84) as to be difficult to determine.

The relationship of the Argylla Formation to the Leichhardt Metamorphics is discussed on p. 62. No regional unconformity has been observed between the Argylla Formation and the Corella Formation (although regional considerations require one), but at lat. 20°54′20″S, long. 140°03′10″E a small body of calc-silicate rock of the Corella Formation unconformably overlies quartzite. The quartzite is considered to belong to the Argylla Formation but could possibly be part of the Mitakoodi Quartzite. The outlier of Corella Formation, which is only a few hundred square yards in area, is not shown in Plate 8 of the Atlas. The failure to observe an unconformity is attributed to the small angular discordance which probably existed at the time of deposition and the intensity of the subsequent tectonic deformation. Basal conglomerates have been observed in the Corella Formation in several places (see p. 88).

The strata now defined as the Argylla Formation were included by Nye & Rayner (1940, pl. 1) in their extensive Kalkadoon-Argylla series. Shepherd (1946 and 1953) did not show the distribution of his units.

Leander Quartzite.

Definition. Derivation of name: Leander Range. The range is composed entirely of rocks of this formation.

Map reference: Mount Isa and Cloncurry 4-mile Sheets (Atlas, Pls. 5 and 8). The type area is in both these sheet areas.

Lithology: Essentially moderately well-sorted fine to medium-grained quartzite (quartz arenite), with subordinate sericite quartzite and sandy shale. Preponderantly argillaceous sediments are rare and carbonate rocks are absent. (Some travertine has been observed; this is believed to have been derived by the weathering of tuff, or a sediment containing a little carbonate). Tuff, chloritic schist, and two or three flows of metabasalt have been recorded. The quartzites are light-brown to grey-white and many are cross-bedded or ripple-marked.

The type area for the formation is the Leander Range. The only other known exposures of the formation are in the range 3 miles west of the Leander Range (mapped as undifferentiated Lower Proterozoic because field relationships and distribution have not been adequately determined).

A typical section may be seen over a distance of 3 miles east from lat. 20°16′40″S, long. 139°29′5″E, following a valley. Cross faulting has, however, taken place along this line.

Thickness: Total thickness not known as base not exposed. Observed thickness about 5,000 feet.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: The type occurrence of the formation forms an elongated dome in the core of which the base of the formation has not been exposed; the underlying formation is therefore not known. Eastern Creek Volcanics conformably overlie the type occurrence. The contact, marked by the lowermost metabasalt of predominantly basaltic Eastern Creek Volcanics, is abrupt.

Description and Comment. Leander Quartzite crops out in the Leander Range over a total area of about 90 square miles. The sediments are thoroughly indurated, and slaty cleavage has developed in the more argillaceous beds, but otherwise metamorphic effects are slight. Folding is strong, with dips in places exceeding 70°, but is relatively simple, owing, probably, to the competency of the strata. A strong joint system has developed parallel to the axial plane of folding (Pl. 14, fig. 2). Fault movement of the order of hundreds of feet has occurred on some of the joints; others have been filled by dolerite dykes, particularly near the crestal zone of the Leander Range structure. Some of the dykes are only two feet wide; one, at least, is up to 300 feet wide.

The strong jointing has given rise to a pattern, in common with the Mount Guide Quartzite, which facilitates recognition of these units on air photographs. The Mount Guide Quartzite also occupies the same stratigraphical position as the Leander Quartzite, possesses a similar lithology (though more feldspathic and with extensive conglomerate at the base), and was similarly intruded by dolerite (now metadolerite) dykes. The two units can therefore be correlated with confidence. It can also be inferred that Leichhardt Metamorphics and Argylla Formation underlie the Leander Quartzite, provided they extend far enough west. The Ballara Quartzite overlies the Argylla Formation, contains one or two metabasalts near its base, and is intruded by metadolerite dykes; it is overlain by the Corella Formation. The metabasalt succession is absent from the region where the Ballara Quartzite is exposed. The Ballara Quartzite is therefore probably of the same general age as the Leander Quartzite (i.e. occupies the same stratigraphical position: since practically all correlations within the Lower Proterozoic are based on relationships to volcanic successions and since in such a wide area the onset and termination of vulcanicity throughout were probably not simultaneous, time correlations may not be precisely correct). The Knapdale Quartzite may possibly be comparable in age to the Leander Quartzite, but is more likely to be equivalent to the Roxmere Quartzite or the Mitakoodi Quartzite (see pp. 94-5).

The Leander Quartzite was included by Nye & Rayner (1940) in their Mount Isa series.

Mount Guide Quartzite

Definition. Derivation of name: Mount Guide.

Map reference: Urandangi, Duchess, Cloncurry, and Mount Isa 4-mile Sheets (Atlas, Pls. 5, 6, 8 and 9). The type area is in the Urandangi and Duchess Sheet areas (through Mount Guide).

Distribution: See p. 66.

Lithology: Quartzite, feldspathic in part, some with random pebbles; arkose, conglomerate, metabasalt. Argillaceous metasediments are rare. The type section extends two miles east and west of Mount Guide.

Thickness: The thickness of the formation varies considerably from place to place. Across the type section the thickness has not been accurately determined. East of Mount Isa the formation may be more than 15,000 feet thick, but movement along the north-striking joint planes, to form strike faults, may have caused considerable repetition. In places south of Mount Guide it is less than 5,000 feet thick. Maximum thickness is not less than 8,000 feet.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Probably overlies the Leichhardt Metamorphics disconformably and the Argylla Formation conformably or disconformably; conformably overlain by the Eastern Creek Volcanics. In the Urandangi Sheet area strata which have been correlated with the Mount Isa Shale overlie the Mount Guide Quartzite, probably unconformably. Granite extensively intrudes the base of the Mount Guide Quartzite.

Description and Comment. The main occurrence of the formation is in a practically continuous belt 80 miles long by a maximum of 13 miles wide, which extends from 12 miles north-east of Mount Isa to near the southern margin of the Duchess 4-mile Sheet area. Smaller outcrops lie to the east of this belt. Four miles west of Mount Isa an area of thoroughly greisenized quartzite and quartz-mica schist, shown as Eastern Creek Volcanics, may be Mount Guide Quartzite because it underlies a succession of metabasalts. The strata appear to have been folded plastically and lack the strong meridional jointing characteristic of most outcrops of the Mount Guide Quartzite. Alternatively they may form a quartzite lens within the Eastern Creek Volcanics, or may be ?Archaean. The total area of outcrop of the Mount Guide Quartzite is over 400 square miles.

An area of outcropping arenaceous rocks in the headwaters region of Stockyard and Rifle Creeks has been shown as Mount Guide Quartzite; but some of the strata, mapped as Plg? probably belong to a younger succession. There are two reasons for this belief:

1. Crystalline limestone occurs in the upper part of this succession, but no limestone has been recorded elsewhere in the Mount Guide Quartzite.

2. A conglomerate, more than 400 feet thick, within the succession, and an apparent divergence of strike, together suggest that the unit as mapped may contain an unconformity, but the presence of faults prevented the resolution of this problem. Because of inadequate information it was not possible to subdivide the succession satisfactorily. Within the anticlinal structure delineated by this succession extensive conglomerate beds, with quartzite and other boulders up to 16 inches by 12 inches, have been observed in close association with altered acid lavas. The conglomerates are probably near-basal Mount Guide Quartzite beds, but may form part of the Argylla Formation; their areal distribution was not determined.

The basal beds of the Mount Guide Quartzite, along practically the whole length of the eastern margin of the main outcrop (more than 50 miles), consist of conglomerate. In places the conglomerate beds are more than 100 feet thick; elsewhere interbedded conglomerate and arenaceous sediments, including arkose, extend through a stratigraphical thickness of several hundred feet (e.g. lat. 21°01′55″S, long. 139°32′35″E). Interbedded conglomerate and metabasalt have also been recorded. The matrix of the conglomerate is commonly highly feldspathic and in places is schistose. East of Mount Guide the conglomerate appears to have been hornfelsed and is now micaceous and blue-grey. It contains pebbles, and some boulders, some of which are more than a foot across; they are generally well-rounded but poorly sorted and are of quartzite, with some quartz, slate, and metarhyolite. Pebbles have generally been stretched during folding or metamorphism.

Overlying the conglomerates is well-bedded to massive light brown to white quartzite which commonly contains a high proportion of feldspathic impurity. Some arkose has been recorded. Grainsize varies from fine to coarse; pebble beds are not uncommon and random pebbles scattered through medium, even-grained feldspathic quartzite were noted extensively, particularly east of Mount Guide Homestead. Some beds are now quite friable, apparently owing to the weathering out of a soluble cement. Argillaceous beds are rare, but sandy slate and quartz-sericite schist occur, particularly south of Dajarra. Ripple-marking and cross-bedding are present, but not common. Interbedded metabasalts are more prevalent in the southern than in the northern part of the main line of outcrop. Metadolerite dykes are

most abundant in the lower—eastern—portion of the succession. They generally follow the strong joint system referred to in p. 65.

A rough fracture-cleavage is well developed in the quartzite, and, together with the axial plane jointing, tends to mask the bedding. The formation is strongly, but openly, folded. Dips up to vertical have been measured, but no overturning of beds has been recorded. The beds have been severely fractured. A well-developed system of north-west-striking oblique faults has generally apparently displaced the north-east block towards the north-west. Extensive movement has probably also taken place in the north-south joint direction.

The relationship of the Mount Guide Quartzite to non-contiguous formations has been discussed under Leander Quartzite (p. 65).

The Mount Guide Quartzite was included by A.G.G.S.N.A. (1937, pl. 4) in the Mount Isa series.

Ballara Quartzite

Definition: Derivation of name: The now abandoned township of Ballara, 3 miles north-north-east of Mount Philp.

Map reference: Cloncurry and Duchess 4-mile Sheets (Atlas, Pls. 8 and 9). The type area is in the Cloncurry Sheet area.

Distribution: See Description and Comment.

Lithology: Light brown, white, and grey quartzite, generally fine to medium-grained, some coarse-grained; some pebble beds; feldspathic impurity common; subordinate sericite quartzite, quartz-mica schist, and conglomerate. One or two flows of metabasalt occur near the base. Some strata are cross-bedded and ripple-marked, but most are massive or poorly bedded.

The type section is exposed along the watercourse which flows westerly roughly half a mile north of the Wee MacGregor copper mine; the full succession may not be exposed here. A good exposure may also be seen in the Corella Creek gorge, east of the Melba copper mine.

Thickness: Owing to the difficulty of elucidating structure, a reliable figure for thickness could not be obtained. It is probably not less than 2,000 feet.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: The Ballara Quartzite overlies the Argylla Formation, apparently conformably. It is overlain by the Corella Formation: no field evidence was found for an unconformable relationship, but it may exist (see pp. 64 and 90). The formation is unconformably overlain by the Deighton Quartzite.

Description and Comment. As mapped, the Ballara Quartzite crops out in five major bodies and several smaller ones in the Cloncurry 4-mile Sheet area and two bodies in the Duchess Sheet area. With the exception of those on the Duchess Sheet, all outcrops are confined to a north-north-easterly belt 17 miles long by 6 miles wide, north of Fountain Range Fault. Total area of outcrop is about 40 square miles.

The Formation is essentially arenaceous; it appears to be intermediate, in proportion of feldspathic material and of conglomerate, between the Mount Guide Quartzite and the Leander Quartzite. The sediments have been silicified and fracture-cleaved. Locally, they are hornfelsed, and at lat. 20°54′10″S, long. 139°57′E, metasomatic introduction of feldspar appears to have produced a granitoid rock out of an original sediment (Spec. R7238, Appendix I, p. 283).

Strong jointing and extensive faulting, together with the fairly massive nature of the strata, have made structure difficult to ascertain in the course of regional mapping, but folding is strong, with some possible overturning.

Several outcrops of Deighton Quartzite unconformably overlie the areas of Ballara Quartzite shown on the Cloncurry Sheet, e.g. at lat. 20°53′20″S, long. 139°53′50″E, but it would be necessary to 'walk out' the boundaries to determine their distribution; they have therefore been omitted from the map.

The presence of basalt interbedded with quartzite near the base and of dolerite dykes and sills (which are believed to be related to the Eastern Creek and Marraba vulcanicity) appears to fix the stratigraphical position of the unit as between the Argylla Formation and the Eastern Creek Volcanics (which are not present in the area—see also p. 65).

The Ballara Quartzite was not distinguished by Honman (1936d) and A.G.G.S.N.A. (1937a) from the quartzite now mapped as Deighton Quartzite, and was shown as part of the Mount Isa series. Nye & Rayner (1940) grouped the quartzites in the Kalkadoon-Argylla series.

Soldiers Cap Formation

Definition. Derivation of name: The name Soldiers Cap series was introduced by A.G.G.S.N.A. (1936a, p. 49) for a succession of schists and amphibolites south-east of Cloncurry. Soldiers Cap is a mesa formed by flat-lying Lower Cretaceous sediments. However, the area in which the unit, as mapped by Honman (1939), occurs is known as the Soldiers Cap area. It is proposed that the rocks in this area, together with an extension south to near the McKinlay River (lat. 21°39′50″S, long. 140°55′30″E), shall be called the Soldiers Cap Formation.

Map reference: Cloncurry and Duchess 4-mile Sheets (Atlas, Pls. 8 and 9). The type area is in the Cloncurry Sheet area.

Distribution: As mapped, the Soldiers Cap Formation forms a single body of total area 780 square miles, entirely east of the Cloncurry line of high-angle reverse faulting. The northernmost exposure is at lat. 20°36′30″S, long. 140°43′00″E, and the southernmost at lat. 21°44′10″S, long. 140°45′35″E, giving a total meridional length of 80 miles and maximum width of 25 miles. This represents a considerable extension of the area included as Soldiers Cap series by Honman (1939), but does not include the large area south-west and south of Cloncurry which was included by Nye & Rayner (1940, pl. 1).

Lithology: The full succession, with the exception of the lowermost beds, and perhaps some of the uppermost beds, may be examined along a seven-mile long section from the core of the anticline in the Snake Creek East area (lat. 20°46′40″S, long. 140°39′50″E) to Weatherly Creek at lat. 20°55′10″S, long. 140°45′30″E. This is the type section. The succession from west to east, that is from the oldest to the youngest, is:

Andalusite-mica schist, andalusite-garnet-mica schist, cordierite-anthophyllite-mica schist, garnet-mica schist and muscovite schist, interbedded throughout with sandy mica schist and subordinate quartzite beds (see Pl. 28, fig. 2).

Schists as above, but with the metamorphic minerals less well developed; some darker (chloritic?) schists and quartzite.

Quartzite and sandy slate.

Andalusite-mica and garnet-mica schist.

Fine muscovite and biotite (or chlorite) feldspar schists (possibly altered arkose or tuff) with interbedded quartzite. Some spotted schist.

Metabasalt.

Quartzite and slate, some chloritic slate.

Medium-fine-grained to cherty quartzite, interbedded with sandy slate; some chlorite.

Metabasalt, some thin beds of quartzite.

Well-bedded ('ribbon') slate.

Sandy sericitic and chloritic slate; quartzite.

Metabasalt.

Fine cherty quartzite (some cross-bedded) and sandy slate.

Very fine-grained white and brown quartzite, some flaggy; altered greywacke or tuff, sandy slate; some metabasalt.

Metabasalt, some interbedded quartzite, also black hornfels.

Grey sandy 'ribbon' slate, cherty quartzite (argillaceous in part) and metabasalt. Black siliceous slate, probably carbonaceous.

Interbedded metabasalt and dark grey bedded cherty quartzite; some chert, probably some hornfels.

Interbedded dark cherty quartzite and grey siliceous slates.

Along the type section the unit falls naturally into three subdivisions; these are, from oldest to youngest, the high-grade pelitic succession, interbedded metabasalts and medium-grained quartzite (with subordinate pelites), and interbedded metabasalts, cherty quartzite, chert and slate. Honman (1939, p. 8) makes a division at the base of the lowermost metabasalts into Upper, or Volcanic, Stage and Lower, or Schist, Stage. The three divisions referred to above have not been made into formal units as they can be recognised throughout a relatively small area only. There are numerous occurrences of concordant basic rocks in the Duchess Sheet area, but they have been metamorphosed to such a degree that it was not possible to establish whether they were flows or sills. The amphibolites recorded along the type section and those occurring farther north are undoubtedly altered flows, as evidenced by vesicles and texture (see also Honman, 1939, p. 8). Metamorphosed arkose and hematite quartzite have been observed in the middle division, and metamorphosed calcareous rocks may form a minor part of the two upper divisions. Carbonaceous slate has been recorded in a number of localities. North of the section-line quartz-sericite schist is interbedded with metabasalt in the upper division.

Thickness: The thickness of the type section, after allowing for observed structures, is about 29,000 feet. This suggests a total thickness for the unit as exposed of not less than 30,000 feet. After allowing for unobserved minor structures, the probable maximum thickness of the exposed portion of the unit is considered to be 25,000 feet. An unknown thickness at the base of the succession is not exposed.

Figures for thickness of the succession elsewhere, particularly in the Duchess Sheet area, are difficult to obtain owing to the absence of readily recognisable structure over any appreciable distance across the strike.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: The Soldiers Cap Formation is overlain by the Corella Formation. At many points the contact is faulted and in others the relationship is obscure, but the numerous outliers of Corella Formation, within the geographical limits of the Soldiers Cap Formation, indicate that the former overlies the latter unconformably. This may be well seen at lat. 20°45′50″S, long. 140°40′00″E.

On the Duchess Sheet in many places the Soldiers Cap Formation appears to overlie the Corella Formation but mapping has shown that the strata are consistently overturned to dip east.

Description and Comment. Practically all the outcropping Soldiers Cap rocks in the Duchess 4-mile Sheet area appear to be high-grade pelites, with interbedded psammites. They are more nearly akin to those of the lowest division in the Cloncurry Sheet area than to either of the other two. It is not clear whether this is due to a sedimentary facies change or whether the upper portions are absent. The apparent pelitic character of these rocks may be due in part to greisenization by nearby granites, giving a high mica content, but andalusite and garnet are extensively developed. The succession differs from that in the Snake Creek area in the presence of concordant amphibolites, which could have been basalts.

The high proportion of pelites, compared with most other formations in the region, is a feature of the Soldiers Cap Formation. A further distinction is that the pelites have, except in the uppermost division in the Cloncurry Sheet area, been raised to a much higher grade of metamorphism than is usual in the other prominently pelitic successions—Marimo Slate, Answer Slate, Kuridala Formation, and Mount Isa Shale. The andalusite-garnet-mica suite is developed throughout the Snake Creek area (an excellent exposure, with andalusite crystals up to 1½ inches by 1 inch, can be seen in a rock face in a watercourse at lat. 20°56′45″S, long. 140°40′50″E, from which locality the specimen shown in Plate 28, figure 2, and Specimens J678, J680, R6927 and R7199, described in Appendix I, p. 285, were collected), and much of the area of outcrop in the Duchess Sheet. Garnet-anthophyllite-cordierite-quartz rock has also been found in the Snake Creek area (Spec. J482B, Appendix I, p. 286). Granite may occur at shallow depth beneath these high-grade pelites.

Honman (1939, p. 8) describes as felsitic the aphanitic rocks of the uppermost division—which, he states, under the microscope display granulitic texture—because 'the field evidence shows that they are acid volcanic flows. Portion of the field evidence consists of frequent presence of amygdules.' These features were not observed by us, although some vugs formed by the weathering out of crystals were recorded. Several specimens were examined in thin section and proved to be chert or very fine granular quartzite (see Appendix I, p. 286, Spec. R6931). Some possible tuffs were recorded in the field, but are so metamorphosed that their identity is in doubt.

The metabasalt is typically fine and even-grained. It breaks with a sub-conchoidal fracture and exposes a few cream feldspar grains (3 mm.). Its weathered surface is pitted and iron-stained in places. A specimen examined in thin section consists almost entirely of xenoblastic amphibole and feldspar grains up to 0.2mm. across, with small grains of iron oxide (0.05mm.) evenly distributed throughout. Some sphene and rare epidote are present. A few thin feldspar laths (0.5mm.) are relics of an original igneous texture. The feldspar appears to be a fairly sodic variety. Metamorphism of the original basaltic rock is between albite-epidote-amphibolite and the amphibolite facies. (See Appendix I, p. 287, Spec. R7000, R7063).

Air photographs reveal the structure of the northern portion of the formation with great clarity. The basic structure probably consists of two north-pitching anticlines, separated by a syncline with a generally northerly axial trend, west of Weatherly Creek. East of Cloncurry, however, bedding trends are generally west-north-westerly, possibly indicating a zone of pitch change (Pl. 26, fig. 1).

Honman (1939, p. 11) divides the Soldiers Cap area into northern and central synclines and a southern anticline. In the Duchess Sheet area bedding trends are slightly west

of north and tend to parallel the 'Cloncurry Overthrust' (see p. 184), against which beds are overturned to dip east.

The only stratigraphical unit whose relationship with the Soldiers Cap Formation is established by contact is the Corella Formation. The contact is unconformable; the Corella Formation is the younger. The metabasalts of the Soldiers Cap Formation are probably related to the Marraba and Eastern Creek vulcanicity; and hence the pelitic, non-volcanic lowest division of the Soldiers Cap Formation is contemporaneous either with the lowermost Marraba Volcanics or the Argylla Formation. No acid lavas have been found near the base of the Soldiers Cap Formation, nor any dykes and sills related to the basic vulcanicity; but a system of radial metadolerite dykes, with related sills, cuts across the lowest division. These dykes are believed to have been intruded after the Soldiers Cap anticlinal structure had been formed. They have been affected by granite.

The schists, with some amphibolites, in the upper Mort River area, at lat. 21°43′00″S, long. 140°35′00″E, which have been assigned to the Kuridala Formation, are lithologically indistinguishable from the schists in the southern part of the Soldiers Cap Formation. Possibly the uppermost strata of the Soldiers Cap Formation are equivalent in age to portion of the Marimo Slate. The case for contemporaneity is strengthened if one accepts the presence of acid lavas (felsites) in the former, as claimed by Honman, because agglomerate, and also (according to Honman) rhyolite, occur in what has now been mapped as the Marimo Slate. In the Marimo Slate, however, metabasalts occur only in the lowermost few hundred feet.

Honman (1939, p. 7) regarded the Soldiers Cap series as Upper Archaeozoic, intermediate between the Kalkadoon-Argylla and Mount Isa series. The present writers regard all three 'series' as Lower Proterozoic (see pp. 129-131).

Marraba Volcanics

Definition. Derivation of name: Marraba railway siding.

Map reference: Cloncurry and Duchess 4-mile Sheets (Atlas, Pls. 8 and 9).

Distribution: The Marraba Volcanics crop out over an area of 220 square miles, mainly in a large north-pitching anticline north and north-west of the township of Malbon. The formation has also been identified in the southerly extension of the eastern limb of the same anticline, south of the Wimberu Granite (lat. 21°27′S, long. 140°18′E).

Lithology: From base of succession to top:—

Fine-grained quartzite, well-bedded to massive, pink-brown in colour.

Metabasalt, vesicular in part.

Quartzite, sericitic and sandy schists, some fine mica schist, metabasalt, altered tuff.

Sericitic and sandy schist, altered tuff, metabasalt (including vesicular and amygdaloidal metabasalt).

Sandy schist and slate, recrystallized limestone and limy slate, and altered tuff and metabasalt.

Black slate, altered tuff, impure quartzite, and metabasalt.

In general arenaceous rocks are most abundant at the base of the succession. Although difficult to identify in the field because of metamorphism, tuffs appear to constitute an important part of the middle and upper portions of the succession. Metabasalt is abundant throughout, but less so near the top of the succession than in the middle. Metamorphism is evidenced by fracture-cleavage and schistosity; and some thermal metamorphism has taken place (occurrences of hornfels are probably related to later basic intrusions rather than a non-outcropping granite).

The type section is from lat. 20°41′45″S, long. 140°13′50″E, to lat. 20°53′20″S, long. 140°15′00″E. Tuff does not appear to be as abundant in the type area as farther east, and calcareous rocks have not been recorded. In the eastern portion of the area underlain by the formation outcrop is poor.

Thickness: Maximum thickness is probably not less than 10,000 feet. However, in detail, structure cannot be readily determined. The involved folding which is apparent in the overlying Mitakoodi Quartzite (see Fig. 10) indicates that the Marraba Volcanics are probably strongly and intricately folded, as they would have been rather less competent than the Mitakoodi Quartzite. In the west of the area it appears from outcrop width that the maximum thickness may not exceed 5,000 feet.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Conformably underlain by Argylla Formation. The uppermost quartzite of the Argylla Formation is similar in appearance to that of the base of the Marraba Volcanics; but acid lavas are present in the Argylla Formation. Mitakoodi Quartzite conformably overlies the Marraba Volcanics. The change to the arenaceous strata of the Mitakoodi Quartzite is fairly abrupt and is accompanied by a diminution in metabasalts.

Description and Comment. The lavas of the Marraba Formation all appear on field examination to be metabasalt. The few specimens that have been examined petrologically are essentially similar. both in mineral assemblages and metamorphic grade, to those of the Eastern Creek Volcanics (see Appendix I, p. 287, Spec. R6992,3). The metabasalt of the Soldiers Cap Formation is generally more highly metamorphosed. Tuff appears to be more abundant in the Marraba Volcanics than in the other two formations. In general the metasediments are less arenaceous than those of the Eastern Creek Volcanics; they are much more arenaceous than those of the lowest division of the Soldiers Cap Formation, but, except at the base, less than the middle division.

The formation appears to be thicker in the east than in the west. This may be due to structural deformation, but the presence of at least 200 feet of black slate, and calcareous metasediments, in the east, which have not been recorded farther west, suggests that the thickening may be a depositional feature.

In the air photographs a very strong fracture pattern, due to close-spaced jointing, can be seen; this tends to mask bedding trends and to make resolution of detailed structure difficult, but in the overlying Mitakoodi Quartzite the fractures cut across fold axes. The direction of strike of the fractures swings from about 030° in the south-west to 090° in the east (Fig. 11). The pattern continues into the Mitakoodi Quartzite. Probably some movement has taken place along these joints.

Metamorphism has not been very intense. Mica schist has developed in places; elsewhere slate and sericitic schists are the normal rock types. Much of the metabasalt is schistose and is commonly recrystallized. Generally the greenschist mineral assemblage is found in the metabasalt (see Appendix I, p. 287, Spec. R6992 and 6993).

The metabasalts of the Marraba Volcanics are correlated with those of the Eastern Creek Volcanics and Sodiers Cap Formation on rock type, superposition, and structure. The base of the Marraba Volcanics is considered to be roughly the same age as the base of the Mount Guide Quartzite (see Fig. 9), as indicated by the cessation of acid vulcanicity. The top of the Marraba Volcanics does not represent the end of basaltic eruption, as some metabasalts occur in the Mitakoodi Quartzite and the base of the Marimo Slate.

The Marraba Volcanics and the Mitakoodi Quartzite together, therefore, are probably roughly equivalent to the Eastern Creek Volcanics. As no acid lavas are exposed at the base of the Soldiers Cap Formation close correlation with the Marraba Volcanics is difficult, but if the earliest basalt flows are of the same age in both formations, the base of the Marraba Volcanics is of the same age as the base of the middle division of the Soldiers Cap Formation. The trends in sedimentation during the periods of vulcanicity in the two formations can be matched in general terms, but not in detail. The sediments in the Soldiers Cap Formation are generally less arenaceous than those in the Marraba Volcanics and Mitakoodi Quartzite.

A.G.G.S.N.A. (1937a, pl. 4) and Nye & Rayner (1940) included the area of outcrop of the Marraba Volcanics, together with those of the Mitakoodi Quartzite, Answer Slate, Staveley Formation, and Kuridala Formation, within the Soldiers Cap series, and regarded the whole as Upper Archaeozoic.

Eastern Creek Volcanics

Definition. Derivation of name: Eastern Creek, a tributary of Gunpowder Creek. Shepherd (1931, p.225) equated altered basalts six miles east-north-east of Mount Isa (which are here included in the Eastern Creek Volcanics) with the Spring Creek series. There is no earlier published reference to this name. The name Spring Creek Basalts was used by David (1932, p. 30) and Shepherd (1946, p. 146) and the name Spring Creek Volcanics by Shepherd in 1953 (p. 386). Although no map showing the distribution of the Spring Creek lavas has been published it is clear that they are the same as those to which the present writers apply the name 'Eastern Creek Volcanics'. Spring Creek is abandoned as the unit name because of its lack of distinction (see Raggatt, 1950, p. 172: there are at least four Spring Creeks within the Precambrian of north-western Queensland). For field use during mapping the name 'Eastern Creek Basalt' was adopted; and since the quickening of interest in the region occasioned by the discovery of uranium the name has been used by field geologists generally. Eastern Creek Volcanics is therefore now used as the formal name for the unit.

Map Reference: Camooweal, Mount Isa, Urandangi, Glenormiston, Dobbyn, Cloncurry, and Duchess 4-mile Sheets (Atlas, Pls. 1, 4-9). The type section is on the Cloncurry 4-mile Sheet.

Distribution: See Description and Comment (p. 75).

Lithology: The succession throughout is essentially of interbedded metabasalt and metasediments; some intermediate and acid lavas occur near the top. Grade of metamorphism varies considerably from place to place because the formation, as mapped, is so widely distributed. The types and thickness of metasediments and the relative abundance of lava and sediment also vary considerably throughout the formation. It is proposed that the section along the Mount Isa-Cloncurry road, from 1½-5 miles from Mount Isa, although far from Eastern Creek, shall be the type section, because the full stratigraphical succession appears to be exposed here and because it is readily accessible.

In the type section the metabasalt is fine to medium-grained, is commonly vesicular, and in places has amygdules of calcite, epidote, or quartz; some flows

appear more acid than others, but no flows of intermediate composition have been recognised under the microscope. The lavas are commonly stressed, and locally sheared, and are partly recrystallized. Flows are generally rather thin, but some probably reach a couple of hundred feet; no thicknesses have been measured. The interbedded metasediments, which are thinner in the type area than in most other places, consist of quartzite, epidote quartzite, greywacke and pebble beds, sandy and calcareous slate, crystalline limestone, and some schist. Altered tuffs are probably also present.

North of the type section (to approximately lat. 20°36′50″S, long. 139°04′20″E) the proportion of sediment to lava is rather different in the upper levels. Here arenaceous lenses, including feldspathic quartzite, attain thicknesses of 2,000 feet or more. Throughout the whole area of outcrop, variations occur in the thickness of sediment and in sediment-to-lava ratio, of the order to be found in the two localities cited above. In general, the sediment-to-lava ratio and the silica content of metasediments are greater towards the top of the succession. The proportion of sediment also increases greatly in the south of the outcrop area.

Rocks of the formation have been subjected in different places to regional, thermal, and dislocation metamorphism, or combinations of these; as a result a wide range of metamorphic types is to be found. Regional metamorphism is generally in the greenschist facies, but some rocks are in the amphibolite facies (see also Joplin, 1955, p. 36). West and north-west of Mount Isa, e.g. south of Leander Range, intense fracturing and shearing have produced highly cleaved and schisted metamorphics. West of Mount Isa thermal effects have been superimposed by the Sybella Granite to produce some high-grade metamorphics. Thermal effects are pronounced throughout the Urandangi Sheet, particularly where greisenization has reinforced the high-temperature effects. Over wide areas, particularly south of Ardmore Homestead, the basalts and associated sediments have been converted to micaceous schists and gneisses, and locally granitized and migmatized. The possibility that some of the higher-grade metamorphics belong to an older succession is discussed on p. 59.

Thickness: The stratigraphic thickness of the type section appears to be about 15,000 feet; farther north the formation is probably more than 20,000 feet thick. Estimates of thickness in the Urandangi Sheet are difficult, owing to incomplete exposure of the succession, poor outcrop, or lack of knowledge of structure.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: On the Duchess and Urandangi Sheets, Eastern Creek Volcanics are conformably underlain by Mount Guide Quartzite; on the Mount Isa and Cloncurry Sheets by Mount Guide and Leander Quarzites; and on the Dobbyn Sheet, disconformably by Argylla Formation. They are overlain by Myally Beds, Surprise Creek Beds, Judenan Beds, and Mount Isa Shale, unconformably in places and conformably elsewhere. Boulder conglomerate, including basaltic

pebbles and boulders, commonly forms the base of the younger strata along the western margin of the tectonic land (see pp. 50 and 99). A probable unconformity between Eastern Creek Volcanics and Mount Isa Shale was seen at lat. 20°58′00″S, long. 139°28′30″E. Silicification with quartz stringers marks the contact; so it may be faulted. In the north of its outcrop area the Mount Isa Shale unconformably overlies both the Eastern Creek Volcanics and the Myally Beds (see Pl. 14, fig. 2).

Description and Comment. Eastern Creek Volcanics crop out over a total area of 1,540 square miles, over a meridional distance of 175 miles from lat. 19°25′S, 90 miles north of Mount Isa, to lat. 22°05′S, 92 miles south-south-west of Mount Isa. It is not exposed east of long. 139°45′E. Although a large number of discrete bodies crop out, most of the lavas almost certainly belong to the one peroid of vulcanicity; and, with the exception of some of the higher-grade metamorphics in the Mount Isa and Urandangi Sheet areas, which may possibly be of Archaean age, the distribution of the formation is substantially as represented (see p. 76).

The Eastern Creek Volcanics are remarkable for the uniformity of lava type throughout, apart from the minor acid and intermediate flows in places at the top of the succession. Joplin (1955) has given some descriptions and chemical analyses. Two specimens of little-altered basalts are described in Appendix I, p. 289, Spec. R6970, R6974.

The metabasalt falls into two main textural groups— a fine-grained greenschist, and a slightly coarser intergranular rock, which is porphyritic or glomeroporphyritic in some specimens and is composed mainly of feldspar laths. The greenschist metabasalt is even-grained and has a poorly developed lepidoblastic fabric. It is composed mainly of chlorite (penninite), with some altered feldspar, epidote, hornblende, and subordinate green biotite. There are a few relict feldspar laths and phenocrysts; other mineral grains are xenoblastic. In the intergranular metabasalt the phenocrysts or aggregates are of feldspar, mostly andesine, and are up to 3 mm. across; some of the feldspar, owing to metamorphism, is albite. In some specimens the texture is doleritic; feldspar laths, of average length 0.5 mm., are the main constituent of the groundmass. Chlorite, the main dark mineral, is interstitial to the feldspar laths, and may be accompanied by lesser amounts of calcite, sericite, epidote, and rarely hornblende or biotite. Opaque iron minerals, associated with sphene, are evenly distributed as discrete grains. Rare accessory minerals are quartz and apatite.

Apart from the infillings in vesicular metabasalt referred to in the description of the type section, chlorite, pink feldspar, actinolite, biotite, hornblende, and rarely iron oxide and sphene, have been found in amygdules.

Honman (1937, p. 6) records augite andesite from the Bower Bird area, west of Gereta Homestead, and Jensen (1941, p. 6) records andesite, with interbedded rhyolite, from the Lochness area, about 16 miles to the north-north-west. No specimens from these areas have been petrologically examined in the course of the present work, but de Keyser (1958, unpubl.) has recorded rhyolite, basaltic andesite, and dacite from the top of the Eastern Creek Volcanics and the base of the immediately overlying Judenan Beds, a few miles north of the junction of Gunpowder and Gidyea Creeks (Camooweal 4-mile Sheet).

Although few occurrences of tuff have been recorded, it is probably locally abundant.

In the Dynamite Creek area, around lat. 19°28′S, long. 139°39′E, the base of the Eastern Creek Volcanics consists of arkosic conglomerate, arkosic greywacke, siltstone, and quartzite, and is overlain by basalt flows without interbedded sediments, other than lenses of boulder conglomerate. The conglomerate is made up of boulders and cobbles, commonly caught up in the flows, of rhyolite, porphyry, and granite (Ewen Granite). Similarly, the basalt (or andesite) flows in the Bower Bird area are interstratified with boulder conglomerate, included in which are pebbles of rhyolite. The flows are probably near the base of the formation.

Metasediments observed in the succession, which have not been recorded in the type section, include feldspathic quartzite; black (carbonaceous?) slate (e.g. lat. 20°16′40″S, long. 139°31′30″E); and thin beds of conglomerate and 'greenstone' which may be derived from greywacke or sandy shale, tuff, or intensely sheared basalt. 'Greenstone' is plentiful south of the Leander Range about lat. 20°25′05″S, long. 139°26′55″E. In places the dominant metasediment is epidote quartzite; the epidote is finely disseminated through the quartzite, giving the whole rock a green colour.

Joplin (1955, Table 1 and p. 47 ff) has described and classified the metamorphism of the basic igneous rocks of the region, including basalts of the Eastern Creek Volcanics. She shows that several mechanisms or processes have produced the metamorphism and that the end products accordingly differ considerably from place to place. The range of metamorphism is clearly evidenced by the associated metasediments. In places pelitic sediments have been raised to the rank of weakly-cleaved slates only; elsewhere they have become phyllites; where regional and thermal effects reinforce one another cordierite-andalusite-sillimanite gneiss may be formed (see Joplin, 1955, p. 38, and Appendix I, p. 288, Spec. J9A, J321A, B, and C). Later field work has failed to produce any conclusive evidence for inliers of an older metamorphic complex (see p. 59), although evidence has been found for an ?Archaean granite. The schists and gneisses described by Dr Joplin in paragraphs 1 and 5 of p. 38, and par. 1 of p. 39, have therefore been mapped as Eastern Creek Volcanics; but more detailed work may show that they are older. Close to the Sybella Granite, migmatite, with laminae of feldspar and biotite, has been formed in places; where greisenization was extensive, the formation may be represented largely by muscovite and biotite schists. South of Ardmore Homestead quartz gneiss has been observed.

Folding throughout the formation has generally been strong but simple, with dips up to vertical, giving rise to broad structures which are clearly indicated by the distribution of the formation. Beds are overturned west of the Mount Isa Fault. Here structure appears to be rather more complex than elsewhere; in the southern portion of the Urandangi Sheet structure has not been deciphered.

The formation has been extensively faulted. The faults appear to belong to several systems of different ages and have been responsible for the absence of the Eastern Creek Volcanics east of long. 139°45′E, and for several repetitions of the formation in a north-south direction. The pattern and significance of faulting are discussed on p. 187.

The relationship of the Eastern Creek Volcanics to the Marraba Volcanics and the Soldiers Cap Formation is discussed under those formations. The metabasalts in all three are attributed to the same period of vulcanicity. If this is the case, the Corella Formation must be younger than the Eastern Creek Volcanics, although no contact between the two is known.

Officers of the Aerial, Geological and Geophysical Survey of North Australia regarded the Eastern Creek Volcanics as the lowermost division of their Mount Isa series.

Mitakoodi Quartzite

Definition. Derivation of name: Mitakoodi railway siding, between Cloncurry and Malbon. Mitakoodi is also the name of the aboriginal tribe which inhabited the region now represented by the south-eastern portion of the Cloncurry Mineral Field.

Map reference: Cloncurry and Duchess 4-mile Sheets (Atlas, Pls. 8 and 9). The type area is in the Cloncurry Sheet area.

Distribution: The Mitakoodi Quartzite flanks the northern and eastern margins of the Marraba Volcanics; that is, it forms a belt, from 1 to 6 miles wide, which trends from lat. 20°50′45″S, long. 140°05′05″E. (8 miles south-east of the Mary Kathleen uranium mine) for 18 miles in an east-north-easterly direction, then south and south-south-east for 30 miles, to the Wimberu granite, south of Florence Creek. It has also been recognised south of the Wimberu Granite.

Four other smaller occurrences are shown in Plates 8 and 9 (Atlas). Those in the Duchess Sheet area are rather more doubtful than that in the Cloncurry Sheet area.

Lithology: Medium to fine-grained, massive to well-bedded quartzite, generally pink or white, with some interbedded metabasalt, altered tuff and altered argillaceous sediments; some impure crystalline limestone. The quartzite is commonly poorly sorted and impure and in places approaches the composition and texture of a quartz greywacke; feldspar and clay are common impurities. Clay in places occurs as small pods or lenses. Some of the arenaceous sediments have a sugary texture and weathered specimens tend to be friable. Cross-bedding and some ripple-marking have been observed. Argillaceous sandstone (or sericitic quartzite) is fairly common, but slates are rare. Siltstone, calcareous metasediments, metabasalt and tuff, which in places are schistose, form a minor part of the formation.

In the Duchess Sheet area, the formation crops out near the Wimberu Granite; the general grade of metamorphism is slightly higher than farther north. Quartz-sericite and fine mica schists have been recorded.

A section through the formation is well exposed in the gorge east of Mitakoodi railway siding, through which the Cloncurry to Malbon road passes (lat. 20°56′50″S, long. 140°19′10″E). This is the designated type section. However, no metabasalts have been recorded in this section. Metabasalt may be seen along the old track which passes the Southern Cross copper mine.

Thickness: 3,000-4,000 feet maximum. Towards the western end of the outcrop area the formation lenses out. Owing to the complex folding accurate figures for thickness cannot be obtained.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Conformably underlain by Marraba Volcanics, except for the three isolated outcrops on the Duchess Sheet, which overlie the Argylla Formation. On the east the Formation is overlain conformably by Marimo Slate and on the north by the Corella Formation, apparently conformably (but see p. 64).

Description and Comment. The total area of outcrop of the Mitakoodi Quartzite is 140 square miles. The contact between the Mitakoodi Quartzite and the Marraba Volcanics is fairly sharp and is marked by the abrupt appearance of arenaceous metasediments and a diminution of volcanics. Volcanic material, however, is in evidence right through the succession to the base of the Marimo Slate. The lavas have not been examined in thin section, but appear to be metabasalts.

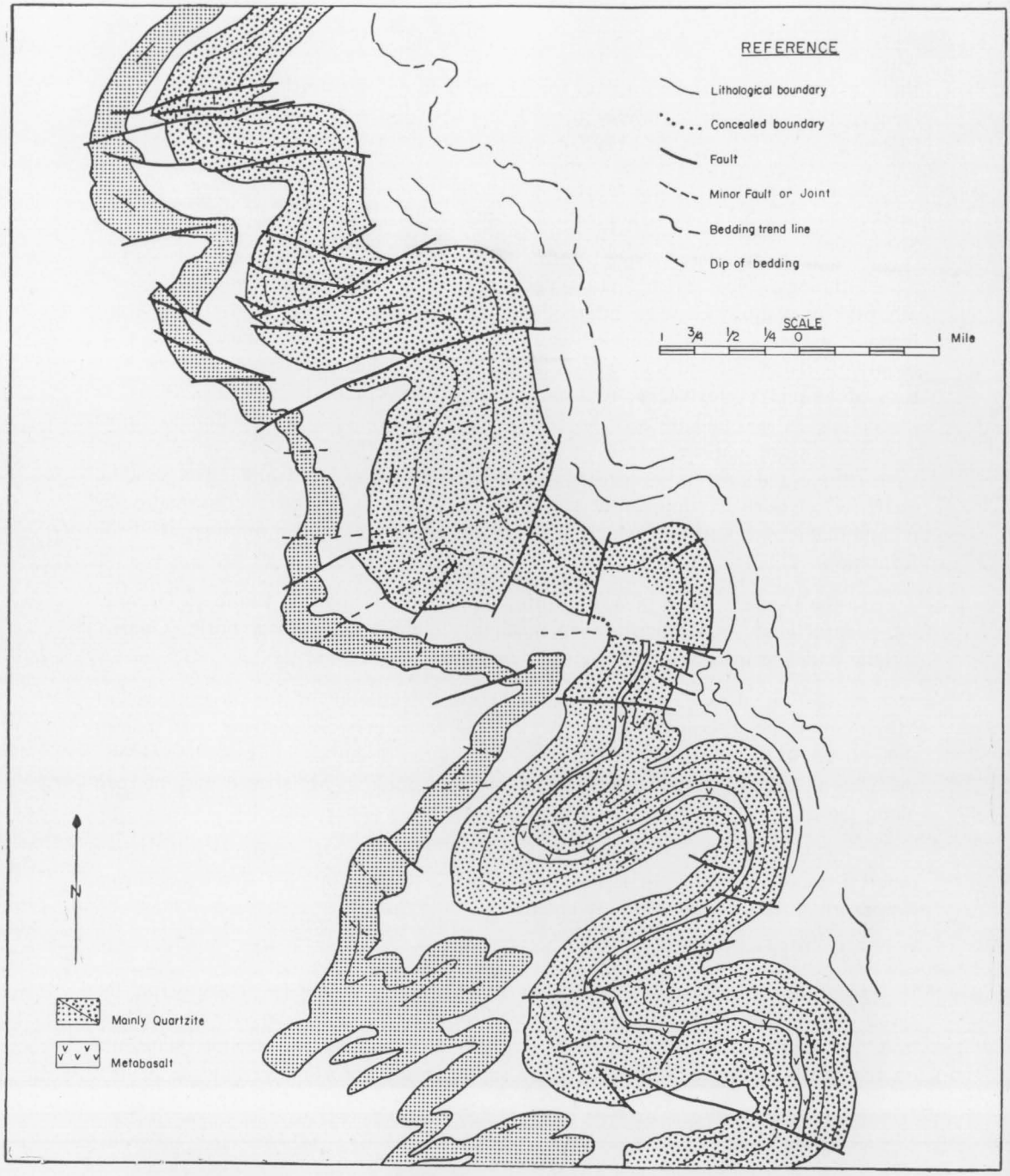


Fig. 10. Detail of folding and faulting in the Mitakoodi Quartzite, east and south-east of Marraba Railway Siding.

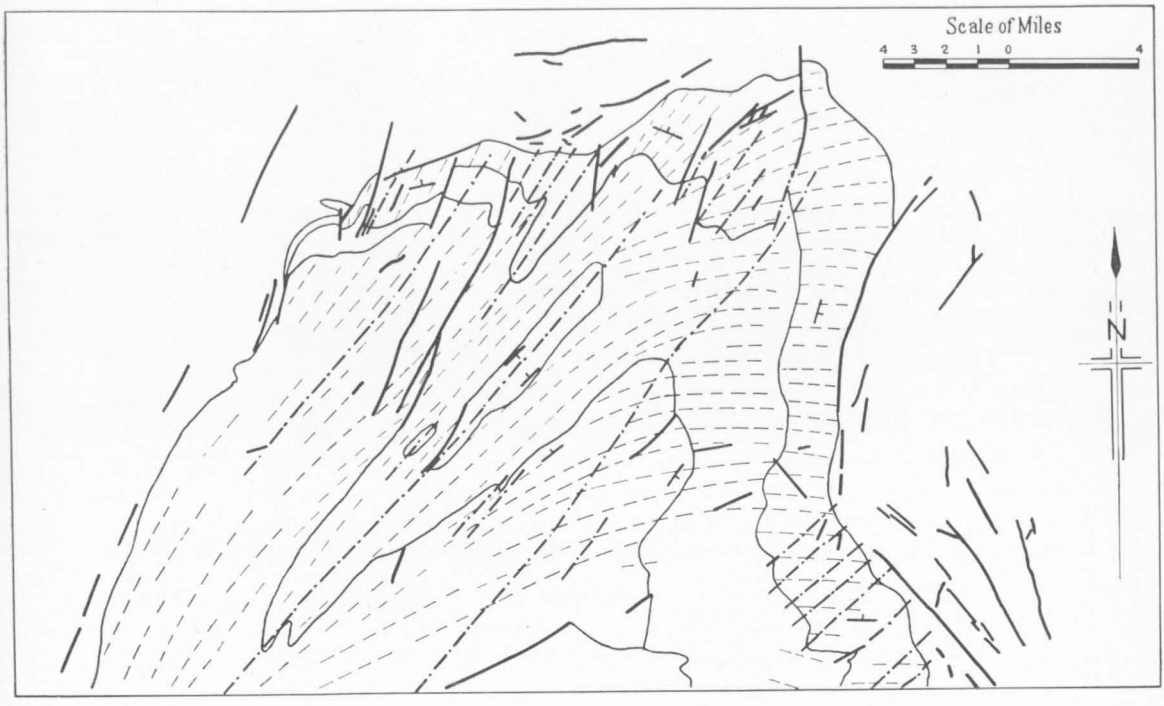


Fig. 11. Structure in the north-pitching anticlinorium south-west of Cloncurry.

Like the Marraba Volcanics, the Mitakoodi Quartzite in general does not appear to have been highly metamorphosed, except near the Wimberu Granite. It has, however, been intricately deformed, as described on p. 181 (see also Figs. 10 and 11). Superimposed on the folds, and cutting across the fold axes, particularly in the east, are large numbers of joints, which extend from the Marraba Volcanics (p. 181). In some places the joint planes show evidence of fault movement.

The Mitakoodi Quartzite is probably roughly contemporaneous with the extensive quartzite lenses at the top of the Eastern Creek Volcanics and part of the uppermost division of the Soldiers Cap Formation. It may also possibly be penecontemporaneous with the Knapdale Quartzite, but the precise stratigraphical position of the latter cannot be established (see p. 95).

A.G.G.S.N.A. (1937a, pl. 4) and Nye & Rayner (1940, pl. 1) included the Mitakoodi Quartzite in the Mount Isa series.

Marimo Slate

Definition: Derivation of name: Marimo siding, 9 miles from Cloncurry, on the Malbon railway line.

Map reference: Cloncurry and Duchess 4-mile Sheets (Atlas, Pls. 8 and 9). The type area is in the Cloncurry Sheet area.

Distribution: See below.

Lithology: Predominantly sandy slate, quartz siltstone, and argillaceous and sericitic quartzite or quartz greywacke. Carbonaceous and graphitic slates are locally well developed and the formation contains some crystalline limestone, calc-silicate rocks, including calc-silicate breccia, calcareous slate and calcareous quartzite. Sparse tuff and tuffaceous sediments and one or two flows of metabasalt occur in the lower part of the succession. Metamorphism has locally produced spotted slate, phyllite, fine quartz-mica schist, and micaceous quartzite.

The type section lies on an east-west line which passes through Mount McNamara copper mine and extends 4½ miles west and 6 miles east from it. In this section extensive faulting and repetition by folding can be seen and portions of the section are concealed by alluvium, but no better or more representative section can be named.

Thickness: The thickness cannot be accurately determined because of the complexity of structure and lack of continuous outcrop. The maximum thickness is probably not less than 8,000 feet and may be considerably more.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Underlain conformably by Mitakoodi Quartzite; the contact is marked by a change in sedimentary types which is gradual in places and abrupt elsewhere. One or two metabasalt flows in the lower part of the Marimo Slate also indicate that there has been no time break between the two.

To the south the Answer Slate is separated only by a fault from the Marimo Slate. The boundary is arbitrary and is necessitated by inadequate knowledge of the stratigraphy within the Marimo Slate. Continuation of the detailed mapping which has been carried out in the Kuridala-Mount Cobalt area would doubtless result in the tracing of the Answer Slate, Staveley Formation, and Kuridala Formation through the Marimo Slate into the Corella Formation.

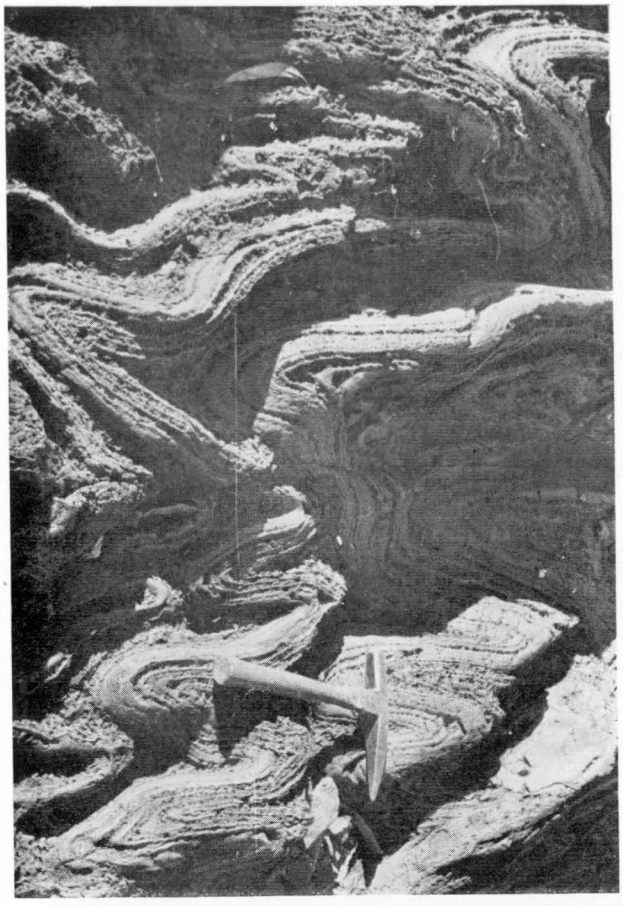


Fig. 1. Contortions in calc-silicate rocks of the Corella Formation, in Cleanskin Creek.

—Photograph by Dr G. A. Joplin.

Fig. 2. Sedimentary breccia in the Corella Formation, south of Mount Isa-Cloncurry road, 12 miles from Cloncurry.

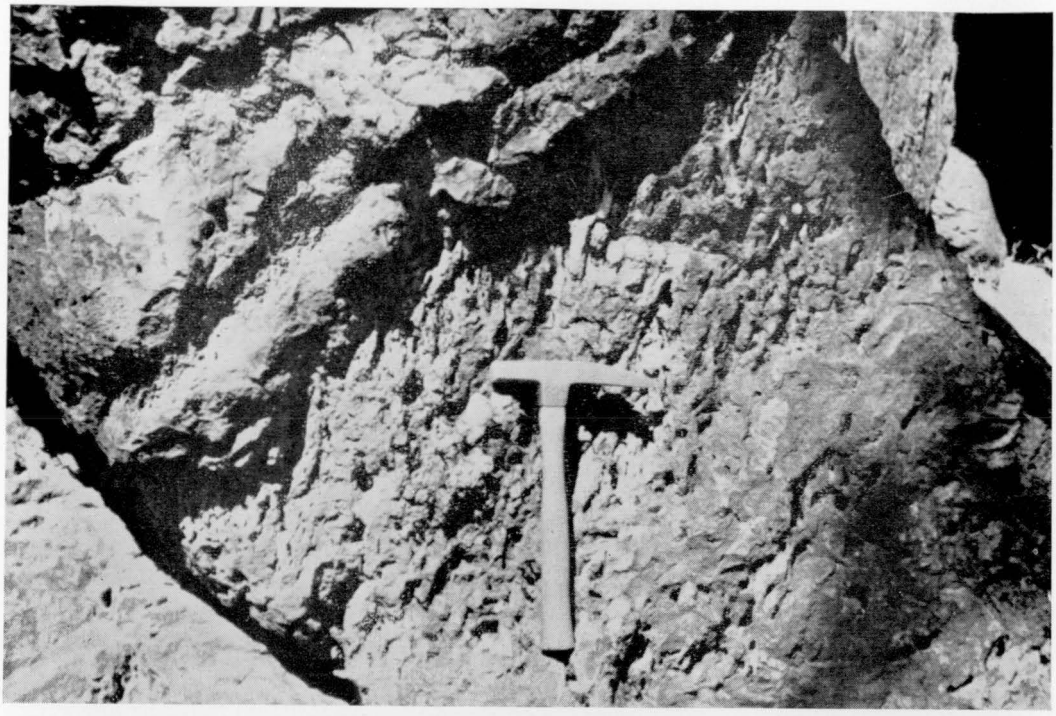


Fig. 1. Oblique arrangement of metamorphic minerals, relative to bedding, in calc-silicate rocks of the Corella Formation (see p. 186). Photograph taken in Corella River bed, near Rosebud copper mine.

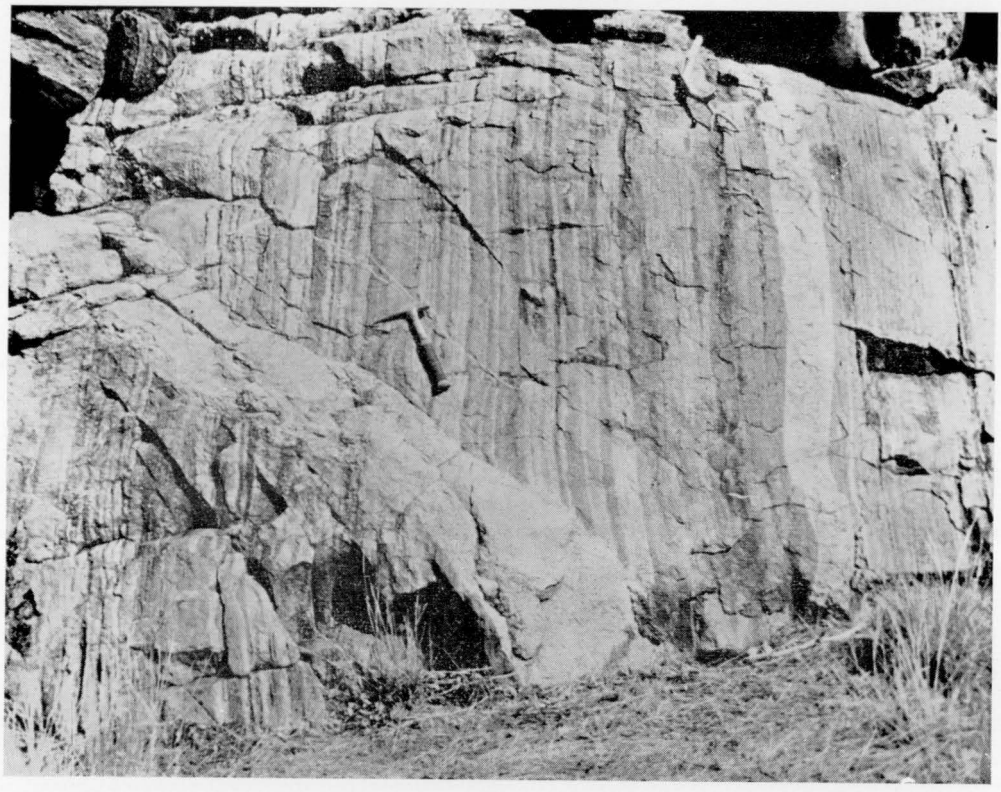
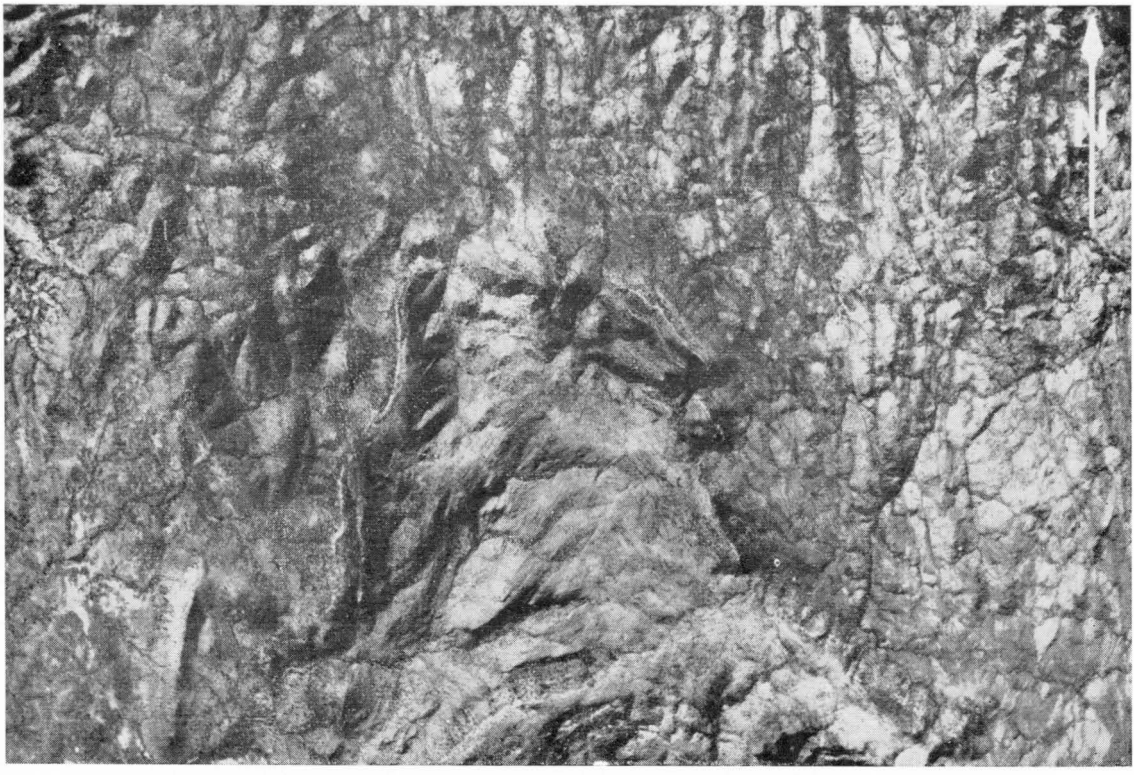


Fig. 2. Granite tongues cutting calc-silicate rocks of the Corella Formation, near Mount Malakoff, 25 miles north of Cloncurry.



Air photograph of unconformity between Deighton Quartzite (centre) and underlying Leichhardt Metamorphics (right), Argylla and Corella Formations (left). Scale about 1:50,000.

—Taken from portion of an official R.A.A.F. photograph: not to be reproduced without authority.

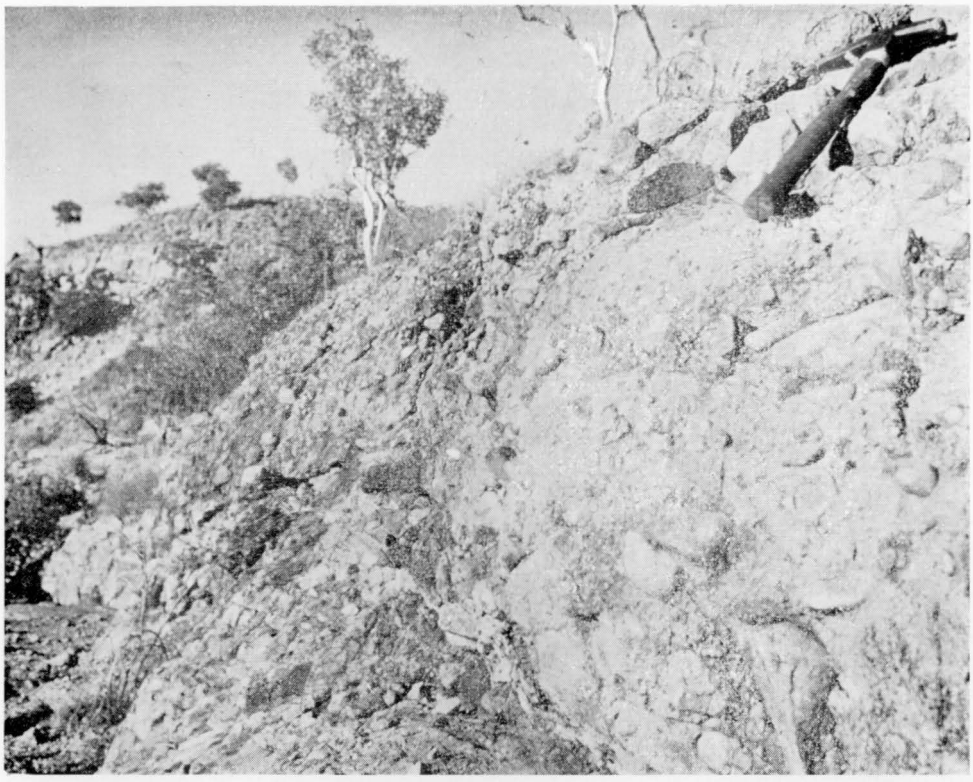


Fig. 1. Basal conglomeratic arkose of Eastern Creek Volcanics, north of Dynamite Creek. Pebbles and cobbles are of granite, rhyolite, and porphyry. The Ewen Granite underlies the arkose.

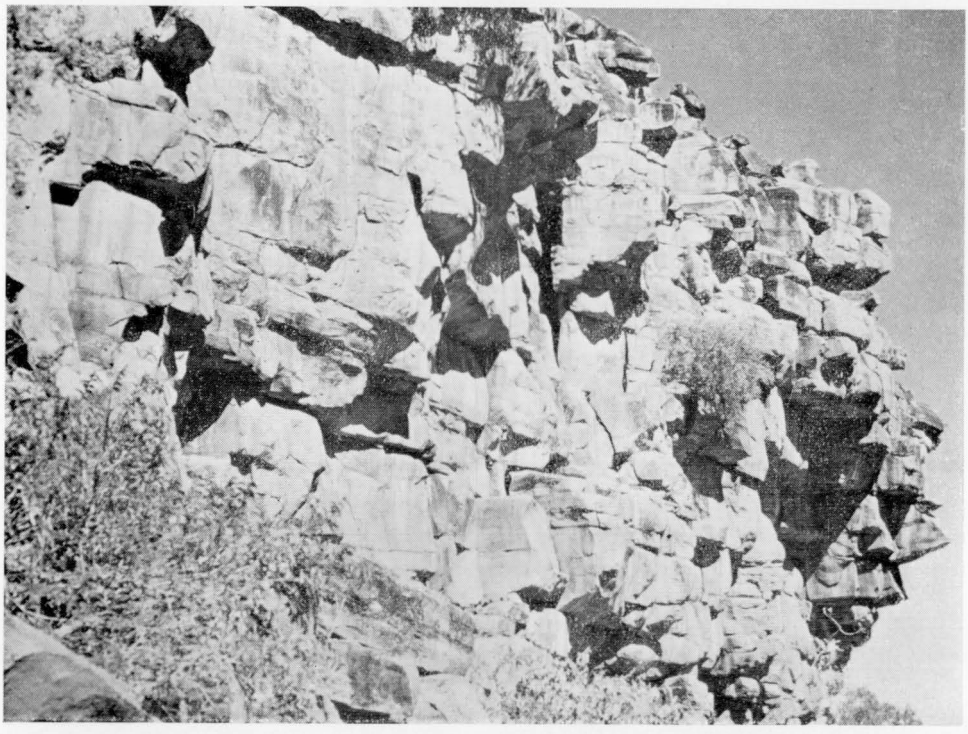


Fig. 2. Near-basal Myally Beds. Flaggy to massive sandstone near Alsace Waterhole, Gunpowder Creek.

The Corella Formation is believed both to overlie and to interfinger with the upper portion of the Marimo Slate; that is, the lower Corella Formation represents a lateral sedimentary facies change of the Marimo Slate, while the upper portion is younger than the Marimo Slate.

Description and Comment. The Marimo Slate crops out in a single area of 500 square miles. It forms a roughly meridional belt of maximum width 11 miles, through which the Cloncurry River passes, from 8 miles south-west of Cloncurry to 7 miles north-west of Kuridala—a distance of 28 miles. The southern boundary, on a fault, is arbitrary, but elsewhere the margins of the formation, though gradational in many places, are fairly clearly recognisable.

Within the Corella Formation are numerous occurrences of metasediments and metamorphics, particularly graphitic and other slates, of lithology similar to that of the Marimo Slate. These have been regarded as lenses within the Corella Formation and belonging to it. However, the belt of graphitic slate, schist, and metabasalt which overlies the northern belt of Mitakoodi Quartzite may properly be part of the Marimo Slate, though separated from the main body by strata of typical Corella Formation lithology.

The chief characteristic of the lithology of the Marimo Slate is the abundance of metasediments of mixed type. Pure quartz arenite, clay slate, or limestone is extremely rare. Many of the arenaceous rocks have a sugary texture, as in the Mitakoodi Quartzite. Coarse-grained metasediments (excluding the calc-silicate breccia, which is discussed under 'Corella Formation' on p. 89) are almost entirely absent. Bedding is moderately well to poorly developed; ripple-marking and cross-bedding are rare. Limy metasediments are more abundant in the north of the outcrop area than farther south.

Vulcanicity is probably confined to the lower half of the succession. Metabasalts only occur in the lowermost few hundred feet; tuffs may extend rather higher. Agglomerate, including scoriaceous agglomerate, has been recorded from lat. 20°59′00″S, long. 140°24′15″E. Honman (1939, p. 10) also reports the existence of rhyolitic agglomerate and rhyolite in the Top Camp area; they have not been recorded by the present workers.

Metamorphism is not very intense. Megascopically visible metamorphic minerals have been observed in graphitic slates and calcareous slates; they are probably chiastolite or andalusite. Granite does not crop out in the Marimo Slate.

Strata have been most extensively faulted and folded. Some are overturned, to dip east. Strike faults, which generally dip east at a high angle, are abundant, particularly in the western portion of the area of outcrop, including the contact with the rather more competent Mitakoodi Quartzite. In general the disharmonic folding in the Mitakoodi Quartzite, with its attendant faults striking north-east to east, does not extend very far into the Marimo Slate.

The strike faults are now commonly filled with iron oxides—limonite and hematite—quartz, and manganese oxides. The manganese oxides occur in economic grade and quantities in places (see p. 242).

The relationship of the Corella Formation to the Marimo Slate is given above. The Answer Slate, Staveley Formation, and Kuridala Formation together are considered to be contemporaneous with the Marimo Slate; they may also possibly extend both lower and higher in the time scale. With the evidence available there are no means of determining the relationship in time between the upper limits of the units. The lower strata of the Marimo Slate may also be contemporaneous with the uppermost division of the Soldiers Cap Formation (see p. 71).

Nye & Rayner (1940, pl. 1) regarded the Marimo Slate as part of the Mount Isa series.

Answer Slate

Definition. Derivation of name: Answer copper mine. Name proposed by White (in press).

Map reference: Duchess 4-mile Sheet (Atlas Pl. 9).

Distribution: The Answer Slate crops out over an area of 110 square miles, in a meridional belt up to 4 miles wide, from 9 miles north of Kuridala to 10 miles south of the Answer mine, a total distance of 46 miles.

Lithology: Siliceous, sericitic, and carbonaceous slate, quartz siltstone, cherty in part, and chert; some quartz-sericite schist. The exposed rocks are generally deeply leached and kaolinitic.

The type area is south of Limestone Creek, in a 3½-mile-long belt, which extends west from lat. 21°23′S, long. 140°22′E.

Thickness: Approximately 2,000 feet; possibly considerably less.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Conformably underlain by Mitakoodi Quartzite; overlain, with local unconformity, by Staveley Formation. The Answer Slate is faulted against the Marimo Slate, with the basal portion of which it is believed to be contemporaneous. As mapped, it is in contact with the Corella Formation at the northern end of the outcrop area, but the relationship is not clear.

Description and Comment. The older strata are poorly to well-bedded quartz siltstone and siltstone, including some greywacke-siltstone. Above these are several hundred feet of fine-grained cherty siltstone and unstratified or poorly stratified chert. The chert is very well developed north of Limestone Creek, around lat. 21°32′S, long. 140°20′E. It is generally dark to light grey on a fresh surface, but weathers to pale brown to white; pyrite casts are common. Profound weathering has reduced the chert to a soft white kaolinitic rock with specks of red hematite. Under the microscope a typical chert was observed to consist of 60% very-fine-grained quartz, and the remainder of orthoclase and untwinned oligoclase, with accessory biotite, leucoxene, apatite, and rare zircon and iron oxides.

The slates are generally grey or black, but many of the siliceous slates are pale yellow. Cleavage is weakly developed and may be completely masked by products of weathering.

Grade of metamorphism varies throughout the outcrop area, according to the proximity of granite. Regional metamorphism appears to have been slight, but owing to the profound weathering common to the region, many surface exposures do not give a true indication of the grade of metamorphism. The effect of weathering is further discussed under 'Staveley Formation'.

The Answer Slate crops out in the western limb of a tightly folded and faulted overturned synclinorium. It is extensively intruded by metadolerite sills. Nye & Rayner (1940, pl. 1) equated the strata in the area of outcrop of the Answer Slate with their Soldiers Cap series. The unit is described in greater detail in White (op. cit.), from whom the description above was largely taken.

Staveley Formation

Definition. Derivation of name: Parish of Staveley (see Qld Department of Public Lands map 4M84, 1952). Name proposed by White (in press).

Map reference: Duchess 4-mile Sheet (Atlas, Pl. 9).

Distribution: As mapped, the Staveley Formation occupies a continuous belt immediately east of the Answer Slate. The belt is 45 miles long and up to 9 miles wide, and extends from 7½ miles north of Kuridala to near the junction of Mistake Creek and Mort River (lat. 21°50′S, long. 140°24′E). It has an area of 110 square miles.

Lithology: Thin-bedded impure dolomite and limestone; dolomitic or calcareous shale and sandstone; calc-silicate rocks, including calc-silicate breccia; siltstone and shale. The grade of metamorphism varies widely through the outcrop area, from little-altered sediments to coarse-grained granulites. The grade of metamorphism bears a close spatial relationship to outcropping granite.

The siltstone and shale form a large lens between Agate Downs outstation and Limestone Creek; it has been designated the *Agate Downs Siltstone Member* (see White, op. cit.).

Many of the exposed rocks of the formation are deeply leached (see below).

The type area is from lat. 21°24′50″S, long. 140°27′20″E, a point one mile north of the Tip-top mine, west for a distance of about 4 miles. This includes a section through the Agate Downs Siltstone Member.

Thickness: The thickness of the unit ranges from probably less than 2,000 feet west of Kuridala to 8,000 feet, or more, south of Limestone Creek.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Conformably overlain by Kuridala Formation; in fault contact with Corella Formation; underlain, with local unconformity, by Answer Slate.

Description and Comment. The Agate Downs Siltstone Member is regarded as contemporaneous with carbonate and calc-silicate rocks farther east. It extends stratigraphically from the base into the upper half of the formation. The constituent rocks are generally red or grey and are thin-bedded. In places (e.g., lat. 21°27′S, long. 140°26′E) they display near-shore, shallow-water phenomena, including ripple marks, slumping, flow casts (?), and mudcracks.

The little-altered dolomitic and calcareous sediments are generally impure. They consist of thinly interbedded, predominantly siliceous, argillaceous, or magnesian limestone beds, some with pyrite and chalcopyrite cubes or casts. Strata are more shaly near the top of the succession than near its base. The calc-silicate rocks contain one or more of the following minerals; diopside, albite, oligoclase, microcline, green hornblende, biotite, calcite, epidote, and hematite, with accessory sphene, apatite, and magnetite. Scapolite has been recorded in places. A very tough green epidiorite occurs between the Labour Victory and Twiggievous copper mines. Metamorphism is attributed to the contact effect of granite, possibly locally reinforced by some metasomatism.

The calc-silicate breccias are similar to those described in the Corella Formation (p. 89); they contain both angular and rounded fragments, the former of which range from a fraction of an inch to several inches across. At lat. 21°25′40″S, long. 140°27′15″E, a

breccia, which was earlier mapped as an agglomerate, was found to pass laterally into a calc-silicate breccia. It is therefore clear that deep weathering has resulted in the complete leaching of a sedimentary breccia to leave a coarse, red-brown porous feldspathic rock.

Numerous bodies of quartz-hematite rock occur in the Staveley Formation. They closely parallel the strike of the bedding, but are believed to be introduced masses of magmatic origin similar to that which forms Mount Philp (see Carter & Brooks, 1955). Hematite has invaded the bordering quartzite in places, but there is no evidence that it is of sedimentary origin.

The area of outcrop of the Answer Slate, Staveley Formation, and Kuridala Formation is more profoundly weathered than most parts of the Precambrian of north-western Queensland. A stable land surface has stood at about the same position as the present surface at least three times previously (see p. 34; also Twidale, 1956 a and b). Many of the surface rocks, particularly the originally carbonate-bearing ones, have been so thoroughly leached and altered that it is difficult to determine the original lithology. White (op. cit.) attributes the character of many of the present surface rocks to pre-Mesozoic weathering and recompaction under the load of Jurassic-Cretaceous sediments. Surface exposures include terra-rossa earth, slickensided clay, deeply leached kaolinitic beds (probably originally limestone), scaly grey sericitic and chloritic schists and phyllites, kaolinized slate, tourmalinized 'siltstone', and many varieties of speckled and streaky kaolinitic, micaceous, and ferruginous rock. White attributes the superficial alteration to decalcification, oxidation, and replacement. He has identified the following minerals in weathered rocks: quartz—including chalcedony—, albite, sericite, chlorite, clay, muscovite, biotite, tourmaline, leucoxene, hematite, black iron oxide, rare rutile and zircon, and possibly brookite and anatase. Surface rocks are commonly cut by veinlets of kaolin.

The Staveley Formation lies, with the Mitakoodi Quartzite and Answer Slate, on the western limb of a faulted synclinorium. Fold axes are generally overturned to dip east.

The calc-silicate rocks and calc-silicate breccia of the Staveley Formation are lithologically identical with those in the Corella Formation. Superposition indicates that they may be of approximately the same age. More detailed mapping of the Marimo Slate would almost certainly show that the Staveley Formation was contemporaneous with its upper part and could be traced through into the Corella Formation.

Nye & Rayner (1940, pl. 1) showed the rocks in the area of outcrop of the Staveley Formation as the Soldiers Cap series, which they regarded as Upper Archaeozoic. The geology of the Staveley Formation is discussed in greater detail by White (op. cit.).

Kuridala Formation

Definition. Derivation of name: Township of Kuridala. Name proposed by White (in press).

Map reference: Duchess and Boulia 4-mile Sheets (Atlas, Pls. 1 and 9).

Distribution: Total area of outcrop, as mapped, is 280 square miles, in a belt from 6 miles north of Kuridala to lat. 22°04′30″S, long. 140°34′30″E, a total meridional distance of 60 miles. The belt, at its widest, is 19 miles across.

Lithology: The succession is mostly arenaceous and micaceous, but its base and top are each defined by several hundred feet of black slate, carbonaceous and pyritic in part. The base has been named, by White, the *Mount Elliott Slate Member* (name derived from Mount Elliott copper mine) and the top the *Hampden*

Slate Member (from Hampden group of copper mines). The black slates of the Mount Elliott Slate Member grade upwards into micaceous slate and phyllite; these are overlain by interbedded quartzite and mica schist, including some andalusite-mica schist, and staurolite-mica schist. The overlying Hampden Slate Member consists of black carbonaceous and calcareous slates, with some "slaty" limestone (locally altered to calc-silicate rock); it is preserved only in the basin structure around Kuridala.

The type section starts at a point 1 mile north of Kuridala and extends west for two miles.

Thickness: Probably differs considerably in different parts of the outcrop area. The average thickness is about 8,000 feet.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Conformably underlain by Staveley Formation; in fault contact with Corella Formation. The unit is not overlain by any Precambrian strata, but is unconformably overlain by Mesozoic sediments.

Description and Comment. West of Selwyn the Mount Elliott Slate Member contains, in addition to the black slate, lenses of siltstone, greywacke-siltstone, and greywacke. Near granite contacts chiastolite has formed in the black slate. The Mount Elliott Slate Member is considered by White to be of an average thickness of 500 feet and a maximum thickness of 800 feet.

The quartzite associated with the mica schist is generally massive to thick-bedded, clean, medium-grained and well-sorted, but in places is feldspathic or micaceous. Between the two slate members, quartzite, with thin interbeds of mica schist, is the major constituent, but mica schist is dominant for 500 to 1,000 feet immediately above the Mount Elliott Slate and also immediately below the Hampden Slate. The staurolite crystals in the schist (see above) are up to half an inch across and are generally extensively altered to form aggregates of mica. The quartzite and mica schist part of the formation is about 6,000 feet thick in the area mapped by White.

The Hampden Slate Member is extensively intruded by metadolerite sills which, in a few places, slightly transgress the bedding. Earlier workers had recorded vesicles in some of the basic rocks and they were generally considered to be lavas; the most recent work has established that they are probably all intrusives, which range in width from a few feet to several hundred feet.

The Kuridala Formation occupies the central portion of an overturned synclinorium. With few exceptions beds dip steeply east. High-angle reverse and normal east-dipping faults are common. The widespread copper mineralization in the formation is generally associated with the faults.

The stratigraphical position of the Kuridala Formation relative to the Marimo Slate and the Corella Formation cannot be precisely established on available information. Black slates occur in the upper beds of the Marimo Slate; these may be of the same age as the Mount Elliott Slate Member. In general it is thought that the Kuridala Formation is contemporaneous with part of the Corella Formation; it may extend in range to equivalence with the Roxmere Quartzite. The mica schist and interbedded quartzite are similar in lithology to the southern part of the Soldiers Cap Formation; but, on available evidence, the Soldiers Cap appears to be older than the Kuridala.

Nye & Rayner (1940, pl. 1) showed the rocks in the area of outcrop of the Kuridala Formation with their Soldiers Cap series, which they regarded as Upper Archaeozoic. White describes the Kuridala Formation in greater detail than is presented here; the description above is largely from his report.

Corella Formation

Definition. Derivation of name: David (1932, p. 29) used the name 'Corella Limestones', following an unpublished classification by Shepherd (1928). Subsequently the name was referred to, but not used, by officers of A.G.G.S.N.A. (1936, p. 50). Shepherd used the term 'Corella Series', defined as 'chiefly altered limestone' (1946, p. 146) and as 'chiefly marmorized limestone' (1953, p. 386). In view of the high grade of metamorphism, which has produced calc-silicate rocks throughout much of this succession, it is proposed that the unit should be known as 'Corella Formation'. 'Corella' presumably derives from Corella River.

Map reference: Dobbyn, Cloncurry, and Duchess 4-mile Sheets (Atlas, Pls. 7-9). The type area is in the Cloncurry Sheet area.

Distribution: See Description and Comment (p. 88).

Lithology: The rocks of the Corella Formation are characteristically thin-bedded; individual beds range in thickness from a fraction of an inch to several inches (see Pls. 10 and 24). Beds more than one foot wide are generally not common. An exception to this is the calc-silicate breccia, which is abundant in the east-central portion of the outcrop area and which is described under 'Description and Comment'. In the field the formation appears to consist dominantly of fine to coarse-grained calc-silicate hornfels, gneiss, and granulite, with thinly interbedded pelitic and psammitic rocks.

In the zones of most intense metasomatism lenses of amphibolite are common; many of these were thought to be basic igneous rocks, but petrological work has shown that some of them, at least, are probably highly metamorphosed sediments, presumably originally of dolomitic composition (Walker, Joplin, Lovering, & Green, 1960). Over wide areas the rocks contain scapolite. Lenses of white or pink calcite are also common. In local zones of intense metasomatism 'red rocks' have been formed by the precipitation of hematite during alteration. Edwards & Baker (1954) have described these rocks in some detail. In addition to the localities to which they refer, 'red rocks' are well developed in the Ballara district, and in other places along the belt from south of the Trekelano copper mine to north of the Dugald River lead-zinc prospect. Thin bands of chert have been recorded in a number of places in the east-central and northern part of the formation; these are probably silicified limestone, but may prove on petrological examination to be very-fine-grained calc-silicate rocks.

Within the succession are a number of lenses of slate and schist, including carbonaceous slate and graphitic schist, up to about ten miles long and several hundred feet thick. One belt extends discontinuously from the headwaters area of Cattle Creek to the Deighton Pass area; another from north of the Dugald River prospect to the northern limit of the Mitakoodi Quartzite. The grade of metamorphism of these pelitic lenses varies considerably from place to

place; they reach the highest grade in the Cattle Creek area, where staurolite-garnet-mica schist and an unusual garnet-biotite schist, with ovoids of biotite up to ¼ inch long, are to be found in abundance (see Pl. 24, fig. 2, Pl. 29, fig. 1, and Appendix I, Spec. R6928).

In places, particularly in the Dobbyn Sheet area, quartzite appears to form a rather greater proportion of the succession than usual. West of the type area of the Deighton Quartzite, around lat. 20°40′45″S, long. 139°50′50″E, the grade of metamorphism is apparently lower than is commonly the case; here limy, sandy, sericitic slate and schist predominate.

Metabasalt has been recorded quite extensively north of the Mitakoodi Quartzite (generally on Chumvale property) and probable metabasalt has been mapped on the Dobbyn 4-mile Sheet. Waning vulcanicity was operative early in Corella time (see Mount Philp Agglomerate); but the amphibolites are generally too highly metamorphosed to determine readily in the field whether they are of igneous origin or not; and only where diagnostic features such as vesicles are observed can one distinguish between flows and sills or metasediments. There may be some tuffs.

Current-bedding has been observed by Broadhurst (1953) in the Duchess area, and a single record of cross-bedding in the same area was made by the present workers; but it is extremely rare. Ripple marks and conglomerate are also rare. Some sedimentary structures have been found in the upper Cattle Creek area. Edwards & Baker (1954, p. 8) have identified under the microscope graded bedding from the Duchess area.

Petrology of the calc-silicate and other high grade metamorphic rocks of the formation is discussed below, and metamorphic processes on pp. 164 ff.

The type locality can be seen from a point half a mile east of the Federal copper mine, on the Cloncurry-Mount Isa road about 23 miles from Cloncurry, thence westerly along the road 2-3 miles to the old Mary Kathleen mine road, which is then followed for about ten miles to an outcrop of the Wonga Granite. This traverse cuts obliquely across the strike of the formation, but contains some excellent exposures of some of the higher-grade calc-silicate rocks; slate and schist may also be seen near the Federal copper mine. The type area contains many faults and intricate folding, so that many repetitions occur along the section and probably not all the formation is exposed. An excellent example of the calc-silicate breccia can be seen on the south side of the Cloncurry-Mount Isa road, 12 miles from Cloncurry. (See Pl. 10 fig. 2; footnote on page 16).

Thickness: The strata of the Corella Formation have been highly deformed. Extensive plastic flowage and intricate crenulation have undoubtedly taken place so that, even in apparently simple structures, no accurate thicknesses can be measured (see Pl. 10, fig. 1). The greatest thickness it has been possible to measure in a single apparently simple structure is roughly 10,000 feet. This is probably rather greater than the true thickness, but no single structure contains the full succession. The best estimate for the thickness of the formation is not less than 5,000 feet and possibly more than 10,000 feet. The unit thickness

probably varies greatly throughout the outcrop area. Mapping by E. K. Sturmfels in the Dugald River lead-zinc prospect area indicates a thickness of scapolite-pyroxene and scapolite marbles of 5,000-10,000 feet (see Edwards & Baker, 1954, pp. 24, 25).

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Underlain, with regional unconformity, by the Argylla Formation (see p. 64, also Fig. 6C); basal conglomerates at lat. 19°56′40″S, long. 139° 59′50″E, and lat. 19°57′30″S, long. 139°58′30″E* indicate at least a disconformity with the underlying Argylla Formation. Structural relationships could not be determined.

The formation is unconformably underlain by the Soldiers Cap Formation and, without evidence of unconformity, by the Ballara and Mitakoodi Quartzites. It is contemporaneous in part with, and overlies in part, the Marimo Slate (lateral transition due to change in sedimentary facies), and probably also with the Staveley Formation. It is possibly disconformably overlain by Roxmere Quartzite (see p. 94) and is unconformably overlain by Deighton Quartzite, Quamby Conglomerate, and Mount Birnie Beds. The Mount Philp Agglomerate probably forms a lens near the base of the Corella Formation, and the Chumvale Breccia probably overlies the Corella Formation unconformably.

Description and Comment. The Corella Formation occurs widely in the metamorphic belt of north-western Queensland; it is absent only in the west of the belt. It crops out over 1,930 square miles, in an inverted "Y" pattern. The northernmost point is 16 miles east of Kamileroi Homestead, east of the Leichhardt River, at lat. 19°19′20″S, long. 140°16′50″E; the south-western prong terminates at lat. 21°44′20″S, long. 139°54′40″E, 26 miles south of Duchess; and the south-eastern prong at lat. 21°49′40″S, long. 140°51′50″E, 14 miles south-west of Answer Downs Homestead.

Edwards & Baker (1954) have discussed in detail the petrology of the scapolite-bearing rocks, including 'red rocks', which occur mainly in the Corella Formation; they include 19 chemical analyses. Joplin (1955), in her treatment of the petrology and metamorphism of the Cloncurry Mineral Field, also discusses the rocks of this formation (pp. 43-5), and the metamorphic processes that have produced them. The rocks described by them are the products of moderate to strong regional metamorphism, extensive thermal metamorphism, and soda-chlorine metasomatism, on a regional scale. Names given to rocks described include scapolite-pyroxene granulite, scapolite-hornblende granulite, scapolite-hornblende-pyroxene granulite, scapolite-biotite schist, scapolite marble, albite-biotite schist, albite-hornblende schist, hornblende-biotite schist, biotite hornfels, and scapolite-albite-hornblende schist (Edwards & Baker, 1954). Joplin (1955) also records granulitic rocks interbedded with pelites which contain kyanite and sillimanite; but the recognition of kyanite appears to have been erroneous. A sillimanite-bearing rock from the upper Cleanskin Creek area is described in Appendix I (p. 291, Spec. J421B). Walker (1956) describes various pyroxene-amphibole granulites and hornfelses, some of them scapolite-bearing, and others garnet-rich, from the Mary Kathleen and Rosebud mine areas. Nearly all specimens of basic rocks examined by Walker were regarded as of primary sedimentary origin (see Appendix I, p. 292). Other rock types which have been identified under the microscope include cordierite-anthophyllite gneiss, from lat. 20°44″30′S, long. 139°58″20′E (see Appendix I, p. 291, Spec. R6935), and elsewhere, and staurolite-garnet-mica schist, from upper Cattle Creek area

* Atlas, Plate 7, incorrectly shows a contact between Argylla Formation and Kalkadoon Granite at this point.

(Spec. R6928, Appendix I, p. 290). Some staurolite crystals attain a size of half an inch; they generally show cruciform twinning, and are so abundant that locally they form 10-20% of the gravels in watercourses.

Edwards & Baker state that the scapolite is dipyre, $Ma_{75}Me_{25}$, and the pyroxene is green ferriferous augite. Accessory minerals include sphene, apatite, epidote, tourmaline, orthite (allanite), garnet, fluorite, zircon, and iron oxides. In many specimens diopside is the most abundant pyroxene. In the field, rocks rich in epidote and bladed hornblende (or actinolite) are abundant.

The soda-chlorine metasomatism which has produced the scapolite was most extensive: scapolite occurs not only throughout the zone of distribution of 'red rocks' from south of the Trekelano copper mine to north of the Dugald River lead-zinc prospect, but also in the extensive belt of highly altered and deformed calc-silicate rocks adjoining the Williams Granite in the south-east of the region. It may occur in the similarly metamorphosed (originally limy) strata east of the Leichhardt River, in the Dobbyn 4-mile Sheet area. Scapolite probably occurs in the calc-silicate rocks of the Marimo Slate and has also been identified under the microscope from the Staveley Formation, from Mount Elliott and Hampden copper mines, from the Soldiers Cap area (Falcon, or Rose and Thistle, gold mine), and from the Charley Creek Formation. Large euhedral crystals of scapolite have been submitted for determination by prospectors from the Prospector Creek area. Petrological descriptions of three scapolite-bearing rocks and two 'red rocks' from the Corella Formation appear in Appendix I (pp. 291-3, Spec. R6876, R6933, and R7207, and pp. 293,4, Spec. R7209, 10).

Reference has been made to calc-silicate breccia in the Marimo Slate and Staveley Formation and also in the definition of the Corella Formation. Honman (1939, p. 9) regarded breccia outcrops in the Soldiers Cap area (which are now shown as outliers of Corella Formation) as agglomerate because they were commonly associated with the faults and because some of the fragments appeared to have volcanic affinities. Some agglomerates do occur north of the Top Camp area and the specimen examined petrologically by Honman may possibly have been agglomerate; but the vast majority of the breccias observed are sedimentary breccias. All breccias occur in lenticular bodies. Breccia near the old Cloncurry-Mount Isa road, 12 miles from Cloncurry, crops out over at least 1½ miles and is nearly 100 feet thick. Outcrop is poor and there may be more than one lens. Other lenses lie stratigraphically above and below that measured. Fragments are generally angular, but a few are slightly rounded. They are invariably poorly sorted to unsorted and may be as as large as two feet long; the normal length is two to four inches. The angular inclusions are generally of material similar to that of the matrix, but quartz and quartzite fragments have been observed in an impure carbonate or calc-silicate matrix, and fine-grained altered calcareous fragments are known to occur in a rather sandy matrix. In some places the rock is extensively brecciated, but bedding is only slightly dislocated. A typical calc-silicate breccia is shown in Plate 10, figure 2.

More than a hundred occurrences of calc-silicate breccia have been recorded within the Corella Formation. Clearly the vast majority of these have been formed during sedimentation, when diagenesis of the subsequently brecciated strata was well advanced. A few may be fault breccias. In a couple of instances the breccia was observed to be confined to the nose of a fold; this may be fortuitous or may indicate brecciation during folding. The remainder may have been formed by either (a) cementation of organic reef detritus, (b) wave action on near-shore limy deposits, possibly associated with fluctuations in sea-level, (c) slumping or destruction by density currents of deposits on a slope, or (d) contraction during lithification or volume change due to dolomitization.

The recognition of possible algal fossils near the Mary Kathleen uranium mine (see p. 132), with breccia nearby, has provided evidence for the possible existence of algal limestone reefs in the area; so some of the breccias, at least, may represent reef detritus. Breccias are most dense within a few miles of the Mitakoodi Quartzite. This may be because breccia occurs mainly in the lower part of the Corella Formation or because it was formed close

to a shore-line or submarine ridge. The structure is not known in enough detail to determine whether the first possibility is correct. The significance of the second possibility, which is favoured, is that the breccia could have been derived from fringing reefs, from shoreline wave action, or from slumping on an off-shore slope. The absence of ripple marks and cross-bedding in the formation indicates that in general sedimentation took place below wave-base. The type of sediments fits Rich's (1951) description of sediments deposited in the 'fondo' environment (level bottom below wave-base), near the foot of a slope. Rich states that brecciation of dense limestone is common in the 'fondo' environment, and attributes it to contraction during diagenesis. In the Corella Formation, however, some examples show clear evidence of local slumping; others show evidence of some transportation. It therefore appears that the majority of the calc-silicate breccias have been formed by slumping and density-current action at or near the foot of a slope below wave-base. Some fringing reefs, with associated breccias, may have existed.

The Corella Formation is believed to have extended westwards by onlap as sedimentation progressed and the sea advanced over the welt or tectonic land which had developed during the growth of the basaltic successions.

The formation has been intensely deformed. Intricate crenulation as a result of plastic flowage is associated even with apparently simple structures (see Pl. 10, fig. 1). Because of the well defined bedding and the resistance to weathering of the calc-silicate rocks, structures are commonly very clear, but the tracing of individual beds requires very detailed mapping. Folding is generally strong to isoclinal, on more or less meridional axes, the planes of which commonly dip steeply west in the central and western areas of outcrop; west of Cloncurry and north of the Mitakoodi Quartzite, however, the major fold axes are commonly east-west. Major faulting conforms to the regional pattern. The Corella Formation is cut or bounded by many of the major faults of the region.

The relationship of the Charley Creek Formation (see p. 92) to the Corella Formation is not entirely clear; but it is considered most likely to be a lateral variant of the Corella Formation, or a conformably overlying succession. As onlap probably occurred during the deposition of the Corella sediments, the Charley Creek Formation was probably contemporaneous with the upper part only of the Corella Formation.

Officers of the A.G.G.S.N.A. were in some doubt about the stratigraphical position of the Corella Formation, the strata of which they described variously as limestone, schist, and gneiss. In general, the eastern portion of the Corella Formation, as mapped by the present workers, was included in the Mount Isa series, and the western portion in the Kalkadoon-Argylla series (see Nye & Rayner, 1940, pl. 1, and A.G.G.S.N.A., 1937a, pl. 4).

Mount Philp Agglomerate

Definition. Derivation of name: Mount Philp, in the western margin of the area of outcrop of the formation.

Map reference: Cloncurry and Duchess 4-mile Sheets (Atlas, Pls. 8 and 9). The type area is in the Cloncurry Sheet area.

Distribution: The limits of the Mount Philp Agglomerate have not been very accurately determined, as the contact with the Corella Formation is very irregular. The single occurrence covers, as mapped, an area of 10 square miles, east and south of the now-abandoned township and railway station of Ballara.

Lithology: The formation consists of a red crystalline rock with angular unsorted fragments of a rock rich in bladed hornblende and of recrystallized basic igneous rocks. The fragments range in size from fractions of an inch up to 24

inches, and constitute up to 30% of the rock. Interbedded with the breccia, which is considered to be a metamorphosed and metasomatized agglomerate, are irregular flows of recrystallized metabasalt; altered tuff; calc-silicate beds, including the 'red rock' described by Edwards & Baker (1954, p. 15); and thin-bedded quartzite, current-bedded in places. The sediments are best developed in the south of the outcrop area, where a conglomerate with boulders more than a foot across was also observed.

The type section is from the edge of the formation, south-east of Ballara, to the waterhole at lat. 20°58′25″S, long. 139°59′20″E. This section is poor in metasediments. The agglomerate is also well exposed in the abandoned railway cutting half a mile east of the site of Ballara.

Thickness: The structure of the formation has not been resolved, although it may be domal. For this reason, together with the known complexity of structure within the formation, a figure for thickness cannot be given. It is at least several hundred feet thick.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: The Corella Formation is the only unit known to be in contact with the Mount Philp Agglomerate. The presence of numerous inclusions of fibrous hornblende, which appear to have been formed from carbonate-rich sediments, indicates that deposition of the Corella sediments had begun before the onset of the volcanic episode which gave rise to the Mount Philp Agglomerate. The latter therefore probably forms a lens within the Corella Formation.

Description and Comment. The metamorphism and metasomatism of the Mount Philp Agglomerate are comparable in degree and type with those of the adjacent Corella Formation. In particular, the precipitation of finely divided hematite, as described by Edwards & Baker (1954), has given the rocks of the whole area a red colour. Scapolite is doubtless present. Recrystallization has been so thorough that the original texture of the rocks has been destroyed, and the determination of the major rock type as an altered agglomerate is based on megascopic appearance, constituent basic igneous fragments, associated lava flows (some of which are amygdaloidal), and field relationships, rather than on petrology.

In thin section a specimen of lava exhibits blastophitic fabric; the mineral grains show no signs of a directional trend. Large, irregular diopsidic pyroxene grains (1 mm.) are penetrated in a number of places by andesine laths (0.3 mm.), and hornblende (0.1 mm.) is more abundant than pyroxene. Iron oxide is evenly distributed throughout, and apatite, rare biotite, calcite, and sphene are accessories. The rock is thermally metamorphosed and is in the cordierite-anthophyllite sub-facies of the amphibolite facies.

The Mount Philp Agglomerate has been intruded by a great many basic and acid igneous rocks. Of the former—metadolerite and gabbro—some may be related to the vulcanicity. A very coarse gabbro, with bladed amphibole and prominent feldspar laths, may be seen near the northern end of the outcrop, on the old Ballara-Devoncourt track. Numerous dykes and bosses of pegmatite and granite (including graphic granite) have been observed.

The northern part of the outcrop area, as mapped, consists of a roughly circular mass about 2 miles across, of lava and agglomerate, with very little metasediment. It is considered by the senior author to have been derived from a point-source eruption. Further mapping would probably show that the formation extends north of the area shown.

This volcano is the only one recognised. It probably marks a final recrudescence of the Eastern Creek-Marraba-Soldiers Cap vulcanicity. The Mount Philp Agglomerate is probably roughly contemporaneous with that found in the Marimo Slate at Top Camp.

Charley Creek Formation

Definition. Derivation of name: Charley Creek, which joins the East Branch of the Leichhardt River at lat. 20°40′40″S, long. 139°47′20″E.

Map reference: Cloncurry 4-mile Sheet (Atlas, Pl. 8).

Distribution: As mapped, the Charley Creek Formation has a total area of outcrop of 15 square miles, on either side of the East Branch of the Leichhardt River and of Charley Creek.

Lithology: Interbedded arenaceous and crystalline carbonate and calc-silicate rocks. The interbeds are mostly thick: each lithological type commonly attains an uninterrupted thickness of several hundred feet. Strata are generally well-bedded, with extensive cross-bedding and some ripple-marking. Some greywacke and thin conglomerates, with pebbles of rhyolite, quartzite, and quartz, have been recorded.

Charley Creek Formation is probably not less than 4,000 feet thick.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Underlain, probably unconformably, by Argylla Formation (see below for relationships with other units).

Description and Comment. In general, the upper beds of the Charley Creek Formation are fairly well sorted, but the lower ones poorly sorted. Some basal conglomerate has been observed, but it is not well developed. Overlying this are fracture-cleaved sub-greywackes and metamorphosed impure limy rocks and schist. At lat. 20°42′30″S, long. 139°46′55″E, is a bed, about 10 feet thick, which appears in the field to consist almost entirely of actinolite or fibrous hornblende. Above this is crystalline limestone or dolomite, some of which is highly siliceous, and calc-silicate rocks with clearly visible metamorphic minerals that stand out on weathered surfaces. The grade of metamorphism is as high as in the Corella Formation: some scapolite has been observed under the microscope (see Appendix I, p. 294, Spec. R6932). The carbonate and calc-silicate rocks are, throughout the succession, interbedded with quartzite. In places carbonate and calc-silicate rocks form the bulk of the succession; elsewhere quartzite is dominant. The pattern of sedimentation differs from that of the Corella Formation, in which the types alternate every few feet at most, and clay appears to have formed an important primary constituent: in the Charley Creek Formation the major alternations, at least, occur every few feet to every few hundred feet, and (except near the base) original sediments appear to have contained less clay. A ten-foot pebble bed in the upper half of the succession contains poorly rounded pebbles, generally 1-2½ inches across, of metarhyolite, with some quartzite and quartz, set in an impure carbonate matrix. In the middle of the succession the carbonate beds have a red-brown surface colour; elsewhere they are black. The quartzite is generally medium to fine-grained, though some coarser beds occur near the base of the succession; it is generally light-brown to pink.

The stratigraphical position of the Charley Creek Formation has not been established beyond doubt. It is probably penecontemporaneous with, or immediately succeeds, either the Corella Formation or the Deighton Quartzite, probably the former.

Arguments in favour of correlation with the Corella Formation are:

(1) Similarity of lithology. The difference in depositional characteristics can readily be explained if the Charley Creek Formation is regarded as a near-shore facies of the Corella sediments, or as slightly younger than the Corella Formation. The cross-bedded and ripple-marked quartzites, which contain little pelitic material, and the presence of poorly-rounded rhyolite pebbles high in the succession indicate that a strandline was probably close by; the few observations of cross-bedding orientation, although insufficient to be really definitive, all indicate that land lay to the west.

(2) The grade of metamorphism, including fracture-cleavage, which, particularly in the lower part of the succession, is comparable with that in parts of the Corella Formation.

(3) Faulting. In the Charley Creek Formation faulting appears much more extensive than in the Deighton Quartzite.

In favour of correlation with the Deighton Quartzite:

(1) The degree and type of folding—open and approaching the basin type of fold—are closely similar to those of the Deighton Quartzite and appear to be in contrast to those of the Corella Formation. However, closed structures are common in the Corella Formation and the more open folds in the Charley Creek Formation may merely reflect the greater competence of the rocks.

(2) The presence of carbonate rocks in the Charley Creek Formation and their absence from the body of the Deighton Quartzite may be explained by the closer proximity of the former to the strandline. Alternatively the one may stratigraphically overlie the other. Neither seems likely, however, as the outcrops of the two units are only four miles apart.

(3) The metamorphic grade of the Deighton Quartzite is difficult to assess because of the virtual absence of clay and carbonates. Evidence, although meagre, suggests that the Deighton Quartzite is older than one granite intrusive, at least; it may have been subjected to all the metamorphic and metasomatic processes to which the Charley Creek Formation was subjected, although this is considered most unlikely.

It is concluded, on the balance of evidence, that the Charley Creek Formation is correlatable with the Corella Formation, or at least belongs to the same cycle of sedimentation. The overall pattern of sedimentation (see p. 42) suggests that the Corella Formation may have gradually extended west by onlap. So the Charley Creek Formation is probably the same age as, or younger than, the upper part of the Corella Formation.

Nye & Rayner (1940, pl. 1) include the area of outcrop of the Charley Creek Formation in the Kalkadoon-Argylla series.

Roxmere Quartzite

Definition. Derivation of name: The landholding of Roxmere, the homestead of which is nine miles south of Cloncurry.

Map reference: Cloncurry and Duchess 4-mile Sheets (Atlas, Pls. 8 and 9). The type area is in the Cloncurry Sheet area.

Distribution: As mapped, the outcrop area totals ten square miles. It occurs in four separate outcropping bodies within a south-trending strip, 22 miles by 8 miles, whose north-western corner is 7 miles south-east of Cloncurry. The stratigraphical equivalence of the southernmost body, in the Duchess Sheet area, is not certain.

Lithology: Medium-grained to fine-grained, thick-bedded to massive quartzite, with some minor impurities; grey to light-brown; some ripple-marking.

The type section is from lat. 20°49′00″S, long. 140°33′10″E, due east for a distance of 8,000 feet.

Thickness: Probably 3,000-4,000 feet.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Underlain by Corella Formation; no overlying rocks. The Corella-Roxmere contact is commonly faulted. The two formations do not appear to be unconformable, but may be disconformable.

Description and Comment. The relationship of the Roxmere Quartzite to the Corella Formation has not been adequately studied in the field. The four occurrences all appear to have been let down against the adjoining strata by faults. Faulting may be more extensive around the type occurrence than is shown on the map, but some sharp contacts, which do not appear to be fault contacts, have been seen.

The Roxmere Quartzite is very different from the Corella Formation, and the contact between calc-silicate rocks of the Corella Formation and the quartzite of the Roxmere Quartzite is abrupt. The quartzite appears to be fairly well sorted and clean and shows ripple-marking, implying probable deposition above wave-base, but the calc-silicate rocks appear to have been deposited below wave-base. Further, the Roxmere Quartzite is more openly and simply folded than the Corella Formation, though this is probably due to the competence of the quartzite.

The available evidence suggests that the Roxmere-Corella contact is possibly disconformable, but there is no angular unconformity. Lithologically the Roxmere Quartzite and Knapdale Quartzite are similar; they may be penecontemporaneous. The Roxmere Quartzite may be, but is probably not, contemporaneous with the Deighton Quartzite.

Honman (1939, pl. 1) differentiated the three northernmost outcrops of the Roxmere Quartzite and regarded them as upper Mount Isa series. He also differentiated other quartzite outcrops from the carbonate rocks, but these are now considered to be interbedded with the calc-silicate rocks and slates of the Marimo Slate. Nye & Rayner (1940, pl. 1) included the Roxmere Quartzite in the Mount Isa series.

Knapdale Quartzite

Definition. Derivation of name: Parish of Knapdale, which lies west of Naraku railway siding (see Queensland Department of Lands 4-mile Series map 4M84, 1952). The single exposure of this formation lies entirely within the parish boundary.

Map reference: Cloncurry 4-mile Sheet (Atlas, Pl. 8).

Lithology: Light brown to grey quartzite (quartz arenite), some schistose. The strata are generally massive, but are well-bedded in places; some are cross-bedded and ripple-marked. A few beds of calcareous quartzite occur near the base. The type section is across the outcrop from lat. 20°15′05″S, long. 140°09′00″E, i.e., west from the Dugald River lead-zinc prospect.

Thickness: Not known, as contacts are probably faulted. Probably not less than 6,000 feet.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Entirely surrounded by Corella Formation; relationships unknown because of extensive faulting and poor exposure.

Description and Comment. The single outcrop area for this formation is 9 miles long, in a meridional direction, and up to 1¾ miles wide; total area of outcrop is 11 square miles. The contacts with the Corella Formation are, within the limits of exposure, sharp. Some are clearly faulted, but faults have not been proved to exist along either the eastern or western margin. Probable strike faulting has been recorded within the formation. The strata dip west fairly uniformly throughout the unit.

Because of the uncertainty as to the formation's structural relationships its stratigraphical position cannot be resolved; and it cannot be soundly correlated with any

other arenaceous succession in the region. Two arenaceous units, the Ballara and Mitakoodi Quartzites, predate the Corella Formation, and two, the Roxmere and Deighton Quartzites, post-date it. The Deighton Quartzite lies unconformably on the Corella Formation, but the strike and dip of the Knapdale Quartzite are the same as those of the adjoining Corella Formation strata; the Knapdale Quartzite, in contrast to the Deighton Quartzite, is therefore probably not unconformable with the Corella Formation, and is older than the Deighton Quartzite. There is no evidence, such as the presence of metadolerite dykes, that the Knapdale Quartzite is older than the basic vulcanicity of the region, as is the Ballara Quartzite; it also has no volcanic material in it, such as the Mitakoodi Quartzite has. The shape of the outcrop is not that of a depositional lens, unless it has been extensively modified by faulting. The formation is therefore probably younger than, but not unconformably over, the Corella Formation; further it bears a close resemblance to the Roxmere Quartzite. Correlation of the Knapdale and Roxmere Quartzite on lithological and stratigraphical grounds appears reasonable, but is speculative.

The Knapdale Quartzite was shown by A.G.G.S.N.A. (1937a, pl. 4) as Mount Isa series. Nye & Rayner (1940), included it in the Kalkadoon-Argylla series.

Chumvale Breccia

Definition. Derivation of name: The pastoral property of Chumvale, within the boundaries of which the formation lies. The homestead is situated 7 miles north-east of the type area.

Map reference: Cloncurry 4-mile Sheet (Atlas, Pl. 8).

Distribution: As mapped, the formation consists of 4 outcrops, totalling 4 square miles, within an area 5 miles by 6 miles. Of these, only the two more southerly outcrops may properly belong to the formation.

Lithology: In the type area the formation consists of breccia with a very ferruginous matrix of quartz-sericite and sericite schist. Fragments, which in some places form only a small proportion of the total rock volume, but elsewhere are abundant, are of jasper, schist, quartzite and quartz. Banded jasper, quartz-sericite schist, and arenaceous beds also form part of the succession. In places the arrangement of the breccia fragments is chaotic; in others strata are barely dislocated. In the other outcrops breccia is absent to sparse and arenaceous and calc-silicate beds form a large part of the succession, together with quartz-sericite schist.

The type section is from lat. 20°44′45″S, long. 140°18′10″E, northwards for 2,000 feet.

Thickness: About 1,000 feet?

Age: Precambrian, probably Lower Proterozoic (see Description and Comment, below, also p. 129).

Contacts: Underlain, probably unconformably, by Corella Formation.

Description and Comment. The problems of the origin, relationships, and age of the Chumvale Breccia have not been resolved. Its distribution and mode of occurrence exclude the possibility that it is a fault breccia, except perhaps as part of a thrust-sheet. It was possibly formed in a large-scale slump.

A study of air photographs indicates that the relationship to the Corella is probably unconformable. Field examination of the type area failed to resolve the point beyond doubt, owing to lack of exposures and limited time available for inspection. However, the presence of metasediments of the Corella Formation within the core of the arcuate occurrence can hardly be explained without either unconformity or faulting. No evidence was found for faulting, but field work was inadequate to exclude the possibility. Nye & Rayner (1940, pl. 1) show an outlier of Mount Quamby series (Quamby Conglomerate) in approximately the same position as the type area of the Chumvale Breccia. This is not considered justified because the breccia shows no lithological or genetic relationships with the Quamby Conglomerate, and on account of its grade of metamorphism is thought to be older than some, at least, of the granites of the area, whereas the relationship of the Quamby Conglomerate to the granites has not been established.

The northern and western outcrops have been included largely because on the air photographs they appear similar to the type outcrop. They may not properly belong to the Chumvale Breccia.

Deighton Quartzite

Definition: Derivation of name: Deighton Pass, the highest point on the Cloncurry-Mount Isa road.

Map reference: Cloncurry 4-mile Sheet (Atlas, Pl. 8). One outcrop, probably of Deighton Quartzite, occurs on the Duchess Sheet.

Distribution: As mapped, the Deighton Quartzite occupies about 30 square miles, made up of eight separate outliers, all of which form structural basins. They lie within a north-south belt 38 miles long by 10 miles wide, the centre of which lies about 2 miles north of Deighton Pass. In addition to the outcrops shown on Plate 8 of the Atlas, smaller bodies are known to overlie the Ballara Quartzite. In the Duchess Sheet area the probable occurrence covers about 4 square miles and lies 4 miles north-east of Bushy Park Homestead.

Lithology: Generally more or less pure quartzite, tending towards quartz greywacke near the base, where extensive light conglomerate occurs in places. Throughout the succession rounded quartzite pebbles, up to 3 inches long, are sparsely scattered in the quartzite. The main impurity is clay (sericite), with some feldspar in places, and possibly lime. The strata are generally medium to fine-grained, rarely coarse; bedding is poorly to well defined. Cross-bedding and ripple marks are common. The quartzites are dominantly light brown, but some of the finer-grained beds are white; dark-brown and grey beds form prominent parts of the section in places where the strata are more impure than usual.

The type section is from a point 1½ miles west-north-west of Deighton Pass, for a distance of 2¼ miles in a northerly direction.

Thickness: Maximum thickness is probably not less than 7,000 feet.

Age: Precambrian, probably Lower Proterozoic (see below; also p. 129).

Contacts: Overlies, with major angular unconformity in places, Leichhardt Metamorphics, Argylla Formation, Corella Formation (see Pl. 12), and Ballara Quartzite. An excellent exposure of the unconformity may be seen at lat. 20°42′10″S, long. 139°50′45″E, where the underlying rock belongs to the Corella Formation. In places, such is the intensity of the folding, that the succession appears conformable.

Description and Comment. The Deighton Quartzite is a moderately well-sorted arenaceous succession, but its characteristics vary from place to place. In the type area conglomerate has not been observed, but farther south it is well developed and the succession is generally less well sorted than in the type area. To the north-east, however, beds tend to be of purer quartzite and to be massive. The northernmost occurrences are very similar in appearance and composition to portions of the Myally Beds. Pebbles throughout the succession are well-rounded and are essentially of quartzite and quartz. Except at the very base of the formation no locally-derived material, such as rhyolite or calc-silicate rock, has been observed. Shale and siltstone around lat. 20°30′50″S, long. 139°53′50″E, have been included in the formation, but elsewhere are absent.

Folding has been strong—dips up to 80° have been measured—but folds are invariably simple and basin-like.

The major fold axes are parallel to those of the underlying strata. The formation has been faulted, but is not cut by the north-east-trending regional faults which are such a prominent feature of the underlying beds. Quartz veinlets are common, but conspicuous major quartz reefs are absent.

The age of the formation in relation to the granites and of the sediments in the western belt (Fig. 4) cannot be established beyond doubt. On the following grounds the Deighton Quartzite is believed to be older than at least the youngest granite:

1. Fracture-cleavage has been developed and sericite formed in the less competent, originally clay-bearing, strata of the formation.
2. Arkose and granite pebbles have not been recorded.
3. The formation has been strongly folded, probably in the final Lower Proterozoic orogenic phase, which was accompanied by granite.
4. At lat. 20°32′55″S, long. 139°48′20″E, a small body of quartzite, believed to belong to the Deighton Quartzite, has been cut by a coarse mica pegmatite vein.
5. In a cliff immediately north of, and about 200 feet above, Old Man Waterhole thin red stringers, probably of soda feldspar, have been seen in Deighton Quartzite.

Correlation of the Deighton Quartzite with the Surprise Creek Beds, or younger formations, can only be speculative, though, on grounds of similarity of lithology and structure, it may well be contemporaneous with the Surprise Creek Beds. The possible relationship with the Charley Creek Formation is discussed on pp. 92-3.

A.G.G.S.N.A. (1937a, pl. 4) showed the Deighton Quartzite as part of the middle division of the Mount Isa series. Nye & Rayner (1940, pl. 1), however, did not differentiate it from the Kalkadoon-Argylla series.

Myally Beds

Definition. Derivation of name: Myally Creek, a tributary of the Leichhardt River.

Map reference: Dobbyn, Camooweal, Cloncurry, and Lawn Hill 4-mile Sheets (Atlas, Pls. 3, 4, 7 and 8). The type area is in the Dobbyn Sheet area.

Distribution: See Description and Comment, below.

Lithology: The Myally Beds are essentially of quartz arenite, generally medium-grained to coarse-grained sandstone and quartzite, with conglomerate and pebble beds near the base, particularly along the eastern margin of the main outcrop area. Siltstone, argillaceous sandstone, and shale are locally important. Feldspathic sediments are common, particularly in the lower and easterly parts of the succession; elsewhere some sediments are micaceous. In the northern part of the main area of outcrop the top of the succession is defined by several

hundred feet of volcanics, both basic and acid, associated with agglomerate and, in places, boulder conglomerate. Volcanics have been observed from near the eastern margin of the formation, south of Myally Creek, to near the Seymour River. The outcrop areas of the unit in the Lawn Hill Sheet also contain volcanics. Rhyolite has been observed at lat. 19°23′30″S, long. 139°03′30″E. The small fault block containing Myally Beds, near the McLeod Hill copper mine, includes several hundred feet of rhyolite, acid tuff, and a flow of amygdaloidal basalt or andesite. Further mapping would doubtless reveal a much wider distribution of the rhyolite, as it has been recorded at several points in the Judenan Beds.

The type section is along a line which extends from a point on the old Dobbyn-Mount Oxide track at about lat. 19°20′40″S, long. 139°32′10″E—northerly for 7 miles on true bearing 345° and southerly 3 miles on true bearing 172°. This section is incomplete and is faulted.

Thickness: The base of the succession is not exposed in the Camooweal Sheet area. Along the type section, on the Dobbyn Sheet, thickness of the incomplete succession is probably between 20,000 and 30,000 feet.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Unconformably underlain by Eastern Creek Volcanics, Leichhardt Metamorphics, and Argylla Formation along the eastern margin of the main area of outcrop and the western edge of the eastern block (Atlas, Pl. 7).

Farther west it is conformable with the Eastern Creek Volcanics. It is overlain by Surprise Creek Beds, Ploughed Mountain Beds, Gunpowder Creek Formation, and Mount Isa Shale. The contact with the Surprise Creek Beds is conformable; that with the Ploughed Mountain Beds, Gunpowder Creek Formation, and Mount Isa Shale is marked by local unconformities in places but is otherwise conformable, though the Mount Isa Shale may be disconformable.

The Judenan Beds are more or less contemporaneous; the boundary is arbitrary.

The Myally Beds are intruded by the Weberra and other granites (see below).

Description and Comment. As mapped the Myally Beds crop out over about 1,630 square miles in the Camooweal, Dobbyn, Cloncurry and Lawn Hill 4-mile Sheet areas. The main outcrop area is in the Camooweal and Dobbyn Sheet areas, but the unit extends discontinuously south to a point 4 miles east-north-east of Mount Isa. The inclusion of many of the fault-bounded outcrops in the unit is somewhat speculative; in fact the boundaries of the unit everywhere, except where determined by the presence of volcanics, will probably be considerably revised if the area is mapped in more detail. These remarks apply to many of the units in the western belt.

The lavas at the top of the succession represent a brief period of vulcanicity associated with marked crustal movements, as indicated by the boulder conglomerate which is commonly associated with the lavas, and by what appears to be a strong, but local, unconformity at lat. 19°06′10″S, long. 139°04′10″E, between the lavas and the Ploughed Mountain Beds. The contact, which shows on air photographs as a 90° discordance in trends, was examined in some detail on the ground and no faulting was observed. It does not appear that slumping is responsible; the contact must therefore represent an unconformity. For

this reason the lava-conglomerate succession was included in the underlying Myally Beds rather than the Ploughed Mountain Beds. With further mapping it could be made a separate unit. Other similar, pronounced, but very local, unconformities occur between the Myally Beds and the Gunpowder Creek Formation about lat. 19°36′50″S, long. 139°24′30″E, and between the Myally Beds and the Mount Isa Shale at lat. 20°17′25″S, long. 139°33′30″E; the latter is probably due to faulting before and during the laying down of the Mount Isa Shale.

Boulder conglomerate occurs discontinuously along the contact with the underlying units to the east. The conglomerate beds range up to 100 feet thick and contain, in places, cobbles and boulders more than a foot across. Pebbles are of quartzite, porphyry, red granite (Ewen Granite), rhyolite, basalt, and quartz. Beds associated with the conglomerate are commonly highly feldspathic. The basal conglomerate is well exposed on the old Dobbyn-Mount Oxide track (lat. 19°21′30″S, long. 139°39′45″E) and at lat. 19°25′45″S, long. 139°48′E.

Owing to the lack of trend-lines in the Argylla Formation unconformity with the Myally Beds is difficult to establish. It is however, clearly visible in the Mistake Creek gorge, 4 miles upstream from White Hills Homestead, at lat. 19°36′40″S, long. 139°48′20″E, where flow-lines in the volcanics strike normal to the bedding of the overlying quartzites. An unconformable contact with the Eastern Creek Volcanics can be seen 4 miles north-east of Mount Isa. As mapped, the Surprise Creek Beds lie directly on the older strata in places: the Myally Beds are absent.

As is to be expected from a basin which received sediments from several directions, the sedimentary rocks vary considerably in composition, grainsize, and texture. The arenaceous beds are generally medium-grained; but a few grey-white cherty quartzites occur, and quartz siltstone and shale are very well developed in places, particularly along Paroo Creek, where a thick, well-bedded, even-grained succession of light-brown to red-brown strata overlies the Eastern Creek Volcanics. The bedding of the unit ranges from massive to flaggy and thin-bedded (see Pl. 13, fig. 2). Cross-bedding and ripple-marking are abundant. Mud-cracks have been recorded from a number of points in the succession.

The lavas at the top of the succession have been described in the field as basalt, andesite, and rhyolite; they are associated with tuff and coarse agglomerate. Specimens R3224 and R7245 have been determined petrologically as rhyolite, specimen R6979 as quartz xenocryst basalt, and specimens R3200 and R6947 as basic and acid tuffs (see Appendix I, pp. 294-6). Tuff has been recorded from parts of the formation other than the dominantly volcanic upper part.

In texture the lavas range from fine-grained and massive to vesicular or scoriaceous. The surfaces of outcrops are red-brown to blue-brown. Amorphous silica forms amygdules in some flows; less commonly chlorite, crystalline quartz, and calcite infill vesicles.

Thin sections of basalt show basaltic fabric consisting predominantly of feldspar laths, whose arrangement ranges from poorly intergranular to trachytic. The grainsize varies from fine to fairly coarse for basaltic rocks. Feldspar laths (0.5 mm.) are iron-stained, and appear to be of oligoclase. Rarely feldspar phenocrysts are completely sericitized. Small amounts of iron oxide occur between the laths. Apatite is an accessory mineral.

The basalts are slightly more acid than those of the Eastern Creek Volcanics and are almost unmetamorphosed; but many of them have been severely altered by a low temperature or hydrothermal process, and strongly iron-stained by weathering. Much of the lime has been leached out, and veining indicates that some silica has been added. Quartz forms small interstitial grains and aggregates of grains throughout the rock.

Many of the acid lavas are porphyritic, and have feldspar and quartz phenocrysts set in a fine-grained to aphanitic groundmass. Both potash feldspar and plagioclase phenocrysts, many of which are lath-like, are extensively clouded by alteration products, and finely-divided hematite abounds. The specimens determined are rhyolite.

Folding throughout is open, but strong, particularly in the eastern portion of the outcrop area. The major synclinal structures, which are associated with extensive faulting, are more tightly folded than the intervening anticlinal structures. In the western part of the outcrop area the folding is much less directional, and basin-and-dome fold patterns are prevalent.

Three systems of faulting can be recognised: normal faults trending north-north-east to northerly, which may have operated in part during sedimentation; east-west normal faults, which are largely confined between the major meridional faults; and a conjugate strike-slip system, consisting of north-east and north-west faults, which is attributable to east-west compression. Cleavage is very poorly developed, only the rare originally clay sediments having a well developed fissility. Except near granite, grade of metamorphism is low—probably generally the sericite stage. The contact effects of granite are slight and are confined to narrow zones.

The portion of the Myally Beds shown by Nye & Rayner (1940, pl. 1) was included in the Mount Isa series.

Judenan Beds.

Definition. Derivation of name: Judenan Creek, a tributary of Gunpowder Creek, which it joins at lat. 19°53′35″S, long. 139°15′20″E.

Map reference: Camooweal, Mount Isa, and Urandangi 4-mile Sheets (Atlas, Pls. 4-6). The type area is in the Mount Isa Sheet area.

Distribution: See Description and Comment.

Lithology: Quartzite, sandstone, siltstone, shale, argillaceous sandstone, pebble beds and conglomerate, some rhyolite and basalt. Strata are generally only slightly metamorphosed; cleavage is well developed in places. Between the Mount Isa Fault and the Sybella Granite, however, quartz-sericite, quartz-mica, and quartz schists have been developed.

The sandstone commonly has clay, mica, feldspar, or lime impurities; it ranges from fine-grained to coarse-grained and is commonly friable. Cross-bedding and ripple-marking occur extensively. Conglomerate and pebble beds do not form an important part of the succession. Bedding is poorly to moderately well developed. In weathered outcrop the sediments are generally light-brown to white; some are ferruginous, and in the type area the unit is distinguished by the relative abundance of yellow sediments.

The type area is west from lat. 20°03′S, long. 139°19′E, i.e., west of Barney's Well. The area is folded and faulted and the complete section may not be exposed.

Thickness: Owing to the complexity of structure and inadequate mapping any estimate of thickness must be very inaccurate. The unit appears to be not less than 6,000 feet thick.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Conformably underlain by Eastern Creek Volcanics and possibly unconformably by the Leander Quartzite (see p. 112).

The formation is more or less contemporaneous with the Myally Beds; it is conformably overlain by the Gunpowder Creek Formation and the Mingera Beds and is unconformably overlain by the Pilpah Sandstone.

Description and Comment. The Judenan Beds, as mapped, crop out over an area of 420 square miles. They extend from near the Mammoth copper mine in the north, discontinuously southwards to a point 15 miles south of Mount Guide Homestead, at lat. 21°16′00″S, long. 139°24′40″E, in the Urandangi Sheet area — a meridional distance of 110 miles. They occur both to the east and west of the Sybella Granite. The limits of the unit west of the Mount Isa Fault were hard to determine: some of the strata attributed to the Judenan Beds may actually be an arenaceous succession at the top of the Eastern Creek Volcanics. The stratigraphical position of some of the strata in the south-west of the outcrop area is also not fully known.

In general the sediments of the Judenan Beds are slightly finer grained, less well sorted and bedded, and more argillaceous than those of the Myally Beds.

Rhyolite and rhyolitic tuff have been recorded in several places. Specimen J216 from the south side of the Barkly Highway, at lat. 22°22′40″S, long. 139°14′30″E, has been determined petrologically by Dr G. A. Joplin as a rhyolitic tuff with glassy shards, and Specimen J104 is a sheared rhyolite (Appendix I, p. 296). Basic rocks, probably basalt, have been recorded, some in association with basic tuffs. All these volcanics appear to be near the top of the succession, as in the Myally Beds. Some basalt, dacite, and tuff occur at the base of the unit where it conformably overlies the Eastern Creek Volcanics (see, for example, de Keyser, 1958, unpubl., p. 5 and Appendix).

The Judenan Beds are part of Nye & Rayner's (1940, pl. 1) Mount Isa series.

Ploughed Mountain Beds.

Definition. Derivation of name: Ploughed Mountain.

Map reference: Dobbyn, Camooweal and Lawn Hill 4-mile Sheets (Atlas, Pls. 3, 4, and 7). The type area is in the Lawn Hill Sheet area.

Distribution: The unit forms a belt, up to 20 miles wide, to the north and west of the Myally Beds, from lat. 19°08′50″S, long. 139°41′10″E, to lat. 19°43′20″S, long. 138°57′45″E. The belt broadens and extends north-westward across the Gregory River to Ploughed Mountain and Caroline Range. The total area of outcrop is about 1,550 square miles.

Lithology: Quartzite and sandstone; interbedded dolomite, dolomitic limestone, dolomitic shale, shale, sandy shale, siltstone and sandstone; quartz greywacke. The bulk of the formation is composed of fairly fine-grained interbedded impure dolomite, shale, and sandstone. These are overlain by massive to thick-bedded, fine to medium-grained sandstone and quartz greywacke, well exposed east of the Lawn Hill silver-lead field and in Ploughed Mountain. In the east of the outcrop area carbonate rocks are rare; the base of the formation is composed of a considerable thickness of massive to thick-bedded quartzite and sandstone which are commonly feldspathic or micaceous, and a few pebble beds and conglomerate bands. Ripple marks and cross-bedding are abundant except in the quartz greywacke. The bulk of the unit is thin-bedded to flaggy, and composition changes at short intervals across the strike. Fracture cleavage is locally well-developed.

In certain of the dolomitic beds nodular or concentric cherty structures are abundant (chert beds also occur). Some of these are probably concretions, but some, notably those outcropping at lat. 19°00′10″S, long. 139°16′35″E, are fossil algae (see Pl. 23, fig. 2); some are similar to forms in the Paradise Creek Formation.

The sediments, particularly in the dolomitic part of the succession, are dark grey-brown or deep red-brown; but the arenaceous part of the unit is mostly light-brown to grey and white. On Ploughed Mountain there is a sequence of thin, black, fine-grained quartz greywacke.

The type area is Ploughed Mountain, but only the upper portion of the succession is exposed in the anticline there. The remainder of the succession may be seen in the general vicinity of Fiery Creek, from lat. 19°07′50″S, long. 139°10′20″E, on true bearing 020°. It is not clear whether the quartz greywacke at the top of the succession is absent in this area or is concealed beneath the alluvium. With further mapping the Ploughed Mountain Beds may readily be subdivided.

Thickness: Between 10,000 and 15,000 feet?

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Underlain with local unconformity by the Myally Beds (see p. 98); penecontemporaneous with the Surprise Creek Beds and jointly with the Paradise Creek Formation and Gunpowder Creek Formation. The succession is overlain by the Lawn Hill Formation; no unconformity has been observed. It is unconformably overlain by the Middle Cambrian Thorntonia Limestone and by the Tertiary Carl Creek Limestone.

Description and Comment. The base of the Ploughed Mountain Beds lies directly above the lavas and conglomerate of the Myally Beds. As the lavas and conglomerate are less abundant farther south the bases of the Surprise Creek Beds and the Gunpowder Creek Formation are not everywhere so clearly delineated as that of the Ploughed Mountain Beds.

The Surprise Creek Beds are lithologically much more diverse than the Ploughed Mountain Beds; dolomite forms a much smaller proportion of the succession. No dolomite has been recorded in the Ploughed Mountain Beds within the Dobbyn Sheet area.

The Gunpowder Creek Formation is lithologically similar to and roughly contemporaneous with the lower part of the Ploughed Mountain Beds, but is more silty than the eastern part. The dolomitic part of the Ploughed Mountain Beds is similar to that in the Paradise Creek Formation: the two are probably of about the same age.

Structure is similar to that of the Myally Beds, with moderately strong open basin-and-dome type of folding. Dips approaching vertical have been recorded, but they do not generally exceed 50°; the average dip is 25°-35°. Faulting follows the same pattern as in the Myally Beds, but is not so well developed.

The Weberra Granite intrudes the Ploughed Mountain Beds, but the contact effects are slight; some calc-silicate rock has been formed, and marginal arenaceous beds have been silicified and hornfelsed.

Jensen (1941a) included the strata of the Caroline Range and Ploughed Mountain in his Lawn Hill series. In the present subdivision they have been included in the Ploughed Mountain Beds as they are rather different lithologically from the remainder of the Lawn Hill strata.

Surprise Creek Beds.

Definition. Derivation of name: Surprise Creek, a tributary of the Leichhardt River, which it joins at lat. 20°01′30″S, long. 139°50′20″E.

Map reference: Dobbyn, Cloncurry, and Camooweal 4-mile Sheets (Atlas, Pls. 4, 7 and 8). The type area is in the Cloncurry Sheet area.

Distribution: In the Dobbyn Sheet area the unit crops out in two north-south belts 8-12 miles apart and up to 8 miles wide, whose northernmost exposures are near Myally Creek and Spring Creek. In the Cloncurry Sheet area the two belts merge and extend south to lat. 20°41′50″S, long. 139°39′00″E, 10 miles east of Mount Isa. About lat. 20°S a westerly extension of the western belt reaches into the Camooweal Sheet area. As mapped, the total area of outcrop is 470 square miles.

Lithology: The lithology of the Surprise Creek Beds is more diverse than that of the other contemporaneous units. It consists of quartzite, sandstone, siltstone, shale or slate (generally sandy), impure dolomite, conglomerate, carbonaceous slate, and carbonaceous siltstone. The characteristic lithology is more or less impure interbedded arenaceous and argillaceous beds. Feldspathic sandstone and micaceous sandstone are common. In the northern half of the outcrop area carbonate-bearing strata are rare and conglomerate bands are thin and are not abundant. The upper part of the succession in the north-eastern part of the outcrop area is essentially arenaceous. Ripple-marking and cross-bedding are fairly common throughout; strata range from massive to well-bedded and flaggy and are generally fine to medium-grained, though some coarse sandstone occurs and conglomerate is prominent in the south of the outcrop area. Some of the slates are highly fissile, but cleavage is generally confined to the less competent strata. Metamorphic effects other than cleavage are very local: quartz-mica schist, quartz-sericite schist, chlorite schist, phyllite, conglomerate schist, actinolite rock, and crystalline limestone have been produced near to granite or in shear zones.

The type section is along Doughboy Creek from lat. 20°19′15″S, long. 139°46′25″E, to Glenroy Homestead, thence across the Leichhardt River for about a mile in a south-westerly direction. The succession here is incomplete and has been faulted. The succession in the north of the outcrop area may be seen along the old Dobbyn-Mount Oxide track from a point about eight miles north-west of the Gunpowder Creek crossing.

Thickness: Probably about 20,000 feet maximum (see below).

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: The Surprise Creek Beds are generally conformably underlain by the Myally Beds. In places, in the east of the outcrop area, Surprise Creek Beds are unconformably underlain by lavas of the Argylla Formation. An excellent contact with an older granite may be seen at the head of Sunday Gully where the base of the Surprise Creek Beds is formed by a conglomeratic arkose which overlies a coarse, porphyritic granodiorite (Kalkadoon Granite). There is no record of the nature of the contact between the Surprise Creek Beds and the Eastern Creek Volcanics in the Dynamite Creek area.

The succession is regarded as contemporaneous with the Ploughed Mountain Beds, the boundary being placed where lavas disappear from the top of the Myally Beds. It is unconformably overlain by flat-lying freshwater Mesozoic sediments.

Description and Comment. From lat. 20°35′20″S, long. 139°42′35″E northwards for a distance of 11 miles, a tightly folded syncline pitches continuously north at 60° to vertical, without any apparent significant faults. The apparent stratigraphical thickness, therefore, is not less than 40,000 feet, even after allowing for possible flowage and other post-depositional effects. Both limbs have been overturned, in places to the east and in other places to the west. The sediments are sandstone, quartzite, siltstone, dolomite, carbonaceous slate and siltstone, and conglomerate. The material was derived mainly, or wholly, from tectonic land immediately to the east. The pebbles and boulders of the conglomerate (the largest measured was 20 inches long) are essentially of quartzite. Towards the base of the succession basic rocks, probably metabasalts, are exposed. The succession therefore probably includes both Myally Beds and Surprise Creek Beds, but as it has been found difficult to make a division it has been shown entirely as Surprise Creek Beds.

On page 66 it was stated that the arenaceous succession north and east of the Rifle Creek dam may not belong in its entirety to the Mount Guide Quartzite: the part shown as Plg? may belong to the Surprise Creek Beds or the Myally Beds.

Folding of the Surprise Creek Beds is more pronouncedly linear and is stronger than in the Myally Beds, possibly because of lesser competence. Fold axes strike almost north-south. A remarkable feature of the structure of the Surprise Creek Beds, and to a lesser extent of the Myally Beds, is the scarcity of south-pitching folds. The persistence of the unit over such a great distance in a north-south direction can only be attributed to numerous fault-produced repetitions, some of which have been recognised in the field.

The Surprise Creek Beds are believed to be contemporaneous, in part at least, with the Paradise Creek Formation, together with the Gunpowder Creek Formation, and with the Ploughed Mountain Beds.

Nye & Rayner (1940, pl. 1) included the Surprise Creek Beds in the Mount Isa series.

Gunpowder Creek Formation

Definition. Derivation of name: Gunpowder Creek. The formation was defined by de Keyser (1958, unpubl.).

Map reference: Camooweal and Mount Isa 4-mile Sheets (Atlas, Pls. 4 and 5). The type area is in the Camooweal Sheet area.

Distribution: As mapped, from 15 miles north of Mount Oxide, in a near-meridional belt, which contains several separate areas of outcrop, south to the Barkly Highway. The belt is 75 miles long and up to 24 miles wide. The formation crops out over about 200 square miles.

Lithology: Siltstone, shale, sandstone; a dolomitic lens occurs near the top of the formation and a siliceous dolomite bed near the base. Beds are commonly micaceous or chloritic and some have a small carbonate content. Sediments are generally pale—white, purple, green and brown. In places sandstone and siltstone are thinly interbedded; elsewhere flaggy siltstone is important. Silty ribbon shale crops out widely.

The type section is along the valley of Paradise Creek, from lat. 19°46′20″S, long. 139°07′40″E, downstream for three miles.

Thickness: At least 2,000 feet maximum, probably differing widely from place to place.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Generally conformable with the underlying Judenan and Myally Beds, but a local unconformity occurs at lat. 19°36′50″S, long. 139°24′30″E. A discordance in strike has been observed in this area and no evidence of faulting could be found. The overlying Paradise Creek Formation is conformable with the Gunpowder Creek Formation; the contact is sharp in most places, but in others the rocks grade in composition from one unit to the other.

The Gunpowder Creek Formation and the Myally Beds together are roughly contemporaneous with both the Surprise Creek and the Ploughed Mountain Beds. The boundaries between the Gunpowder Creek Formation and the Surprise Creek Beds and between the Gunpowder Creek Formation and the Ploughed Mountain Beds are arbitrary.

Description and Comment. The lithology of the Gunpowder Creek Formation differs considerably from place to place. For example, a dolomite bed west of the Mammoth copper mine becomes dolomitic shale or siltstone to the south and west and gradually thins. Some beds are sandier in the north and north-east of the outcrop area than farther south and west.

The uppermost bed of the formation in places consists of a bleached, white, porous flaggy siltstone which appears to occupy the same stratigraphical position as the graphitic shales which form, in part, the host rock for the Mount Oxide copper orebody.

Quartz grains in the siltstone and sandstone vary in size from 0.01 to 0.1 mm. and are generally well-sorted, equidimensional, and sub-angular. Some ripple marks and mudcracks have been recorded in the formation.

Folding in the Gunpowder Creek Formation is moderate to strong, but open. Folds are very irregular, particularly west of the Mount Gordon Fault-zone. Faults are numerous throughout the formation, particularly in the Mount Gordon Fault-zone. Shale and siltstone are commonly strongly fracture-cleaved.

The Gunpowder Creek Formation is described at greater length by de Keyser (1958, unpubl.). The area in which the formation crops out was included by Nye & Rayner (1940, pl. 1) in the Mount Isa series.

Paradise Creek Formation

Definition. Derivation of name: Paradise Creek, a tributary of Gunpowder Creek, which it joins at lat. 20°45′45″S, long. 139°17′25″E. The formation was defined by de Keyser (1958, unpubl.).

Map reference: Camooweal and Mount Isa 4-mile Sheets (Atlas, Pls. 4 and 5). The type area is in the Camooweal Sheet area.

Distribution: As mapped, from near the Mount Oxide copper mine, in the north-east (lat. 19°28′20″S, long. 139°23′40″E), and 3 miles north of Black Rock Creek in the north-west, southwards to Mingera Creek. Within this region the formation has several separate areas of outcrop; it occurs at the surface over about 400 square miles. In general exposures are poor in the southern and western parts of the outcrop area.

Lithology: Dolomite, siltstone, sandstone, and gradations between them, which are commonly thinly interbedded. Sediments are rarely pure. Gradations from one rock type to another along the strike are common. Generally the formation is more silty and less dolomitic in the west than in the east, and could probably be subdivided with further mapping.

The dolomite is grey to nearly black on fresh surfaces, but is usually weathered to yellow, ochre, pink, white, or red-brown. In places fragmental dolomite is common. The dolomitic strata are well-bedded and laminated, but do not readily part along laminae (see Pl. 15, fig. 1). Dolomite is more abundant in the lower part of the formation than in the upper.

Specimens of impure dolomite from about lat. 19°56′30″S, long. 139°15′E, and of dolomitic shale from near Mount Oxide, were found, on analysis, to contain

CaO	17.2%	11.6%
MgO	11.1%	9.3%
Insolubles	43.6%	54.8% (Analyst: S. Baker).

A feature of the Paradise Creek Formation is the presence of abundant algal biostromes; they are best developed in the Lower Paradise Creek area (lat. 19°43′S, long. 139°11′30″E), but have been recorded from several other places and from several stratigraphic levels. The fossils appear in several forms; some locally form biohermal reefs. They are most abundant in dolomite, which in places has been altered to chert by superficial silicification. Specimens are described on p. 131 and illustrated in Plates 22 and 23 (see also Robertson, 1960).

Shales and siltstones are weakly to moderately fracture-cleaved. A few ripple marks and cross-laminae have been observed. The strata are deeply weathered over wide areas.

In no single section is the whole unit exposed. The lower part of the formation is represented by a section up the Paradise Creek valley for about seven miles from near its junction with Gunpowder Creek. The base of the formation, a silicified biostromal bed several feet thick, occurs at lat. 19°46′00°S, long. 139°17′00″E. The upper part can be seen along a line that extends from lat. 19°48′20″S, long. 138°59′20″E (about three miles west of Lady Annie copper mine) north-west for about three miles.

Thickness: 10,000-15,000 feet in the type areas. The unit may be thinner farther south.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Conformably underlain by the Gunpowder Creek Formation and the Mingera Beds; probably contemporaneous with the upper parts of the Surprise Creek and Ploughed Mountain Beds.

The Pilpah Sandstone and flat-lying Cambrian and Mesozoic strata unconformably overlie the Paradise Creek Formation.

Description and Comment. The formation is deeply weathered, particularly where the present surface lies near the level of the Mesozoic land surface. In places the shale and siltstone are represented at the surface by ferruginous and siliceous outcrops. Exposures in gullies, or other places below the level of the elevated outcrops, generally show soft, somewhat friable, sediments.

The contact of the Gunpowder Creek Formation with the Paradise Creek Formation is sharp in the type area, but in other places appears to be gradational.

The formation is strongly to gently, irregularly, folded. In the type area along Paradise Creek dips rarely exceed 20°, but considerably steeper dips have been recorded in other parts of the formation. Many faults have displaced the strata of the formation.

De Keyser (1958, unpubl.) has described the Paradise Creek Formation in greater detail. The area in which the formation crops out is shown by Nye & Rayner (1940, pl. 1) as Mount Isa series.

Mingera Beds

Definition: Derivation of name: Mingera Creek.

Map reference: Mount Isa 4-mile Sheet (Atlas, Pl. 5).

Distribution: See Description and Comment.

Lithology: Boulder conglomerate with quartzite boulders, cobbles and pebbles; pebble beds; coarse sandstone, commonly highly feldspathic; quartzite; siltstones and shales, ranging in colour from dark red-brown to green, grey and white. The finer-grained sandstone, siltstone and shale are commonly micaceous. The strata are well-bedded and in places display cross-bedding and ripple-marking. Cleavage is absent to poor.

The relationship of the coarse arenaceous beds to the shales is discussed below.

The type section is from a point 2 miles south-east of May Downs Homestead (i.e. from lat. 20°27′10″S, long. 139°05′30″E) on true bearing 167° for a distance of 15 miles to a point 2 miles west of Monaghan's Bore.

Thickness: Not accurately determined because of the complexity of structure; probably about 5,000 feet.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Conformably underlain by Judenan Beds; conformably overlain by Paradise Creek Formation; unconformably overlain by Pilpah Sandstone.

Description and Comment. As mapped the unit crops out over an area of about 80 square miles. It forms a belt up to 4 miles wide which extends from a point 2 miles east of May Downs Homestead, at lat. 20°26′25″S, long. 139°05′40″E, south-south-easterly for a distance of 18 miles, and discontinuously north-easterly from the same point for 6 miles. Other outcrops outside these limits probably belong to the Mingera Beds. These include a belt south from the main outcrop area, from the Templeton River to Gap Bore, thence in an arcuate outcrop to near Carter's Bore, and another discontinuous group of outcrops extending from the same starting point south-west to Yaringa Creek. Shales which probably belong to this succession have also been mapped north of the Barkly Highway.

The unit is readily divisible into two. One part consists of conglomerate, coarse feldspathic sandstone, pebble beds and quartzite, and the other part of shale. The division is sharp. In the central part of the outcrop the rudaceous and arenaceous sediments directly overlie the Judenan Beds and are overlain by the siltstone and shale. Elsewhere the siltstone and shale follow the Judenan Beds conformably. Shepherd (1934) remarks on the lensing character of the strata.

In a deep watercourse at lat. 20°21′50″S, long. 139°08′45″E. dolomitic strata, which are referred to the Paradise Creek Formation, overlie siltstone of the Mingera Beds, apparently conformably. The Mingera Beds were therefore laid down contemporaneously with the Gunpowder Creek Formation. At lat. 20°33′25″S, long. 139°06′30″E, small outliers of gently-dipping Upper Proterozoic Pilpah Sandstone unconformably overlie the fairly steeply-dipping Mingera Beds.

Structure in the Mingera Beds is comparable in type and intensity with that in the adjoining Judenan Beds. The main structure is a north-pitching syncline, faulted near the

axis. Two reversals of pitch in the southern half of the main outcrop area are reflected in the distribution of highly deformed shales.

The Mingera Beds have been faulted against the Sybella Granite by a post-granite fault. The age relationships of the Mingera Beds and the various granites of the region are not known.

The area of outcrop of the Mingera Beds has not been previously mapped. Shepherd (1934) inspected the May Downs gold workings, but did not produce a geological map of the area. He records a total thickness of over 4,000 ft. of sediments in the area and concludes, on the evidence of numerous large quartz veins related to the Templeton (Sybella) Granite, that the succession is older than the granite. However, he did not differentiate between the Judenan and Mingera Beds.

Mount Isa Shale

Definition: Derivation of name: Saint-Smith (1924, p. 411) used the term 'Mount Isa Series' to refer to the rocks east of the fossiliferous (Middle Cambrian) strata along the Templeton River. The rocks, or area, to which the name was intended to apply were not stated, but the succession would include amphibolite, quartzite, and schist west of Mount Isa, and possibly the lead-zinc and copper-bearing shale at and east of Mount Isa. David (1932, p. 29) referred to the Mount Isa Shales (see p. 28); Shepherd (1932, p. 377; 1946, p. 146; and 1953, p. 386) used Mount Isa Series, apparently for the shale sequence at, and east of, Mount Isa, and its basal quartzite. In A.G.G.S.N.A. (1936a, p. 53) the name Mount Isa Shale was used in the sense in which Shepherd used Mount Isa Series; but on pages 49 and 50 the name was extended to include the thick successions of sandstone, shale, dolomite, quartzite, and basalt to the north, in that part of the western belt mapped by them. The quartzitic successions in the eastern basin and part of the Corella Formation were also later included (see e.g. A.G.G.S.N.A. 1937a, pl. 4).

In 1937 Blanchard & Hall referred to the 'Mount Isa Shale series which comprises a two-mile thickness of thin evenly bedded shale between quartzites'. Knight (1953, p. 354) reserved the name Mount Isa Shale Group for the shale west of the Leichhardt Fault. He did not name the remainder of the shales.

It is proposed that the name Mount Isa Shale shall be retained for the succession to which it was apparently applied by Shepherd and clearly indicated by Blanchard & Hall.

The township of Mount Isa is regarded as the source of the name.

Map reference: Mount Isa, Cloncurry, and Urandangi 4-mile Sheets (Atlas, Pls. 5, 6, and 8).

Distribution: The Mount Isa Shale is confined to a narrow meridional belt about the longitude of Mount Isa township. Its greatest width is about 8 miles and it is generally only 3 miles wide. It extends from 20 miles south of Mount Isa (west of Mount Guide) to 35 miles north of the township.

A smaller occurrence of similar lithology in the headwaters region of Waverley and Jayah Creeks, about lat. 21°27′30″S, long. 139°23′10″E, has been correlated with the Mount Isa Shale and mapped under the same name.

The total area of outcrop of the unit is about 140 square miles.

Lithology: Thin-bedded clay shale, dolomitic shale, siliceous shale, carbonaceous shale and siltstone, claystone, siltstone, sandstone, quartzite, and conglomerate. Some 'greenstone' near Mount Isa may belong to the formation. Cleavage is generally weakly developed, but is not readily discernible; in places near the Mount Isa Fault phyllite is developed. Some of the shales are pyritic.

A specimen of dolomitic shale from near the southern end of the main outcrop area was found, on analysis, to contain:

CaO	15.0%	
MgO	8.1%	
Insolubles	51.0%	(Analyst: S. Baker).

The type section for the Mount Isa Shale is along a line west from the Leichhardt River to the Mount Isa Fault, crossing the Barkly Highway half a mile north of Spear Creek. This covers the upper part of the section, but the effect of the Leichhardt Fault is not known. Exposures are fair to good. The lower part of the succession may be seen along the Mount Isa-Leichhardt Dam road.

Thickness: Probably not less than 10,000 feet maximum. Knight (1953) indicates a thickness of not less than 13,000 feet. The effect of faulting is not fully known.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Locally unconformably underlain by Eastern Creek Volcanics (see Pl. 14, fig. 2), Myally, and (?) Judenan Beds. Unconformities are not readily discernible in the field. The relationships between the Myally Beds and Mount Isa Shale appear unconformable at lat. 20°17′25″S, long. 139°33′30″E, and between Eastern Creek Volcanics and Mount Isa Shale in the same area and at lat. 20°58′00″S, long. 139°28′30″E; in the latter place the contact zone is somewhat silicified, but evidence for fault movement is lacking. Along much of the contact between Mount Isa Shale and Eastern Creek Volcanics no evidence for unconformity was found, but the basal beds of the Mount Isa Shale vary throughout. North-east of Mount Isa the contact between Mount Isa Shale and Myally Beds appears conformable, but widespread thin conglomerate indicates the possibility of a disconformity. The western margin of the Mount Isa Shale is for the most part a fault contact.

Description and Comment. The lithology of the Mount Isa Shale is described by Knight (1953); that in the environs of Mount Isa Mines is described by S. R. Carter (1953). The strata are characterized by the persistence over many miles of beds only a few inches thick (see Pl. 16). Certain marker beds have been recognised by company geologists; these would probably materially aid any detailed mapping of the formation. In some of the siliceous dolomitic shale near the top of the succession both large and small scale slumping, with brecciation, has been recognised. A good example may be seen near Spear Creek, at lat. 20°39′40″S, long. 139°28′15″E, and 2½ miles farther north. Small-scale cross-bedding also occurs in the same beds around Mount Isa, and elsewhere. The beds in both the northern and southern extremities of the main outcrop area appear to be more sandy than in the vicinity of Mount Isa. South of Sybella Creek carbonaceous siltstone and siliceous shale are well developed. In the Waverley Creek area, on the Urandangi 4-mile Sheet, the main sediments are siliceous, dolomitic, and carbonaceous shales and quartzite.

Quartzite is rare in the body of the formation; several hundred feet of it occur at the base, together with a thin conglomerate band. The stratigraphical position and nature of the 'greenstone' is not clear (see p. 140). Two specimens from a drill-hole in the southern part of Mount Isa Mines Ltd lease were petrologically examined by R. D. Stevens. One was described as 'partly reconstituted, chloritized, fine greywacke'; the other was thought to be a highly altered igneous rock, either flow or intrusive. No basalts have been recorded in the field in the Mount Isa Shale, but some possible tuffs have been recorded, and east-west-striking dolerite dykes occur near the aerodrome. The 'greenstone' could occur in a fault block and be part of the Eastern Creek Volcanics.

The overall structure of the Mount Isa Shale is a faulted north-pitching syncline, with minor pitch reversals, and terminating in the north with a south-pitching closure. Owing to faulting, only the eastern limb of the syncline is present for the most part. Strike-faulting forms one of the most important features in the area. Such faults in many cases do not leave a prominent trace and, as pointed out by Knight, may be more abundant than mapping to date has shown. Major drag-folds are associated with the Mount Isa Fault and have apparently served to localize the orebodies. The character and regional significance of the Mount Isa Fault is further discussed on p. 188. Oblique north-west and north-east faults, which predate at least the final movement of the Mount Isa Fault, have offset the bedding in places and have brought the fault-block composed of outcropping Eastern Creek Volcanics, south of Mount Isa, into its present position.

Lawn Hill Formation

Definition: Derivation of name: Dunstan (1913, Pl. 21) first used the name 'Lawn Hill Series' for the succession subsequently named (in part) Constance Range series. Ball (1931, p. 263), quoting from an unpublished report by R. Blanchard, referred to 'Lawn Hills greenstone (mudstone) and Lawn Hills shale'. Shepherd (1932, p. 377) applied the name to the silver-lead-zinc-bearing strata in the Lawn Hill area, which unconformably underlie the limestone to which Dunstan applied the name. Shepherd's naming, however, was not based on his own field work. Jensen (1941, p. 7 ff) and A.G.G.S.N.A. (1940a, p. 23) used Lawn Hill series in the same sense as Shepherd. It is proposed that Lawn Hill Formation be used for the same succession as that to which Lawn Hill series was applied by Jensen, except that the lowermost beds, which crop out in the Caroline Range, Ploughed Mountain, and east of the Mended Hill and Star of the East mines, and which consist of quartz greywacke, sandstone, and dolomite, have been included in the Ploughed Mountain Beds.

Jensen did not state what geographical feature he took the name from. Lawn Hill Creek is therefore here designated as the source of the name.

Map reference: Lawn Hill 4-mile Sheet (Atlas, Pl. 3).

Distribution: From near Verdon Creek at lat. 19°00′00″S, long. 138°40′00″E in the south, discontinuously north to between Elizabeth and Accident Creeks — a meridional distance of 60 miles. The easternmost outcrop is 4 miles east of Ploughed Mountain. On the west the margin is generally marked by the Constance Range Scarp, but several inliers of the Lawn Hill Formation crop out in the Constance Range area. The best exposures are in the Lawn Hill silver-lead field. The formation crops out in Queensland over an area of 180 square miles. Contemporaneous sediments are probably also exposed in the Northern Territory west of the Lawn Hill Sheet.

Lithology: Sandstone, quartzite in part, siltstone, shale, including some carbonaceous shale, slate, tuff, and felsite. The sandstone is flaggy to massive, in part feldspathic, commonly grading towards quartz greywacke, and except near the top of the succession, is generally interbedded with siltstone, shale and cherty slate. Some of the sediments are micaceous. Carbonaceous slate is associated with some of the lead lodes, and also has been observed in unmineralized areas. The slates are in places thinly laminated and fissile. They are well exposed at White Crossing, where they are grey and are polygonally cleaved. They are probably calcareous in part. The felsites are widely distributed throughout the area of outcrop but are confined to the lower part of the unit. They are aphanitic, banded rocks with the appearance of chert or a fine-grained acid lava. Their colour ranges from pale green to pink and light brown. The greatest development observed was at lat. 18°31′35″S, long. 138°40′30″E, where at least four bands occur, associated apparently with tuff. Green banded felsite east of Lawn Hill Creek, at lat. 18°17′20″S, long. 138°37′30″E, displays small-scale ripple-marking. Four specimens were examined in thin section by Mrs J. Beck. Two were described as welded tuff, one as tuffaceous claystone and the fourth as silicified shale, possibly tuffaceous. Jensen (1941a, p. 8) records a rhyolitic tuff from north of Hann's Ridge and reports that rhyolite was intersected in bores drilled by the Queensland Mining Trust.

No type section was given by Jensen. The complete section, apart from the uppermost sandstone beds, which occur north of Lilydale Springs, is present from Lawn Hill airstrip north to the Caroline Range. Exposures of part of the section are poor.

Thickness: Not less than 2,000 feet, possibly 5,000 feet.

Age: Precambrian, probably Lower Proterozoic (see p. 129).

Contacts: Underlain, apparently conformably, by Ploughed Mountain Beds; overlain, with major unconformity, by Upper Proterozoic Constance Sandstone and Middle Cambrian Thorntonia Limestone.

Description and Comment. The succession as given by Jensen (1941a, p. 8) agrees approximately with that observed by the present workers. His divisions (v) — lower quartzite, and (vi) — limestone with quartzites and slates interbedded, have been included in the Ploughed Mountain Beds. Sections (iii) — grey quartzite, and (iv) — slate with some quartzite bands, do not appear to be well developed in the south of the outcrop area and it is believed that an arenaceous suite of rocks overlies felsitic strata in the south. On the microscopic evidence, volcanic material appears to be rather more widespread than was recognised by Jensen.

Folding is very irregular; the main fold axes swing from north-east, between Caroline Range and Ploughed Mountain, to north-west in the south and west in the north. Dips probably average 30°-40° but readings up to 80° have been measured. The faulting pattern is similar to that in underlying strata; displacement does not appear to have been great. Mineralization is controlled by the faulting.

Jensen correlated strata north of the Nicholson River, in the Westmoreland 4-mile Sheet area, and in the Northern Territory, with the Lawn Hill Formation: he thought that beds in both areas might be Lower Cambrian. However, the units in the Westmoreland Sheet area are regarded as Upper Proterozoic by the present workers, and more nearly related

in age to the strata of the Constance Range, which overlie the Lawn Hill Formation with a strong angular unconformity; the Cliffdale Volcanics may be of the same age as the Lawn Hill Formation.

Shepherd and others have also suggested a correlation, on lithological grounds, of the Mount Isa Shale and Lawn Hill Formation. An equivalence in time is only possible if a disconformity, of a magnitude not recognised, occurs at the base of the Mount Isa Shale.

Undifferentiated Lower Proterozoic Strata

Undifferentiated Lower Proterozoic, or probably Lower Proterozoic, strata have been shown in the Dobbyn and Mount Isa 4-mile Sheet areas. On the Dobbyn Sheet a number of fairly small scattered outcrops through soil, about 9 miles north-north-east of Dobbyn, have not been assigned to any unit because they have not been examined in the field and do not possess a sufficiently distinctive air-photo pattern to enable them to be grouped with any of the units in the area. As they are strongly folded they are presumed to be of Lower Proterozoic age.

In the Mount Isa Sheet an area of 120 square miles of Lower Proterozoic sediments between the Leander Range and Gidyea Creek has proved impossible to assign on the information available. There may be three stratigraphic units involved. Briefly the succession from near the southern end of the Leander Range westward is as follows:— Leander Range Quartzite; Eastern Creek Volcanics; a medium-grained, poorly cemented greywacke (possibly tuffaceous in part) which forms a very uniform succession between the headwaters area of Gunpowder Creek and Letterbox Creek; sandstone, commonly argillaceous, and sandy shale, similar in appearance to parts of the Judenan Beds west of Barney's Well (they form the eastern part of the hills to the west of Gunpowder Creek); thoroughly indurated and surface-silicified quartzite, forming the western edge of the range between Gunpowder and Gidyea Creeks (this quartzite is similar to the Leander Quartzite); Eastern Creek Volcanics. Farther north a large part of the succession is obscured by alluvium.

Throughout, dips are predominantly to the west; such east dips as have been recorded appear not to have a regional significance. Folds are present, however. At the south end of the range of quartzite and sandstone, folds pitch to the south. Strong strike faulting has also been observed in the south of the area. The greywacke overlies Eastern Creek Volcanics; the relationship is probably unconformable but was not ascertained in the field. The greywacke has not been observed elsewhere in the region; it may constitute a unit as yet unnamed or may be part of the Judenan Beds.

If the quartzite which forms the western portion of the range between Gunpowder and Gidyea Creeks belongs to the Leander Quartzite either strike faulting or folding, on a scale not recognised in the area, must be postulated. A second possibility is that the quartzite forms one or more thick arenaceous beds or lenses near the top of the Eastern Creek Volcanics, such as is common elsewhere. In either case the sediments to the east of the range must form one or more separate successions unconformably overlying the quartzites.

Cliffdale Volcanics

Definition: Derivation of name: Cliffdale Creek.

Map reference: Westmoreland 4-mile Sheet (Atlas, Pl. 2.). The unit extends west-south-west into the Northern Territory for about 32 miles.

Distribution: Within Queensland the formation crops out over 150 square miles, in an east-west belt, in the valley of Cliffdale Creek and its tributaries. The belt is between 5 and 12 miles wide and is confined to the west of the Doomadgee Mission — Wollogorang track.

Lithology: The succession consists entirely of lavas and associated pyroclastic material. The dominant rock type is porphyritic acid to intermediate lava with pink euhedral feldspar phenocrysts and commonly a red or dark brown aphanitic groundmass. Flow-lines and, less commonly, vesicles show in their intricate contortions the highly viscous behaviour of the lava on extrusion. In the Northern Territory, adjacent to the border, to the south-west of the outcrop area in Queensland, porphyritic dacite, with white feldspar, biotite, and rare quartz phenocrysts, and a light to dark grey groundmass, is abundant (Appendix I, p. 296, Spec. R6954, R6955). It has also been recorded in minor quantities in Queensland. A white, femic-poor lava and a possible andesite have also been observed, and at lat. 17°41′25″S, long. 137°58′55″E (in the Northern Territory) a flow of basalt, amygdaloidal in part, has been recorded. Near the top of the succession, particularly along the northern margin of the outcrop area, agglomerate and tuff are extensively developed.

The type section for the formation in Queensland is from lat. 17°36′55″S, long. 138°04′40″E, north about 4 miles to the overlying Westmoreland Conglomerate. This section does not include the dacitic lavas seen to the south-west, in the Northern Territory.

Thickness: The base of succession is not exposed, but the unit is probably not less than 1000 feet thick.

Age: Probably Lower Proterozoic (see below, also p. 129).

Contacts: Underlying strata not known; overlain unconformably by Westmoreland Conglomerate and by Peters Creek Volcanics; intruded by Nicholson Granite, which is overlain by the Westmoreland Conglomerate.

Description and Comment. The lavas of the formation have been poured out in several flows, but probably the bulk of the unit is composed of one or two thick flows. Points of eruption have not been identified, but some of the west-north-west faults contain porphyry and could have been outlets at a late stage. The lavas were apparently derived from a high-level magma which also gave rise to the Nicholson Granite (which intrudes them). The relationships of the Nicholson Granite to the stratigraphical units of the area are discussed on p. 115.

The formation crops out in the core of a gentle east-west anticline whose limbs dip at a maximum of about 25°. Extensive axial plane and west-north-west faulting has developed. A strong joint pattern is reflected in the topography.

On the maps the Cliffdale Volcanics are shown as Upper Proterozoic, but, as they (and the Nicholson Granite) unconformably underlie the units above, and provided a source

of material for them, the unconformity may represent a time break sufficiently large to warrant inclusion in the Lower Proterozoic*.

Jensen (1941a) suggested a correlation of the strata north of the Nicholson River with the Lawn Hill Formation. Elsewhere he has suggested that they are Cambrian.

Westmoreland Conglomerate

Definition. Derivation of name: Westmoreland pastoral holding. Westmoreland Homestead lies 3 miles east-north-east from the nearest outcrop of the formation.

Map reference: Westmoreland 4-mile Sheet (Atlas, Pl. 2). The formation also occurs in the Northern Territory.

Distribution: Within Queensland the unit crops out over 180 square miles. It forms a low range of hills between Lagoon Creek and its tributaries, to the north, and Cliffdale Creek and its tributaries to the south. Three smaller bodies crop out south of Cliffdale Creek, along the northern and north-western margins of the Peters Creek Volcanics. The formation extends into the headwaters region of the Nicholson River, in the Northern Territory.

Lithology: Conglomerate to medium-coarse-grained impure sandstone; coarse impure sandstone and interbedded pebble beds and conglomerate predominate (see Pl. 15, fig. 2). Fine-grained sandstones are rare. A basal conglomerate up to 200 feet thick is composed largely of poorly sorted acid lava and quartz pebbles up to 18 inches across; the matrix is coarse, poorly-cemented and poorly-rounded sandstone with a clay cement — probably originally feldspar. Arkose occurs in the two south-westerly outcrops, where the formation overlies granite.

Grainsize diminishes towards the top of the succession, but throughout its whole thickness the succession is characterized by lenses and beds of coarse-grained material ranging up to fine conglomerate; cross-bedding is abundant. In the body of the succession the most abundant pebbles are quartz and quartzite. A few quartz pebbles contain small books of mica, suggesting a pegmatitic origin; but no granite pebbles were found. In places laminae of 'black sands' are numerous, particularly in cross-beds. The succession is fairly uniformly grey-brown, but some white sandstones occur.

The type section is from lat. 17°29′10″S, long. 138°20′15″E, west-north-west for a distance of about 5 miles.

* Recent mapping (1959) by J. W. Smith and H. G. Roberts has indicated a Lower Proterozoic volcanic succession similar to the Cliffdale Volcanics in the Mount Drummond Sheet area, N.T. (E53/12). On this evidence the Cliffdale Volcanics and Nicholson Granite should be regarded as Lower Proterozoic. They were placed in the Upper Proterozoic for two reasons: (1) Petrologically the lavas of the Cliffdale Volcanics are very similar to those in the overlying Peters Creek and Gold Creek Volcanics; they may therefore have had a common source, in which case the time interval between formation of these units would more probably be of the order of a period, or less, rather than greater. (2) Structurally the region north and west of the Nicholson River appears to form an entirely different entity from the Lower Proterozoic of north-western Queensland. Trends and degree of folding are in marked contrast.

Thickness: Maximum thickness is not less than 4,000 feet, but the thickness varies greatly from place to place. In the southern bodies it appears to be not more than 1500 feet thick.

Age: Upper Proterozoic (see p. 129).

Contacts: Underlain unconformably by Cliffdale Volcanics. The Westmoreland Conglomerate overlies, and is younger than, the Nicholson Granite. Peters Creek Volcanics overlie it, probably generally conformably; at lat. 17° 32′20″S, on the Northern Territory border, there appears to be a slight angular unconformity (see Pl. 8, fig. 1), but this probably reflects an initial dip in the conglomerate succession (see below).

Description and Comment. The Westmoreland Conglomerate succession begins abruptly wherever seen, with a heavy basal conglomerate of poorly-sorted and rather poorly-rounded boulders. The composition of the included pebbles varies considerably from place to place. Individual beds are thick, and cross-bedding is most extensive and of the type associated with torrential flow. All cross-beds whose orientation was noted indicated sedimentation from the east. The succession maintains its thickness and coarseness for at least 45 miles along the strike, and roughly along the direction of sedimentation, while thinning to less than half the maximum thickness within 10 miles across the strike. Thus, despite the direction of cross-bedding, much of the sediments must have been locally derived. The basal beds were clearly obtained from the nearby red lavas, but some of the material higher in the succession may have come from the Lower Proterozoic orogenic belt to the east.

The basal conglomerate in the two south-westerly outcrops lies directly on the Nicholson Granite and was deposited after the granite had been emplaced and subsequently exposed by erosion. Jensen (in A.G.G.S.N.A., 1940b, p. 12; and Jensen, 1941b) states that the overlying strata have been indurated by the granite and that secondary crystals of feldspar developed in them; but the present workers regard the feldspar as part of a clearly recognisable conglomeratic arkose. This view is substantiated by the observation at lat. 17°38′10″S, long. 137°59′55″E (in the Northern Territory) of a dyke of porphyry, clearly related to the Nicholson Granite, which has been exposed by erosion and subsequently overlain by the Westmoreland Conglomerate. Several other clear contacts were discovered in the Northern Territory in 1957.

The Westmoreland Conglomerate is gently folded, with dips generally not exceeding 25°; dips up to 80° have, however, been recorded in the vicinity of faults. Faults striking west-north-west are prominent. Some show apparent horizontal displacement of up to 10 miles; true direction of movement is not known, but the faults are thought to have been normal faults. Joints are very well developed (see Pl. 27).

Peters Creek Volcanics

Definition. Derivation of name: Peters Creek, a tributary of Cliffdale Creek.

Map reference: Westmoreland 4-mile Sheet (Atlas, Pl. 2).

Distribution: In Queensland the formation forms a belt 4-6 miles wide, and has an area of outcrop of 150 square miles, between the Nicholson River and Cliffdale Creek, immediately north of the Wollogorang Formation. It extends 2 miles east of the Doomadgee Mission - Wollogorang track, and at least 40 miles into the Northern Territory.

The valley of Lagoon Creek and tributaries is probably underlain by Peters Creek Volcanics. Several small outcrops have been mapped in the valley.

Lithology: Acid and intermediate lavas identical in appearance with those of the Cliffdale Volcanics; some basalt; interbedded tuff and agglomerate and sparse sandstone, arkose, and siltstone. A specimen of a basic lava is described in Appendix I, p. 297 (Spec. R6953). Some of the lavas, particularly near the base of the succession, are scoriaceous and have their amygdules infilled by a green earthy chlorite. An azure blue mineral has also been observed in vesicles. Flows are generally thin, but one flow not less than 275 feet thick was measured.

The type section is from lat. 17°39′50″S, long. 138°17′30″E, south for a distance of 8 miles.

Thickness: Not less than 1000 feet.

Age: Upper Proterozoic (see p. 129).

Contacts: Underlain, probably unconformably, by Cliffdale Volcanics, and probably conformably by Westmoreland Conglomerate; overlain conformably by Wollogorang Formation.

Description and Comment. The lavas of the Peters Creek Volcanics appear to range from intermediate to acid, with some approaching a basic composition. Pyroclastics are abundant in the upper part of the succession, including acid agglomerate with angular fragments 'up to boulder size'.

The main occurrence of the formation in Queensland appears to thin considerably near the Northern Territory border, but may thicken again farther west.

Wollogorang Formation

Definition: Derivation of name: A.G.G.S.N.A. (1940a, p. 29) refers to '. . . . . interbedded limestones and quartzites and slate, in reality the equivalent of the Wollogorang series (2)' in the Northern Territory border area, north of the Nicholson River. 'Wollogorang series' is not used elsewhere in the report, but the reference (2) is to p. 35, where limestone, quartzite and slate, associated with volcanic rocks, are recorded from the Redbank copper field area. The Redbank area is described in greater detail in Jensen (1940b). Field work by officers of the Bureau of Mineral Resources in 1956 and 1957 has confirmed the equivalence of the dolomitic strata in the Wollogorang-Redbank area and those in Queensland. Wollogorang Formation is therefore adopted for the succession in both places.

Jensen did not provide a type area or source for the name. Wollogorang Homestead, on Settlement Creek, in the Northern Territory, is designated the source of the unit name.

Map reference: Westmoreland 4-mile Sheet (Atlas, Pl. 2). The type area is on the Calvert Hills 4-mile Sheet, N.T. (E53/8).

Distribution: In Queensland the formation crops out entirely north of the Nicholson River and east of the Doomadgee Mission - Wollogorang track, in a belt 3-4½ miles wide over an area of 120 square miles. A small outcrop has also been mapped at the southern edge of the body of Constance Sandstone, west of Westmoreland Homestead. It is more extensive in the Northern Territory.

Lithology: Interbedded sandstone, dolomite, dolomitic shale, and siltstone; chert and conglomerate. Some of the sandstones are micaceous and others are

feldspathic; they are generally well-bedded and are cross-bedded and, less commonly, ripple-marked. Except for the basal conglomerate, beds are generally fine to medium-grained. The conglomerate contains cobbles and pebbles of sandstone, quartzite, and, less commonly, red lava. Some of the dolomitic beds contain chert nodules. The chert beds, which are in part chert breccia, are probably silicified dolomite. The succession is rather more arenaceous in the eastern portion of the outcrop area than in the west.

The type area is 5 miles south-east of Redbank mines, on the Wollogorang - Calvert Hills road. A reference area for Queensland is from lat. 17°50′10″S, long. 138°09′00″E, in a north-north-westerly direction for about 4 miles.

Thickness: In the type area the thickness is of the order of 50-100 feet, but in the reference area it is between 500 and 1000 feet.

Age: Upper Proterozoic (see p. 129).

Contacts: Underlain by Peters Creek Volcanics; overlain by Constance Sandstone and by Mesozoic sediments.

Description and Comment. The Wollogorang Formation is gently folded, the main occurrence in Queensland being on the south limb of the regional anticline marked by the outcrop area of the Cliffdale Volcanics. Dips rarely exceed 25° and in many places are less than 10°.

The succession in the Nicholson River drainage area in Queensland is many times thicker than in the type area. The northern exposure in Queensland, in the Lagoon Creek valley, is also thinner than farther south. Insufficient work has been done to establish whether the change in thickness was produced by lensing towards a strandline or by movement of the strandline. However, as the Constance Sandstone and Mullera Formation both thin, and eventually lens out, in the Calvert Hills area a shoreline to the north-west is indicated.

The discovery of algal remains, of *Collenia* type, in the Wollogorang Formation (see p. 132), in association with the chert breccia, lends weight to the view that the breccia is an organic reef breccia. It only occurs in the Nicholson River area.

A specimen of dolomite from the Gorge Creek area, in the south-west of the Westmoreland Sheet, was shown on analysis to contain

CaO 18.0%
MgO 24.6%
Insolubles 3.6%
Phosphate was also present.
(Analyst: S. Baker).

Constance Sandstone

Definition. Derivation of name: Constance Range. Cameron (1901, pp. 156-191) first recorded 'sandstones of the Constance Range'. He recognised an unconformity between the sandstone and overlying limestone. Jensen (1941a) and A.G.G.S.N.A. (1940a) introduced the name Constance Range series for chert breccias, limestones, and arenaceous quartzites. The classification was based on field work in the Lawn Hill mineral field, together with a traverse to the west along Lawn Hill Creek, where it emerges from a gorge south of the Constance Range proper. As a result of this traverse Jensen considered 'the Lawn Hill head station limestones as well as those of the "Dentalium Plateau" [to be] coeval with those interbedded with quartzite of the Constance Range'.

Cameron had already recorded an unconformity between the limestone and quartzite (sandstone). In fact the section apparently inspected by Jensen probably contains an unconformity between the Upper Proterozoic sandstone and dolomite Camooweal Dolomite) and a disconformity between the latter and the Middle Cambrian Thorntonia Limestone.

It is therefore considered that the geographical name 'Constance' should be restricted to the strata which form the bulk of the Constance Range. This, in effect, would be a formalizing of Cameron's usage.

Map reference: Lawn Hill and Westmoreland 4-mile Sheets (Atlas, Pls. 2 and 3). The type area is in the Lawn Hill Sheet area.

Constance Sandstone also crops out in the Northern Territory, in the Mount Drummond and Calvert Hills 4-mile Sheet areas.

Distribution: In Queensland the unit extends discontinuously from lat. 17°05′10″S (8 miles north-east of Wollogorang Homestead) to near Lilydale Springs in the south — a meridional distance of 122 miles — and has an outcrop area of 900 square miles. The main area of outcrop is up to 35 miles wide. The Constance Range scarp is composed of Constance Sandstone (see Pl. 7, fig. 2). The extent of the formation in the Northern Territory is not fully known.

Lithology: This is an almost exclusively arenaceous succession. Strata range from coarse, poorly-cemented and poorly-bedded sandstones to fine-grained, well-bedded compact sandstones. Typically the beds are medium-grained, flaggy to massive, and are cross-bedded and ripple-marked. Conglomerate and pebble beds, some with angular fragments, occur extensively, particularly near the base of the succession and in the north of the outcrop area, rather than the south. Conglomerates are not very thick (generally less than 25 feet), but in places contain boulders of quartzite and sandstone up to 18 inches in diameter. The sediments of the formation are commonly poorly-sorted and contain mica, clay, and rarely feldspar impurities. The unit is almost devoid of shale or siltstone except for one siltstone lens between Elizabeth Creek and the Nicholson River. Beds are generally red-brown to light-brown; the finer bands in places are grey or white.

The type section is from lat. 18°27′35″S, long. 138°17′00″E, east-south-east about 4 miles to the base of the formation.

Thickness: Roughly 1,000 feet to 3,600 feet.

Age: Upper Proterozoic (see p. 129).

Contacts: Underlain by Lawn Hill Formation, with a strong angular unconformity (see Pl. 17); underlain, generally conformably, by the Wollogorang Formation. The Mullera Formation and Gold Creek Volcanics conformably, and the Camooweal Dolomite, Middle Cambrian Thorntonia Limestone, and horizontal Mesozoic strata, unconformably, overlie the Constance Sandstone.

Description and Comment. The Constance Sandstone is gently and openly folded. Folding is of the basin-and-dome type, with fold axes poorly defined but trending generally east-west. Dips in excess of 40° are rare, except near faults, where vertical dips have been recorded; on the Westmoreland Sheet the beds are almost flat-lying. The formation has been extensively faulted; displacements of at least 4,000 feet have been measured. Faults

are commonly silicified and have quartz stringers associated with them. Jointing is very pronounced in some of the coarser-grained and more friable beds. In places the joints have been etched out by weathering to give an extremely broken topography.

North of the Nicholson River the basal conglomerate of the Constance Sandstone contains pebbles of red porphyritic lava, probably from the Peters Creek Volcanics, and of dolomite from the Wollogorang Formation; locally an erosional surface must therefore have existed between the Wollogorang Formation and the Constance Sandstone. Elsewhere the passage between the formations appears to have been conformable. The probable explanation of the contact between the Constance Sandstone and the Gold Creek Volcanics is given on p. 120. The Constance Sandstone appears to lens out in the Calvert Hills Sheet area (in the Northern Territory, west of the Westmoreland Sheet) and also thins in places on the Mount Drummond Sheet (west of the Lawn Hill Sheet). In the Constance Range scarp at lat. 18°38′S, long. 138°28′20″E, and probably farther south (near the site of Pl. 7, fig. 2), a succession of calcareous greywacke, with numerous concretions, and interbeds of sandstone and siltstone, conformably underlies the typical basal beds of the Constance Sandstone. The succession is at least 150 feet thick, but as its distribution is not known it has not yet been constituted as a separate unit.

Mullera Formation

Definition. Derivation of name: Parish of Mullera, in the county of Mueller (see Queensland Department of Public Lands map No. 4M100).

Map reference: Lawn Hill 4-mile Sheet (Atlas, Pl. 3).

Distribution: In Queensland the unit is confined to the western portion of the Lawn Hill Sheet from south of Accident Creek to the latitude of Colless Creek (lat. 18°40′10″S) a meridional distance of 40 miles. Its eastern limit is 32 miles east of the Northern Territory border. The unit crops out widely in the Mount Drummond 4-mile Sheet area, in the Northern Territory. The area of outcrop in Queensland is about 340 square miles.

Lithology: Dominantly thin-bedded, commonly micaceous, siltstone, siliceous siltstone, shale, and fine-grained sandstone. At three stratigraphic levels, including the top of the formation, fine to medium-grained sandstone successions up to 1,100 feet thick contain little siltstone or shale. The lowest of these, and the most heterogeneous, also contains very extensive sedimentary oolitic ironstone, ranging from slightly ferruginous sandstone and siltstone (commonly chamositic below the weathered zone) to moderate-grade iron ore. Beds, particularly the arenaceous and ferruginous beds, commonly lens markedly and the formation varies considerably in thickness from place to place.

The succession is roughly as follows, from top to bottom:

Medium to fine grained quartzitic sandstone, some siltstone and shale — up to 1,200 feet.

Siltstone, shale, thin-bedded fine sandstone — 600 to 1,650 feet.

Flaggy to massive, fine to medium grained quartzitic sandstone; some interbedded siltstone and shale; some poorly-cemented, rather coarse, brown sandstone — 0 to 480 feet.

Siltstone, shale, thin-bedded fine sandstone — 700 to 2,250 feet.

Quartzitic sandstone, siliceous siltstone, siltstone and shale, ferruginous sandstone and oolitic ironstone — 150 to 300 feet.

Siltstone, sandstone, generally thin-bedded and quartzitic, siliceous siltstone and shale — 900 to 2,200 feet.

The sandstones are light-coloured, except for some soft red-brown sandstone and the ferruginous sandstones. The shale, where weathered, is light brown to red-brown, but fresh exposures, which are common in watercourses, are dark-grey, cherry-red, or grey-green. Some dolomitic shale occurs in the north-west of the outcrop area. The formation is notable for the abundance of shallow-water sedimentary structures, including ripple marks, current-bedding, scour-and-fill features, mud-pellet casts, intraformational breccia, and mud cracks. Well-developed cone-in-cone structures occur in the upper Elizabeth Creek area (lat. 18°18′15″S, long. 138°06′55″E).

Thickness: Ranges from about 3,600 feet to 7,000 feet.

Age: Upper Proterozoic (see p. 129).

Contacts: Conformably underlain by Constance Sandstone. Unconformably overlain by doubtfully Upper Proterozoic Colless Volcanics and Camooweal Dolomite, Middle Cambrian Thorntonia Limestone, and Mesozoic sediments.

Description and Comment. In Queensland, the outcrop of Mullera Formation is surrounded by Constance Sandstone. A succession, not more than 50 feet thick, of red-brown sandstone, shale, and dolomitic shale was recognised, in the course of mapping in 1957, in the upper Settlement Creek Valley, Northern Territory (Calvert Hills 4-mile Sheet). It lies conformably above the Constance Sandstone and below the Gold Creek Volcanics. The formation apparently, therefore, lenses out to the north or north-west. This would explain the contact between the Constance Sandstone and the Gold Creek Volcanics in the north of the Westmoreland Sheet area.

Like the Constance Sandstone, the Mullera Formation also thins markedly towards the Constance Range scarp, and some of the beds become coarser in the east than farther west; so the source of sediment was to the east. In the Northern Territory, on the other hand, much of the sediment for the Constance Sandstone and Mullera Formation came from the west. The depositional basin was, therefore, closed, or nearly closed. The sedimentary structures in the Mullera Formation further indicate that the basin through much of its life was extremely shallow, with extensive marginal mud flats at times.

This environment is similar to that in which many of the world's largest sedimentary iron deposits accumulated. The iron beds are also very similar to those elsewhere, notably the Wabana iron deposits (Hayes, 1915). Descriptions of the Constance Range mineral assemblages are given by Edwards (1957a-c., 1959a,b). The main iron minerals in the primary zone are hematite, siderite, and chamosite. They occur both as oolites and as an interstitial cement, but siderite is not common in the oolitic form. Grade of iron ranges down from 60% Fe (rare) to iron-poor ferruginous sandstone. The sediments are unmetamorphosed but some hematite has been recrystallized and replaced by siderite.

Deformation is similar to that in the Constance Sandstone, except that, owing to the incompetence of the strata, faults are much less numerous.

Gold Creek Volcanics

Definition. Derivation of name: Gold Creek, in the Northern Territory. The sucession to which the name Gold Creek Volcanics is applied was named the Redbank series by Jensen (A.G.G.S.N.A. 1940b, p. 12), but this name was pre-empted by Dunstan (1913) who used the name for fossiliferous freshwater Tertiary sediments south of Goodna, S.E. Queensland.

Map reference: Westmoreland 4-mile Sheet (Atlas, Pl. 2); also the Calvert Hills and Robinson River 4-mile Sheets in the Northern Territory.

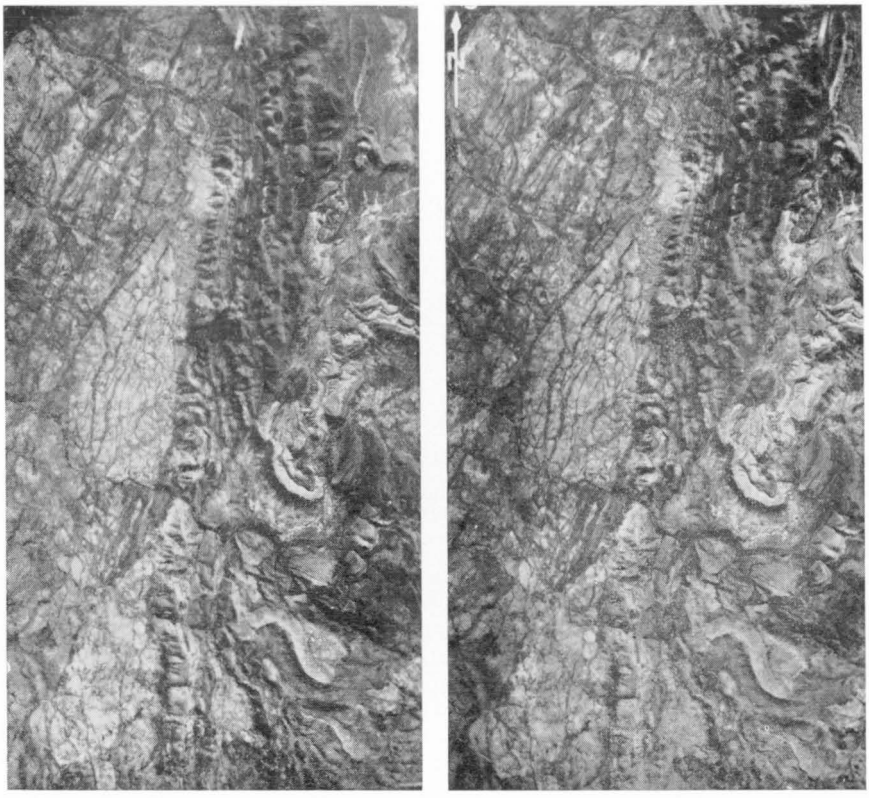


Fig. 1. Stereoscopic pair of air photographs showing the contact between Argylla Formation (left) and Surprise Creek Beds, about 15 miles west of Dobbyn. Dark lines in the Argylla Formation are dolerite dykes. Scale about 1:104,000.

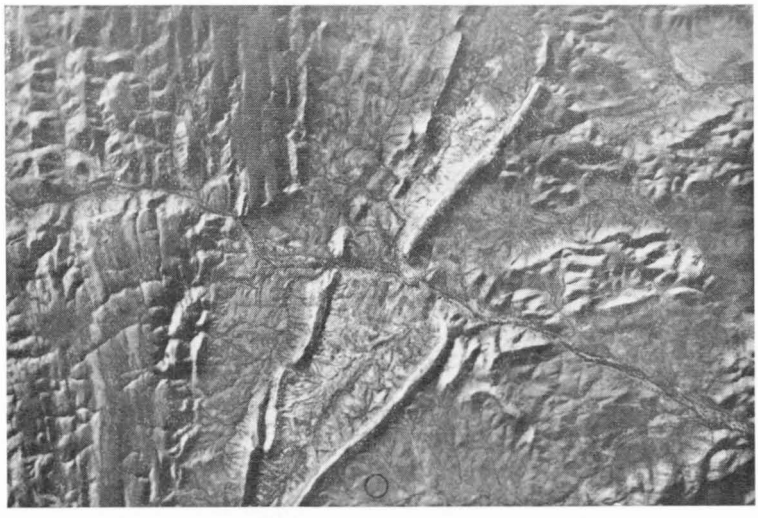


Fig. 2. Contact between Eastern Creek Volcanics (right) and Mount Isa Shale (centre). North of the photograph Mount Isa Shale also unconformably overlies Myally Beds. On the left, Leander Quartzite, with pronounced near-meridional jointing, appears. Scale about 1:75,000.

—Taken from portions of official R.A.A.F. photographs: not to be reproduced without authority.

Fig. 1. Dolomitic strata of Paradise Creek Formation at the Gunpowder Creek crossing, on the Mount Isa-Mount Oxide track.

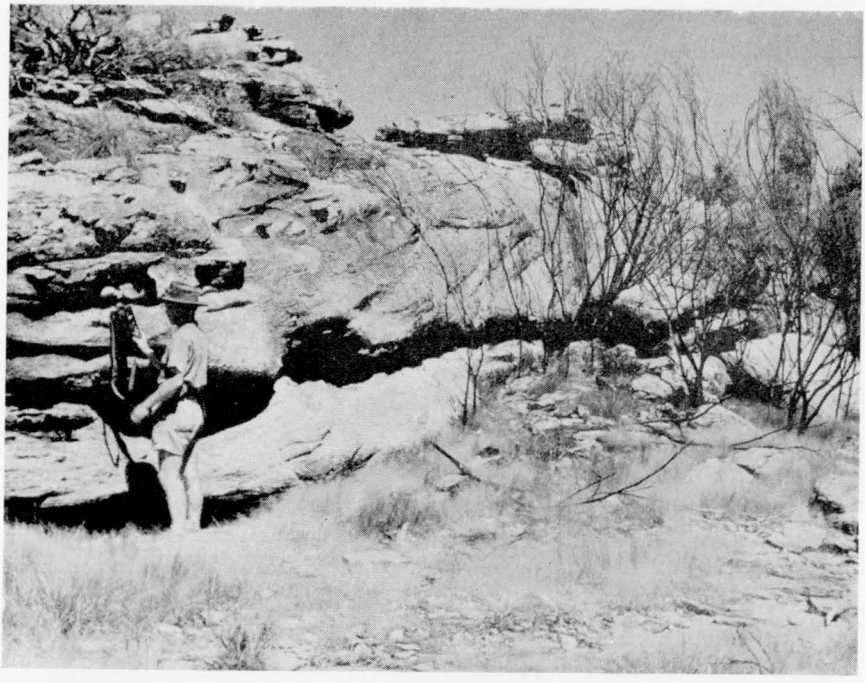


Fig. 2. Coarse cross-bedded sandstone in Westmoreland Conglomerate, near Livingstone's uranium prospect. The grass-covered area is part of a gully formed by weathering out of a joint (see Plate 27).

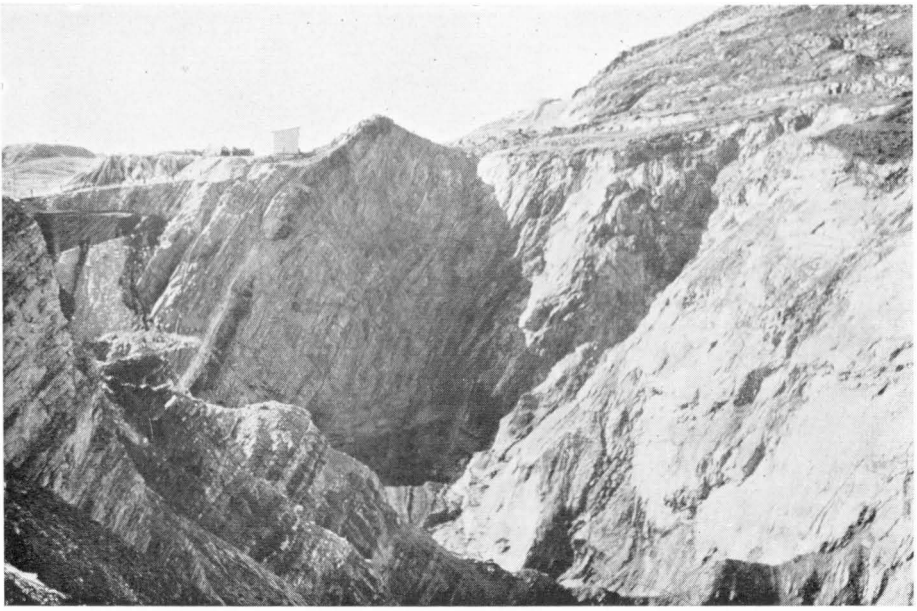


Fig. 1. Open cut and 'glory hole', Mount Isa, showing west-dipping Mount Isa Shale. 1956.

Fig. 2. Small-scale contortions, with eroded upper surface, in siliceous dolomite of the Mount Isa Shale, about 2 miles south of the Mount Isa mine.

Air photograph of unconformity between Lawn Hill Formation (right) and Constance Sandstone. The dark beds on the left of the photograph are of oolitic ironstone, in the Mullera Formation. Scale about 1:50,000.

—Taken from portion of an official R.A.A.F. photograph: not to be reproduced without authority.

Distribution: The formation crops out almost entirely in the Northern Territory. An area of about 3 square miles, 23 miles north-west of Westmoreland Homestead, forms the most north-westerly exposure of Precambrian rocks in Queensland at lat. 17°06′S, long. 138°00′E.

Lithology: Acid and intermediate lavas, amygdaloidal in some flows, coarsely porphyritic in others; tuffaceous siltstone, tuffaceous sandstone, and agglomerate.

The type area is along the Wollogorang - Pungalina road, 7 miles from Wollogorang Homestead (Calvert Hills 4-mile Sheet, Northern Territory).

Thickness: Unknown, but at least 300 feet.

Age: Upper Proterozoic (see p. 129).

Contacts: Underlain in Queensland by Constance Sandstone, apparently conformably; no overlying strata. In the Northern Territory a thin succession of red flaggy sandy and dolomitic strata, believed to be a lateral transition of the Mullera Formation, is interposed between the Constance Sandstone and the Gold Creek Volcanics. The Gold Creek Volcanics are conformably overlain by a succession of sandstone which does not extend into Queensland.

Description and Comment. The Gold Creek Volcanics do not appear south of the anticlinal axis marked by the outcrop of the Cliffdale Volcanics. Their absence is probably due to non-deposition.

Pilpah Sandstone

Definition. Derivation of name: Pilpah Range. The unit was named by Noakes & Traves (1954, p. 36). The definition included here has been formulated in consultation with Mr L. C. Noakes.

Map reference: Mount Isa and Camooweal 4-mile Sheets (Atlas, Pls. 4 and 5).

Distribution: The formation crops out in the Mount Isa Sheet area, and extends for about 2 square miles into the Camooweal Sheet. The bulk of the formation crops out between the Barkly Highway and the Buckley River on the north and the Templeton River in the south. No outcrops are known east of long. 139°18′10″E; the most easterly exposures are north of the highway. The westernmost exposure is at lat. 20°27′30″S, long. 138°14′20″E. The formation crops out over an area of about 650 square miles.

Lithology: Generally fine to medium-grained, well-sorted and well-bedded sandstone, light brown to white. Some coarse sandstone and conglomerate, with quartzite pebbles and cobbles, occur, particularly in the east of the outcrop area. A few of the beds are feldspathic and some in the extreme east are argillaceous and grey. Ripple-marking and cross-bedding are abundant throughout the formation. At lat. 20°20′30″S, long. 139°11′50″E, thick beds with planar cross-bedding may have been formed under local deltaic conditions.

The type section is from lat. 20°20′20″S, long. 138°34′E, south-south-west for about 2¾ miles.

Thickness: About 1,000 feet maximum.

Age: Upper Proterozoic (see p. 129).

Contacts: Unconformably underlain by the Judenan Beds, Gunpowder Creek Formation, Paradise Creek Formation, and Mingera Beds. Angular unconformities can be seen at lat. 20°20′20″S, long. 139°11′30″E and lat. 20° 32′25″S, long. 139°06′30″E. The formation is uncomformably overlain by the Camooweal Dolomite and the Middle Cambrian Beetle Creek Formation, Inca Formation, and Split Rock Sandstone.

Description and Comment. The Pilpah Sandstone is gently to moderately folded. Dips rarely exceed 30°. Folding is very irregular, with some dome-and-basin structures; the general trend of fold axes is about north-west. In places the formation is faulted. Fault zones commonly contain numerous quartz stringers but not large quartz reefs.

The Pilpah Sandstone and Constance Sandstone have many common features and broadly occupy the same stratigraphical position relative to other units. They differ in the direction of the main fold axes and faults, but a correlation appears reasonable, though speculative.

Makbat Sandstone

Definition. Derivation of name: Makbat Creek.

Map reference: Duchess and Boulia 4-mile Sheets (Atlas Pls. 1 and 9).

Distribution: Two groups of outcrops have been mapped. The larger extends south from lat. 21°53′50″S, long. 139°44′00″E, for 11 miles, parallel to and generally about a mile east of Wills River, to within 2 miles (north) of Buckingham Downs Homestead. The smaller outcrop is 2½ miles north-east of the northern end of the main outcrop. Total area of outcrop is about 14 square miles.

Lithology: Dominantly sandstone (quartzite in part), commonly poorly sorted, impure and ironstained, grading up into yellow flaggy sandy siltstone. Feldspar is a common impurity; in places the strata approach quartz greywacke in composition and texture. A bed of dark-brown shale and a bed of conglomerate up to 50 feet thick are also included in the succession.

The type section is from lat. 21°58′40″S, long. 139°45′00″E (7 miles north of Buckingham Downs Homestead) east for a distance of 2½ miles.

Thickness: At least 1,000 feet.

Age: Upper Proterozoic? (see below).

Contacts: Underlain by Argylla Formation and Kalkadoon Granite. No contact was observed because of poor exposures, but a metamorphic discordance exists between the Argylla Formation and the Makbat Sandstone. The latter is believed to be younger than the granite and is presumably separated from the Argylla Formation by a strong angular unconformity.

Description and Comment. The Makbat Sandstone is moderately folded. It is well-compacted and indurated, does not appear to have been metamorphosed, but has been cut by quartz veins. On the evidence available the age of the Makbat Sandstone lies within the range Lower Proterozoic (equivalent to Surprise Creek Beds or younger) to Palaeozoic.

A formation of somewhat similar lithology crops out a few miles to the east of the Makbat Sandstone: it is the Mount Birnie Beds (named by A. A. Öpik), in which Lower Cambrian fossils have been found. The Makbat Sandstone is more arenaceous, and thicker than the

Mount Birnie Beds. It is also more strongly folded and is indurated to a greater extent, but it may be the same age as the Mount Birnie Beds, i.e., Lower Cambrian.

Nye & Rayner (1940, pl. 1) did not distinguish the Makbat Sandstone from the Kalkadoon-Argylla series shown in the area.

Quamby Conglomerate

Definition. Derivation of name: Ball (1921, p. 10) named the auriferous conglomeratic succession at and near Mount Quamby, the Quamby Conglomerates. The succession, together with other conglomeratic occurrences elsewhere, was called the Mount Quamby series by A.G.G.S.N.A. (1936a, p. 50). It is proposed that Ball's original name be retained (but deleting the 's'), the source of the name being Mount Quamby, near the Mount Quamby gold workings.

Map reference: Cloncurry 4-mile Sheet (Atlas, Pl. 8).

Distribution: The Quamby Conglomerate occurs largely in downfaulted blocks a few square miles in area. One is around and south of Mount Quamby; a second trends north-north-easterly for 10 miles from near the Federal copper mine, on the Cloncurry - Mount Isa road (lat. 20°35′20″S, long. 140°10′30″E); a few small outcrops 6 miles north-west of Mount Quamby have also been mapped as Quamby Conglomerate. The total area of outcrop is 9 square miles.

Lithology: Conglomerate, pebble beds, greywacke (arkosic in part), quartzite, and sandstone. Beds are locally extensively hematitic, apparently owing to hydrothermally introduced iron. Strata are well-compacted and lithified, but do not appear to be metamorphosed.

The type section is in an east-west direction through Mount Quamby (no type section was given by Ball, but he referred the succession to the Mount Quamby area).

Thickness: Probably about 1,000 feet.

Age: Doubtfully assigned to Upper Proterozoic (see below).

Contacts: Underlain, with strong angular unconformity, by Corella Formation.

Description and Comment. The conglomerate can be seen well near the old Mount Quamby gold workings. At the base the included fragments are small, ill-sorted, and angular, and are of locally derived material such as carbonaceous slate, calc-silicate rock, and schist. Higher in the succession they are better rounded and larger, and consist of material which is more resistant to abrasion and erosion; pebbles are up to 10 inches long and are of quartzite, quartz, and feldspathic sandstone. Elsewhere red jasper fragments and rare pebbles of rhyolite or metarhyolite have been observed, but no granite pebbles have been found. The matrix is commonly highly feldspathic. Boulder conglomerates are of local extent only; they grade into pebble beds and greywacke. Conglomerate is most abundant near the base of the succession, but occurs as beds or lenses at all stratigraphic levels.

The high feldspar content throughout the succession may be due to erosion of a nearby porphyritic acid lava terrain and not a granitic terrain. The feldspathic beds are coarse greywackes rather than arkoses, except perhaps locally; they contain numerous rock fragments.

The high feldspar content throughout the succession may be due to erosion of a nearby been recorded. The folds are synclinal, but one or other of the limbs is generally faulted out. The folding may be due almost entirely to dragging during down-faulting of the small graben

to which the succession is largely confined. Very strong jointing has been developed, but there is no cleavage or schistosity.

The age of the Quamby Conglomerate cannot be determined with certainty. The inclusion of metamorphic fragments in an unmetamorphosed matrix indicates that the source rocks had been metamorphosed before the conglomerate was laid down, but granites may also have been emplaced at a later date.

The gold in the Quamby Conglomerate may be of hydrothermal origin, as it is associated closely with hematite and is not restricted to the base of the succession.

The presence of hydrothermally introduced material could be regarded as evidence that the succession is older than the granite. On the other hand the post-Middle Cambrian Pilgrim Fault (Duchess Sheet) lies on the same line as the graben which contains the Quamby Conglomerate and possibly the Quamby Conglomerate was deposited during the downfaulting of the graben.

It is of some interest to observe that a conglomerate at Mount Fort Bowen, 80 miles to the north-east of the Quamby Conglomerate, is identical in appearance and grade of metamorphism and includes red jasper fragments similar to those in the Quamby Conglomerate. Unfortunately, the succession at Mount Fort Bowen cannot be dated with any greater precision than the Quamby Conglomerate.

Colless Volcanics

Definition. Derivation of name: Colless Creek, the upper part of which drains the formation area.

Map reference: Lawn Hill 4-mile Sheet (Atlas, Pl. 3).

Distribution: Outcrops are discontinuous in an east-west belt 13 miles long and not more than 2 miles wide, along the south edge of the Constance Range, west of lat. 18°40′35″S, long. 138°26′30″E.

Lithology: Basalt, commonly vesicular to scoriaceous (see Appendix I, p. 298, Spec. R6952); and possibly some intermediate lavas. The vesicles in the basalt are extensively infilled by malachite.

Thickness: About 200 feet?

Age: Probably Upper Proterozoic, possibly Cambrian (see below).

Contacts: Unconformably underlain by Mullera Formation; overlain by Middle Cambrian Thorntonia Limestone. As mapped, the easternmost occurrence is in contact with the Camooweal Dolomite, but the contact was not seen in the field because of poor exposure.

Description and Comment. The age of the Colless Volcanics cannot be accurately determined until its relationship with the Camooweal Dolomite is established. Its attitude was not clearly determined, but it appears to be essentially flat-lying. It probably dips gently away from the Constance Range scarp, in which case it is older that the Camooweal Dolomite, provided that the contact under the soil is not faulted. However, cupriferous basalts in the Northern Territory and elsewhere have been assigned to the Lower Cambrian.

Camooweal Dolomite

This extensive succession, which crops out to the west and south-west of the region dealt with in this bulletin, is defined and described by Öpik (in preparation). A brief description is included in the explanatory notes accompanying the Urandangi, Mount Isa, and Camooweal 4-mile Sheets. It has also been dealt with at

CAMBRIAN AND ORDOVICIAN CORRELATION CHART, NORTH-WESTERN QUEENSLAND

FIGURE 12

BY A.A. ÖPIK

TIME SCALE		BORDER W.H.	SEYMOUR R.	UNDILLA BASIN	WHISTLER'S CK.	BEETLE CK.	MT. MERLIN	SELWYN RA.	BOULIA (incl. DeLittle Ra.)	QUITA CK.	MUNGEREBAR	SYLVESTER CK.	SUN HILL	TYSON'S BORE	TOKO RA.
ORDOVICIAN	LLANVIRNIAN ARENIGIAN	*Unconform. 1.*		*Unconform. 1*	*Unconform. 1*	*Unconform. 1*	*Unconform. 1*	*Unconform. 1*	*Unconform. 1*	*Unconform. 1*			*Unconform. 1*	*Unconform. 1*	*Unconform. 1*
	TREMADOCIAN						SWIFT		SWIFT						TOKO
							Unconform. 2		*Unconform. 2*						*Unconform. 2*
UPPER CAMBRIAN	TREMPEALEAUAN						NINMAROO		NINMAROO		NINMAROO		NINMAROO	NINMAROO	NINMAROO
	FRANCONIAN						*Disconform. 3*		"GOLA" CHATSWORTH		*Disconform. 3*		*Disconform. 3*	*Disconform. 3*	*Disconform. 3*
	DRESBACHIAN						CHATSWORTH		? O'HARA			GEORGINA	GEORGINA	GEORGINA	GEORGINA
MIDDLE CAMBRIAN	LAEVIGATA III			? ? ?				O'HARA	POMEGRANATE		MUNGEREBAR	*(No outcrop)*			
	LAEVIGATA II			*Probably eroded*				SELWYN RA.				"DEVONCOURT"		*1,800' of sediments below Georgina*	"DEVONCOURT" *(In north-west)*
	LAEVIGATA I							DEVONCOURT		STEAMBOAT	STEAMBOAT				
	NATHORSTI			? SPLIT ROCK ?	SPLIT ROCK			ROARING	*Middle Cambrian probably complete*						
	PUNCTUOSUS-NATHORSTI			MAIL CHANGE	MAIL CHANGE					*Diastem*	*Disconform.*				
	PUNCTUOSUS			V-CREEK	V-CREEK					QUITA					
	PARVIFRONS			AGE CK. CURRANT BUSH INCA	INCA	INCA	INCA	*Disconform. 4*		BLAZAN	BLAZAN	*Disconform. 4*			
	ATAVUS	LANCEWOOD								*Disconform.*	*Disconform.*				
CAMBRIAN	ATAVUS - GIBBUS	CURRANT BUSH					*Disconform.*			BEETLE CK.					
	GIBBUS	BORDER W.H.	BEETLE CK. *(at Lawn Hill)*	THORNTONIA	BEETLE CK.	BEETLE CK.	BEETLE CK.			THORNTONIA	"YELVERTOFT"				
	XYSTRIDURA		THORNTONIA *including "Girvanella puddings"*	BEETLE CK. "YELVERTOFT"	"YELVERTOFT"	"YELVERTOFT"	*Disconform.* THORNTONIA			*Unconform. 5*	*Unconform. 5*	*Unconform. 5*	*Unconform. 5*		*Unconform 5*
	REDLICHIA	*Disconform.*		*Disconform.* "UNNAMED"	*Disconform.* CONGLOMERATE	"UNNAMED"	*Unconform. 5* MT. BIRNIE	*Unconform. 5* MT. BIRNIE		RIVERSDALE	RIVERSDALE	SYLVESTER			SUN HILL
LOWER CAMBRIAN		CAMOOWEAL		CAMOOWEAL						*Unconform. 6*	*Unconform. 6*	SUN HILL	SUN HILL		*Unconform.*
		Unconform. 6	*Unconform. 6*	*Unconform. 6*	*Unconform. 6*	*Unconform. 6*	*Unconform. 6*	*Unconform. 6*		BASEMENT	BASEMENT				BOULDER-BEDS
PRECAMBRIAN		CONSTANCE	BASEMENT	BASEMENT	PILPAH	BASEMENT	BASEMENT	BASEMENT							

Bureau of Mineral Resources, Geology and Geophysics. Canberra, A.C.T. July; 1959.

QG 34-14 F.J.R.

some length in the Proceedings of the 20th International Geological Congress (Öpik, 1956b).

The succession consists of dolomite, with chert nodules, and sandy interbeds near the base. It is generally flat-lying, but is gently folded north-east of Urandangi. It is at least 800 feet thick.

Riversdale Formation (Öpik, 1956a, b; 1960)

The Riversdale Formation is exposed in a number of small areas, mainly as mesas, south-east and south of Ardmore Homestead. The main outcrop is at lat. 21°41′30″S, long. 139°16′40″E. The unit has been named by Öpik. It consists of flat-lying red sandy dolomite, red sandstone, and conglomerate, and is about 150 feet thick.

Undifferentiated Upper Proterozoic? Strata

A number of small outliers of indurated conglomerate and sandstone occur in the Duchess 4-mile Sheet area, west and south of Duchess. They are flat-lying or moderately folded. Occurrences of folded rocks may be contemporaneous with the Makbat Sandstone; the possible age of the flat-lying strata lies between Palaeozoic and Lower Proterozoic. One such occurrence is discussed on p. 127.

Cambrian

The Cambrian strata which crop out extensively around the Precambrian belt have been studied by A. A. Öpik. He has subdivided them in some detail. The *Mount Birnie Beds* have been found to be Lower Cambrian; the Makbat Sandstone may possibly be of the same age. Most of the units are Middle Cambrian, with some Upper Cambrian and Ordovician sediments in the south of the region. Figure 12 is reprinted from Öpik (1960), and shows the mutual relationships of the various Cambrian formations. Brief descriptions of lithology appear in the legends of the appropriate 4-mile maps.

Cambrian sediments generally are only slightly folded and faulted. However, in the south of the region there is evidence of rather greater crustal unrest than elsewhere. Middle Cambrian strata are downfaulted in many places against Precambrian rocks; the resultant dragging has produced high local dips. Lower Ordovician strata on the Duchess Sheet have been folded with the Cambrian sediments. The stratigraphy and structure of the Cambrian are dealt with in Öpik (1956a, b, 1960, 1961).

Mesozoic

Flat-lying Mesozoic sediments remain as residuals (except for the Mesozoic sediments of the Great Artesian Basin) on practically all sides of the Precambrian block, and in places encroach extensively on to it (see Pls. 2, 6, 7, and 8). Öpik (Atlas, Pls. 4 and 5) has subdivided the Mesozoic on the Camooweal and Mount Isa Sheets into *Polland Shale, Lees Sandstone,* and undifferentiated. The present authors, in conjunction with C. E. Prichard, have differentiated the marine sediments of the *Rolling Downs Group* on the Dobbyn Sheet, but have made no dif-

ferentiation elsewhere. The Mesozoic succession in the cappings on Precambrian from south of Selwyn to the Northern Territory border, north of lat. 17°35′00″S, show a consistent sequence of freshwater sediments, commonly with quite numerous, but poorly preserved, plant remains, overlain by marine, in part fossiliferous, sediments.

The freshwater sediments consist of conglomerate, pebble beds, coarse sandstone, feldspathic sandstone, arkose, and siltstone and shale, commonly micaceous. The lower beds, particularly, reflect the composition of the adjacent Precambrian rocks. The sediments are almost invariably poorly sorted and in places are extensively cross-bedded. A few miles north of Selwyn, however, thin beds of almost pure kaolinitic clay are interbedded with coarser sediments. Plant fossils are generally fragmentary and completely replaced by limonite. At lat. 21°31′S, long. 140°26′E, some better preserved fossils have been identified by M. White (1957, unpubl.) as *Aspleniopteris pinnatifida* Fontaine and *Pterophyllum (Nilssonia) princeps* O. & M. These indicate an age for the sediments within the range Triassic to Jurassic. *Pterophyllum (Nilssonia) princeps* occurred with the greatest profusion in Lower Jurassic times. Elsewhere the remains are generally of stems. Probable worm burrows have been seen over wide areas and at lat. 19°36′05″S, long. 139° 51′15″E numerous poorly preserved root remains cut across the bedding.

The cappings of marine sediments are mainly of siltstone and 'porcellanite' —a very fine-grained light-brown siliceous rock, probably originally slightly calcareous. Fossils were found at Soldiers Cap and at lat. 21°13′10″S, long. 140° 44′50″E. They have been identified by Crespin & Dickins (1955, unpubl.) as *Bigenerina* sp., *Ammobaculites* sp., *Corbicula*? cf. *Corbicula*? *meeki,* and *Tatella*? sp. nov. from Soldiers Cap, and *Cenosphaera* sp. and a foraminifer (cf. *Dentalina)* from the more southerly location. The age indicated for the rocks is Lower Cretaceous. Pelecypods collected by members of the staff of Mount Isa Mines Ltd in 1957 from lat. 18°16′00″S, long. 138°12′40″E, south of Elizabeth Creek, Constance Range area, have been identified as *Maccoyella?* sp. and *Grammatodon?* sp. by Dickins. These fossils indicate an age for the sediments within the range Jurassic to Lower Cretaceous. Unidentified fragments of pelecypods and mollusc or worm trails have also been found at lat. 18°08′55″S, long. 138°20′55″E. Most cappings measured do not exceed 100 feet.

East of the outcropping Precambrian, Mesozoic limestone crops out in small isolated bodies. At lat. 19°34′24″S, long. 140°04′35″ E *Belemnites* sp. was found in crystalline limestone. Laing & Power (1959a and b) have named the Mesozoic limestone in the Dobbyn Sheet area the *Kamileroi Limestone.*

Whitehouse (1954) has dealt with the sediments of the Great Artesian Basin. From his maps and description the freshwater sediments recorded above appear to belong to the *Blythesdale Group* and the marine sediments to the *Rolling Downs Group.* The Geological Map of Queensland, published in 1953, at a scale of 1 inch to 40 miles, shows the Mesozoic of the area as *Tambo Formation.* Whitehouse, in his cross-sections, shows the marine strata as *Roma* or *Tambo Formation.*

Tertiary

Carl Creek Limestone

The Carl Creek Limestone, which was named by Cameron (1901), forms a number of outliers in the valleys of the O'Shanassy and Gregory Rivers and Carl and Verdon Creeks. It was subsequently renamed Verdon Limestone by Traves & Noakes (1954, p. 40), but there is no valid reason for abandoning the first-given name and it has now been re-established. The nomenclature, distribution, and depositional environment are dealt with at greater length by Öpik (in preparation). The outliers are probably remnants of a lacustrine deposit formed by epeiric movements in Tertiary times.

Other small deposits, generally in valleys, have been recorded, particularly in the Dobbyn and Camooweal Sheet areas, in the course of field work, but have not been shown on the maps. Some are probably of Mesozoic age; others may be of a similar age and origin to the Carl Creek Limestone.

Strata of Unknown Age

At lat. 21°05′30″S, long. 139°39′45″E, an isolated body of flat-lying conglomerate and coarse arkosic sandstone overlies coarse-grained Kalkadoon Granite. Its top is topographically below the level of the surrounding ridges of Lower Proterozoic Mount Guide Quartzite, but no evidence of infaulting was observed. The pebbles and cobbles, up to 24 inches long, but generally less than 6 inches long, are of white quartzite, quartz, and coarse sandstone, and are poorly rounded and sorted. The matrix is of decomposed feldspar and kaolin. Beds are lenticular and cross-bedding is common. Some beds have shallow dips, but the dips are probably depositional. The strata are thoroughly compacted but are not metamorphosed. They are 150 feet thick.

Since the strata are not metamorphosed or folded they are probably not older than Upper Proterozoic, and are thoroughly lithified and are therefore not Recent; beyond this, no age can be assigned to the succession. No fossils were observed; there appeared to be no pebbles of Cambrian cherts and the top of the hill has not been lateritized (nor have surrounding Lower Proterozoic strata).

On the Templeton River at lat. 20°38′30″S, long. 139°13′50″E, two small outcrops of conglomerate, with a matrix of decomposed feldspar, contain pebbles of Middle Cambrian Beetle Creek Formation. Rubbly outcrops, also with Middle Cambrian chert pebbles, occur 3 miles north-east of May Downs Homestead at lat. 20°24′40″S, long. 139°05′20″E. Their age is unknown.

At lat. 20°29′30″S, long. 140°33′25″E a poorly exposed quartzite was observed west of an outcrop of calc-silicate rock. It appeared rather fresher than the Lower Proterozoic quartzites. Its attitude could not be determined and its age is unknown. The small outcrops in the Cloncurry 4-mile Sheet area, to the east of the point just referred to and marked 'Unidentified', were located by air-photo interpretation only.

Recent 'breccia-conglomerate' is to be seen in the beds of watercourses in many parts of the region. Inclusions are angular to poorly rounded and are bonded

by a ferruginous cement. The formation of these deposits is apparently due to the leaching of iron from nearby iron-rich sources, generally ferruginous laterite, and precipitation in the beds of the watercourses, thereby cementing together the stream debris which lay there. A good example may be seen at the crossing of Wills Creek, near Buckingham Downs Homestead, at lat. 22°05′00″S, long. 139°45′00″E.

In the Gregory and O'Shanassy Rivers travertinous limestone is being precipitated from the lime-rich waters, which come largely from underground sources in the Thorntonia Limestone. The deposits are well developed at the junction of the two streams.

Other Outcrops

To the north-east of the main area of outcrop of the Precambrian of north-western Queensland, roughly half-way to outcropping metamorphic rocks of the Georgetown area, there are two small outcrops, shown by David (1932) as Archaean. These are the outcrops which form Mounts Brown and Fort Bowen.

Mount Brown

The outcrop at this point consists of four or five isolated bodies, arranged in a linear pattern in a north-north-westerly direction, and surrounded by heavy-textured soil (locally known as black soil) and alluvium. The total area of outcrop is about a quarter of a square mile.

The strata consist of highly schisted, extremely coarse greywacke or arkose, clearly derived from a nearby crystalline terrain. The rock could be described as quartz-feldspar-mica schist. A few scattered pebbles, most of the same material as the matrix, a few of ferruginous slate, and some possibly of weathered granite, are distributed more or less at random. Bedding is poorly preserved; some current-bedding was seen. The whole outcrop is extensively, but not uniformly, iron-stained. Minor irregular quartz veins and stringers cut the schist.

Folding is strong but irregular. A near-vertical dip was measured, but generally the folding is open and apparently on a near-meridional axis. Schistosity was measured to strike 335° and dip 65°E.

The age of the Mount Brown strata cannot be conclusively established. It is probably Lower Proterozoic; it is certainly greater than that of the Mount Fort Bowen sediments.

Mount Fort Bowen

The area of outcrop is about one square mile, and the sediments are pebble conglomerate, greywacke, and quartz greywacke. The pebble conglomerate forms a thick basal bed and also occurs in lenses throughout the succession. Its pebbles are moderately well-rounded and sorted, rarely exceed 2 inches in length, and are of quartzite, white and clear quartz, slate (generally ferruginous), and red jasper. The pebbles form up to 80% of the rock volume. The matrix is not readily determinable owing to extensive iron-staining and weathering. Beds and lenses of hematite are common, and the conglomerate as a whole is purple. Overlying the pebble conglomerate is a coarse greywacke with, in places, a high feldspar content

and lenses of pebble beds and of coarse sandstone. The youngest beds observed were medium-grained quartz greywackes with some feldspar and other fragmental material. Cross-bedding is common throughout the succession and indicates sedimentation from the south to south-west.

Lithologically the Mount Fort Bowen strata are similar to those at Mount Brown, but are much less strongly deformed and metamorphosed, although thoroughly compacted and lithified. Bedding dips up to 40° were measured. Folding is in the same direction as for the Mount Brown strata—on a north-north-west axis.

The absence of metamorphism indicates that the Mount Fort Bowen sediments are younger than the schists at Mount Brown. Although separated from the Quamby Conglomerate by 80 miles, the similarity in lithology (enhanced by the presence in both of red jasper fragments, which have not been observed elsewhere) and degree of metamorphism points to an age correlation between the Mount Fort Bowen strata and the Quamby Conglomerate. The latter is tentatively regarded as Upper Proterozoic, but it could be either older or younger.

Age of the Precambrian Strata

No firm estimate of the age of the Precambrian rocks can be made on data available at present. We have three facts from which to attempt to determine a time scale.

(a) The oldest known diagnostic fossils in the region are of Lower Cambrian age. These occur in the Mount Birnie Beds and unconformably overlie the Kalkadoon Granite, and Corella Formation. The Lower Middle Cambrian Thorntonia Limestone unconformably overlies the Mullera Formation.

(b) Well-developed colonial fossils occur in the Paradise Creek Formation.

(c) Monazite from a pegmatite in the Mica Creek area, 8 miles south-west of Mount Isa, has yielded an age, based on lead-uranium methods, of 1,000-1,200 million years (see Nier, Thompson & Murphey, 1941; and Holmes & Smales, 1948).

As the pegmatite may be related to any of at least three granites, and the accuracy of the determination may have been affected by the deep weathering, this information is of small value, particularly as recent work has shown that the method used is unreliable where only very small quantities of uranium are present. Later, so far unverified, ages for Mary Kathleen uranium ore and Mount Isa lead ore are several hundred million years greater than for the monazite. A programme of granite sampling has recently been instituted for age determination purposes but no results have yet been obtained.

David (1932 and 1950) regarded the Mount Isa Shales and Corella Limestones as ?Older Proterozoic and the remainder of the Precambrian of north-western Queensland as Archaeozoic. A.G.G.S.N.A. officers (e.g. Nye & Rayner, 1940; Jensen, 1941a; and Honman, 1939) considered the Kalkadoon-Argylla series to be Archaeozoic, the Soldiers Cap series to be probably Upper Archaeozoic, the Mount Isa series to be Lower Proterozoic, the Lawn Hill series and beds in the Westmoreland area to be 'Newer Proterozoic' or Lower Cambrian, and the Constance Range beds to be Middle Cambrian.

The latest official published map of Queensland (published by the Queensland Department of Mines, scale 40 miles to an inch, 1953) shows the whole Precambrian succession of north-western Queensland as the Cloncurry Complex, of Precambrian age. The map of Australia published by the Bureau of Mineral Resources (scale 100 miles to an inch, 1952) differentiates the region into a belt of ?Lower Archaean, and the remainder Upper Archaean, except for the Proterozoic Pilpah Sandstone and Mount Quamby series (Quamby Conglomerate).

An attempt is made below to estimate the interval through which sedimentation has taken place. Figures for rates of sedimentation in different environments are difficult to obtain. Those available show a wide range for apparently similar rock types.

Reference to the correlation table (Table II) shows that we have the following succession by superposition; other units may or may not be contemporaneous:

Middle Cambrian Thorntonia Limestone
—Disconformity—
Camooweal Dolomite
Colless Volcanics
—Unconformity—
Mullera Formation
Constance Sandstone

—Major unconformity—

—Disconformity?—
Wollogorang Formation
Peters Creek Volcanics
Westmoreland Conglomerate
—Unconformity—
Cliffdale Volcanics

Lawn Hill Formation
Ploughed Mountain Beds
Myally Beds

Noakes (1956) discusses the age of the Camooweal Dolomite. He considers it to be Upper Proterozoic; but it may be Cambrian. The position of the Colless Volcanics is not entirely clear, but the lavas would take negligible time for extrusion. In the Northern Territory folded and flat-lying sediments and lavas overlying the Constance and Mullera Formations are more than 10,000 feet thick. These strata would have required at least 25,000,000 years for their formation. The depositional history is involved and probably contains several breaks.

The Mullera Formation and Constance Sandstone, assuming an average rate of sedimentation of 300-400 feet per million years, would require about 30,000,000 years to accumulate. We therefore have at least 50,000,000 years of sedimentation represented below the Camooweal Dolomite to the base of the Constance Sandstone, which is unconformably underlain, where exposed south of the Nicholson River, by the Lawn Hill Formation. Farther north the Westmoreland Conglomerate and lavas lie below the Constance Sandstone.

Even if the Camooweal Dolomite were Cambrian, the succession would extend down into the Upper Proterozoic. It is much more likely that the whole of the folded strata above the base of the Westmoreland Conglomerate are Upper Proterozoic. Probably the Cliffdale Volcanics and Nicholson Granite are Lower Proterozoic. If the Pilpah Sandstone is not contemporaneous with the strata in the Constance Range-Westmoreland area a further time interval must be allowed for sedimentation in the Upper Proterozoic. Noakes (1956) correlated the Constance Range and Westmoreland strata with the Adelaidean of South Australia.

An unbroken sequence of sedimentation, or volcanic activity, may be traced from the Leichhardt Metamorphics to the Lawn Hill Formation (assuming the contemporaneity of the Eastern Creek and Marraba Volcanics). So, despite the evidence for two periods of orogenic deformation, no justification exists for dividing the geosynclinal strata into Lower Proterozoic and Archaean, at least until more adequate age determinations have been obtained and agreement has been reached on the date of the base of the Proterozoic.

Such evidence as is at present available from age determinations indicates that some, or all, the rocks are near the base of the Lower Proterozoic and may be Archaean. However, the presence of highly organized colonial fossils in the Paradise Creek Formation and penecontemporaneous units (see next section) makes the placing of the whole succession in the Lower Proterozoic appear the most reasonable course of action. Any basement rocks may reasonably be regarded as Archaean.

Fossils in the Precambrian

Well-developed, and widespread, organic forms have been found in sediments of the western basin. Morphologically they display considerable variety. Some are similar to forms recorded elsewhere. Those in the Paradise Creek area have been briefly described and freely illustrated by Robertson (1960). Although regarded as of algal origin they have not been assigned to any phylum, but are referred to by the general term stromatolite. Known stromatolite localities are restricted to strata along, or west of, the Mount Gordon fault system. They are best known, and apparently most abundant, in the Paradise Creek Formation which has been mapped in some detail by de Keyser (1958, unpubl.). The best known locality, on a tributary of Paradise Creek, where tubular individuals form an extensive colony, is shown in Plate 22, figure 1.

Stratigraphically the stromatolites of the western basin range from the upper Judenan Beds to the upper part of the Paradise Creek Formation. Although commonly a fossil locality contains only one type of organism no systematic stratigraphic relationship to form is apparent, and one type may occur both stratigraphically above and below another.

Robertson (1960) has divided the stromatolites into three main groups and several sub-groups according to form. His main groups are 'cylindrical,' 'wavy laminae' and 'sub-hemispherical'. All forms consist of parallel, thin, layers of material with convex arcuate or shallow conical upper surfaces. In the 'cylindrical,'

or 'tubular', form superposed cones build up the 'tubes' which are from 1 to 4 inches across and up to 18 inches long, and are not joined laterally to nearby individuals (Pls. 22 and 23). The 'wavy laminae' type is generally smaller, and the laminae are continuous, forming sheets, or beds. The individual convex surfaces, as seen in cross-section, are joined by sharp, down-pointing troughs. Distance between troughs is between 0.2 and 2 inches. The 'sub-hemispherical' form consists of continuous laminae, as in the 'wavy-laminae' type but larger, arranged in roughly hemispherical surfaces about a common centre (Pl. 23, fig. 2). Adjoining hemispheres may be joined. There are some compound forms.

Most of the stromatolite colonies are biostromal in habit, but the 'sub-hemispherical' form appears to have been biohermal. Some of the 'sub-hemispherical' forms have branching tubes near their surface giving a crenulated surface. Specimens of these, three feet in diameter, have been observed and at lat. 19°24′30″S, long. 139°27′10″E. the organism appears to have grown upwards about ten feet, by development of successive, near-parallel, hemispherical surfaces. Adjoining sediments are slumped around the stromatolite.

All the stromatolites are associated with dolomitic strata, but many are now thoroughly silicified and internal structure is obliterated.

In addition to those in the western basin possible fossil organisms have been recorded in the Corella Formation in the Mary Kathleen uranium mine area. They consist of groups of small spheroidal structures (less than one inch diameter) along bedding planes. They are so metamorphosed and metasomatized that no internal structure remains and the organic origin is doubtful.

Collenia-like stromatolites, of a type widely recorded elsewhere, also occur in the Upper Proterozoic Woollogorang Formation.

PETROLOGY

The lavas have been described in their stratigraphic units, and petrographical descriptions of representative metalavas and metasediments appear in Appendix 1. As detailed petrological work on the basic igneous and granitic rocks is reported on elsewhere (Walker, 1958, unpubl.; Joplin & Walker, in press) this section is devoted mainly to their field and general petrological aspects.

Rock specimens and thin sections are in the Bureau of Mineral Resources and the Australian National University, Canberra (see Appendix I).

Hypabyssal Rocks

Acid Intrusives

Very few acid intrusives have been recognized. Many of the porphyritic acid lavas in the Leichhardt Metamorphics and Argylla Formation have been mapped by earlier workers as porphyry; but they are not intrusive (some porphyries were recognized, however, as probable flows).

In the Yaringa Metamorphics at lat. 20°25′10″S, long. 139°11′05″E quartz-feldspar porphyry crops out. It consists of euhedral phenocrysts of clear quartz (2mm.) and white feldspar (4mm.), equally distributed in a light grey aphanitic

groundmass that constitutes more than half of the rock. In thin section the quartz and microcline phenocrysts are seen to be corroded; some grains have a series of parallel fractures at right angles to small mica-filled fractures in the groundmass. Microcline is finely cross-hatched and simply twinned; it shows a fine and even brown clouding. The groundmass consists of very fine quartz and feldspar grains and contains lesser amounts of biotite and sericite as small flakes.

Some acid dykes have been recognized in the Argylla Formation at the Gunpowder Creek crossing of the old Dobbyn-Mount Oxide copper mine track at lat. 19°23′S, long. 139°53′E, and farther south. In addition quartz-feldspar porphyry occurs near the margin of the Ewen Granite. Possibly the dykes and marginal porphyry are genetically related to the granite.

A small intrusion of feldspar porphyry in the Eastern Creek Volcanics at lat. 21°23′10″S, long. 139°26′10″E, is shown in the Urandangi 4-mile Sheet area (Atlas, Pl. 6).

Another quartz-feldspar porphyry is associated with the Weberra Granite. The rock is brick-red and contains abundant phenocrysts of flesh-coloured feldspar (5mm.) and clear quartz (3mm.) in an aphanitic groundmass. Phenocrysts are euhedral, though some quartz crystals are corroded. Alteration prevents the precise determination of the feldspars, but both potash feldspar and plagioclase can be recognized. The groundmass is rusty-brown owing to alteration; it appears to consist mostly of quartz and feldspar.

Red quartz-feldspar porphyry dykes, many of which radiate from the red, dioritic phase of the Nicholson Granite, occur in the Cliffdale Volcanics, north of the Nicholson River. Some occupy easterly and south-easterly fractures in the volcanics. Other similar dykes are, like the Nicholson Granite, overlain by the Westmoreland Conglomerate, e.g., at lat. 17°38′10″S, long. 137°59′55″E (in the Northern Territory). These dykes appear to be related to the volcanics and granite which Jensen (1941a) believes to be co-magmatic. They antedate the deposition of the Upper Proterozoic strata.

Basic Intrusives

In the field, five groups of basic intrusive rocks associated with Lower Proterozoic country rock were recognized; they were distinguished by their field relationships and deformation. Four are designated on the maps by the symbols *db, ds, dl,* and *do,* and the fifth is left without a symbol. The map symbols represent the following rocks:

No symbol: Metamorphosed dolerite without any obvious relationship to regional structure. Most of the dykes form impressive swarms in the Leichhardt Metamorphics, Argylla Formation, and Mount Guide and Leander Quartzites.

db: intrusive metadolerite (mainly anastomosing dykes) in the Leichhardt Metamorphics and Argylla Formation. Outcrops are large, branched, and elongated north-south.

ds: metadolerite sills in the Kuridala and Staveley Formations.

TABLE V.

LOWER PROTEROZOIC BASIC INTRUSIVES

GROUP	MAP SYMBOL	ROCK-TYPE	TYPICAL FORMS	REMARKS
I	No symbol	Amphibolite	Dykes and sills or flows	Outcrops confined to Leichhardt and Yaringa Metas; older than Kalkadoon granodiorite.
II	No symbol and *db.*	Metadolerite & amphibolite	Dykes in swarms and anastomosing dykes.	Dykes most numerous in Leichhardt Metas, Argylla Fn, and Mt Guide Qte; also in Eastern Ck Volcs & contemporaneous & older formations. Probably related to Eastern Ck and contemporaneous basic vulcanicity. Anastomosing dykes *(db)* in Leichhardt Metas; possibly roots of dyke swarms at higher levels.
III	No symbol	Amphibolite & metadolerite	Dykes and sills.	Mostly dykes, including small swarms, in Corella and lower formations. Emplaced before first orogenic deformation.
	ds	Metadolerite	Sills and irregular intrusives.	Sills in Kuridala Fn; some in Staveley Fn and Answer Slate include irregular intrusives with broad outcrops. *'ds'* may belong to Group IV.
IV	*dl*	Dolerite and metadolerite	Dykes & small stocks, radial dykes & sill-like intrusives.	Small stocks and irregular-shaped intrusives widespread from the Soldiers Cap Fn to Eastern Ck Volcs. The radial dykes and sills only in Snake Creek area. Younger than first orogenic folding; intruded by granite. Alteration slight; contrasts with that of Groups I, II, III.
V	No symbol and *dl?*	'Greenstone' (metabasalt or metadolerite)	Irregular intrusives, sills, or flows.	Most in contact with Mt Isa Shale. Some possibly Eastern Ck Volcs. Relationships unknown, but before second orogenic deformation.
VI	*do*	Dolerite	Linear dykes.	Few widely scattered dykes in Kuridala and Corella Fns and Williams and Wonga Granites — confined to eastern belt.
VII	*do*	Dolerite	Linear dykes.	Few dykes, in folded Mt Isa Shale and Ploughed Mtn Beds — confined to western belt.

dl: dolerite or microgabbro dykes and stocks, some metamorphosed. They intrude folds and faults resulting from the first orogenic deformation.

do: little-altered linear dolerite dykes that cut country rock and granite in the eastern geosyncline, and Mount Isa Shale in the west.

Further petrological work (Walker, 1958, unpubl.) has shown that the basic intrusives can be subdivided on the score of their petrology, metamorphism and metasomatism, and field relationships, into seven groups, some of which cut across the field classification. Table V shows the groups into which they are now divided, and under which they are described below.

Table VI attempts to show the igneous events of the region — some of which were prolonged and complex — and their relationship to the tectonic and metamorphic history of the Lower Proterozoic. Into this table the basic intrusive groups can be fitted, though not entirely unambiguously. The first group antedates the Kalkadoon granodiorite; the second and third were emplaced before the first orogenic deformation, and the fourth after it but before the emplacement of the main Sybella Granite. The fifth group has been established to account for the 'greenstones' associated with the Mount Isa Shale and Judenan Beds; all that is known of its age is that it is older than the second orogenic deformation (the petrology of this group is on the whole that of flows rather than of intrusives). The sixth and seventh groups may be contemporaneous; but whereas the seventh group invades folded Mount Isa Shale and so is certainly younger than the second deformation, the sixth only invades older rocks of the eastern belt and the Wonga and Williams granites, and cannot therefore be accurately dated in this way.

Dolerite dykes intrude the Westmoreland Conglomerate and other Upper Proterozoic units north of the Nicholson River, in Queensland and nearby parts of the Northern Territory. No petrological work has been done on them. A dyke of unaltered dolerite on Mica Creek south of Mount Isa should probably be considered younger than any of the grouped rocks.

Group I: Intrusive amphibolites contaminate the Kalkadoon granodiorite, as Joplin (1955) has observed west of Bushy Park Homestead; the Leichhardt Metamorphics also contain some basic flows. Amphibolites in the Yaringa Metamorphics are probably intrusive; their age is not known, though they are metamorphosed and affected by the Sybella Granite.

Group II: As the basic igneous events cannot be traced back accurately before the formation of the eastern geosynclinal area, the oldest event studied in any detail is that which gave rise to the vulcanicity in the Eastern Creek Volcanics, and to related vulcanicity. Many of the dykes (no symbol) in the swarms, and the anastomosing dykes *(db)* probably served as feeders, and they are the main intrusives in Group II. They crop out mainly in the Leichhardt Metamorphics, Argylla Formation, and Mount Guide Quartzite. Some probably occur in the Eastern Creek Volcanics, but are not readily recognizable in air photographs because they lack tone contrast. A few have been recorded in the Leander and Ballara Quartzites. The intrusives are most conspicuous along the near-meridional zones from north of Dobbyn to east of Dajarra (the axis of the tectonic welt, Fig. 4),

and in a large anticline 25 miles south-west of Cloncurry; they form swarms of sub-parallel and intersecting dykes with a mean strike slightly east of north.

The dykes in the swarms are generally linear and their outcrops are up to 150 feet wide and 2 miles long. The anastomosing dykes are from 200 feet to 1 mile wide and up to 12 miles long. These dykes have a distinctive branched outcrop; a good example can be seen about one mile west of the Edna May copper mine. Dykes of the swarms intrude the Kalkadoon granodiorite; for example, near where the old track from Deighton Pass to the Kings Cross copper mine crosses the Wonga Fault (lat. 26°44′S, long. 139°35′E).

The outcrops of the dykes in the swarms commonly form depressions, and consequently, exposures are poor as soil and accumulations of fragmental rock debris cover most contacts. Tabular fragments have developed from the dispersion of close-jointed and sheared metadolerite outcrops. Outcrops of anastomosing dykes commonly have smooth, exfoliated dark surfaces spotted by aggregates, 5mm. across, of feldspar and quartz. They also have broken up, in places, into lenticular flinty rock fragments.

The metadolerite of the swarm-forming dykes is dark grey and medium-grained; it shows glistening facets of dark green amphibole and is flecked with light grains of feldspar. Thin sections consist mainly of hornblende (3mm.) and feldspar laths (2mm.), in the proportion 2:1. The texture is blastophitic, but small granoblastic patches have developed where alteration has been most intense. The green hornblende grains commonly show sieve structure and contain small quartz inclusions. Some feldspar laths have nibbled margins and are heavily clouded; the feldspar ranges in composition from basic andesine to oligoclase. Amphibole is developed along the cleavage traces of some laths. Small amounts of quartz, biotite, epidote, and chlorite occur. Quartz forms mesostasis and also interstitial grains that may have resulted from metamorphism. Opaque iron mineral is rimmed by, or associated with, sphene; slight alteration to leucoxene indicates that it is ilmenite.

Metadolerite from the anastomosing dykes is dark grey and fine-grained; it is spotted with irregular white patches of feldspar and quartz. The thin section shows relict feldspar phenocrysts (3mm.) and aggregates (6mm.) of quartz and feldspar, set in a groundmass reconstituted by metamorphism, of andesine (0.2mm.) and quartz (0.2mm.) grains, and roughly aligned columnar hornblende crystals (0.3mm.). Opaque iron mineral (0.1mm.) and sphene (0.4mm.) are also present. Veining by feldspar occurs in places.

The Group II basics have been affected mainly by a regional thermal metamorphism. Only at the immediate contact of the dykes with the host rock has stress contributed significantly to alteration and produced sheared margins. Some of the metadolerites are veined by aplitic and granitic rocks. Veining by feldspar resulted from regional metasomatism and the general hydrothermal alteration.

The basic intrusives in this group occur in formations beneath the Eastern Creek and contemporaneous strata. Walker (1958, unpubl.) has shown that the basic igneous rock in the dykes is, like that in the flows of the Eastern Creek Vol-

canics examined, a tholeiite. Events resulting in the formation of dykes and flows could, therefore, be reasonably related. Possibly the anastomosing dykes are the deeply eroded roots from which the flows were fed through the dyke swarms; much of the basic intrusive activity was along the tectonic welt. Carter has pointed out (pp. 72-3) the similarity in stratigraphical succession and field appearance between the basalts of the Eastern Creek Volcanics, Marraba Volcanics, and Soldiers Cap Formation, which led him to correlate the three formations and assume a common source area on the welt for all the flows. This would explain why intrusives are present in the Marraba Volcanics and Eastern Creek Volcanics but absent in the more distant Soldiers Cap Formation. But the petrology of the lavas in the three formations, though generally similar, is neither so identical nor so distinctive that their common source can be assured; and the dykes in the Eastern Creek and Marraba Volcanics may belong to the next group.

Group III: In Group III are the dykes (no symbol) and irregular-shaped intrusives (no symbol); they occur in the Corella and lower formations. Some of the intrusives in the Corella Formation may be sills. The concordant sheet-like bodies *(ds)* in the Kuridala Formation, and the coeval intrusives farther south-west in the Staveley Formation, belong either to this group or the next; White (1960) observed minor transgressive off-shoots which proved them to be sills. Furthermore, he was impressed by the absence of extrusive features and by their massive uniform texture.

Although the intrusives in this group are widespread, they are not as abundant as those in Group II. They are most noticeable in the Marraba Volcanics, Mitakoodi Quartzite, and Corella Formation, for in the lower formations their outcrops appear similar to those of Group II intrusives, because the rocks of both groups have the same metamorphic and deformational histories.

Dyke outcrops average about 50 feet in width. Many are lens-shaped or irregular. Those in the Corella Formation include numerous sets of parallel dykes; individual dyke outcrops measure up to 100 feet wide and $\frac{1}{2}$ mile long.

The sills in the Kuridala Formation dip at steep angles and few of their outcrops exceed 500 feet wide and 10 miles long; some are up to $\frac{1}{2}$ mile across.

Most outcrops of dykes, irregular-shaped intrusives, and sills are similar. They break either into blocks or small fragments according to the extent of their jointing. A few show spheroidal weathering. Strongly sheared and jointed outcrops disintegrate into tabular fragments. Margins of dykes are commonly sheared and weather deeply.

The basic intrusives in the Kuridala and Staveley Formations, and many of the other Group III intrusives, are metadolerite, produced by low-grade regional or stress metamorphism; but metasomatism has commonly altered those in the Corella Formation to ortho-amphibolites. Many of the ortho-amphibolites are difficult to distinguish from para-amphibolites, produced by the same process from lime-magnesia sediments of the Corella Formation (Walker, 1956, unpubl. and Walker et al., 1960).

TABLE VI ARCHAEAN AND LOWER PROTEROZOIC IGNEOUS AND METASOMATIC EVENTS

Event	Basic Intrusive Groups (see Table V)	Kalkadoon Granite	Ewen Granite	Wimberu Granite	Naraku Granite	Williams Granite	Sybella Granite	Wonga Granite	Weberra Granite	Nicholson Granite	Granitic Groups
Final L. Proterozoic orogenic deformation; granitic rocks emplaced.	•VI, •VII								Gp, Qp G^7	Gp Gr^8, A	V
Surprise Creek Beds and later sediments deposited: acid volcanics of Lown Hill F. (and Cliffdale Volcs?) extruded.	•VI •VII •V										
General hydrothermal activity		R, Pf •S Mg(sub)	Mg (sub)	•S	R, Pf •S	R, Pf •S Mg?	Pf •S (sub), Pm Mg^6	R, Pf •S Mg^6			
Post-tectonic granitic activity. •Lavas at top of Myally Beds extruded.	IV	•G^3 (sub) •S		•S	•S	G^5 •S	•G^3, •Gr (sub) •S	G^5 •S			IV
Regional metasomatism		•S		•S	•S	•S	•S (sub)	•S			
First L. Proterozoic orogenic deformation; granitic rocks emplaced.		Ma (sub) A(sub), •G^3(sub)		Ma^4 (sub) A^3	Ma^4, Ab A^3(sub)	Ma^4, Pm A^3	Pm •G^3, •Gr (sub)				III
•Lavas at top of Myally Beds extruded. Corella F. and contemporaneous sedimentation ended.	III										
Lavas in Corella F. and Marimo Slate extruded. Eastern Creek and contemporaneous volcanics extruded.	II, •V										
Granitic rocks emplaced.	•I	•Gr^1	Qp G^2								IIB
[2] Acid volcanics of Argylla F. extruded.											
Granitic rocks emplaced?		•Gr^1									IIA
[1] Acid volcanics of Leichhardt Metamorphics extruded.	•I										
Archaean granitic activity											I

KEY

G — Granite
Gr — Granodiorite
A — Adamellite
Mg — Microgranite
Ma — Microadamellite
S — Products of soda metasomatism, possibly including soda aplite and albitite

R — 'Red rock' including quartz-feldspar porphyroblastic and aplitic rocks.
Pf — Albite and microcline pegmatite.
Pm — Mica pegmatite.
Qp — Quartz-feldspar and granite porphyry.
Gp — Granophyre.

• — Alternative positions.
sub — subordinate amounts.
1-8, as affix to acid intrusives: common nos. possibly genetically related.

The metadolerites of low regional grade are typically green-grey with glistening facets of amphibole and fine white grains of feldspar. In thin section they consist mostly of amphibole (1mm.) and plagioclase (1mm.), the amphibole being twice as abundant as feldspar. The minor constituents are generally much smaller. The texture is blastophitic in many thin sections, but in the stressed rocks original textures have been partly or completely destroyed; the amphibole grains are elongated and aligned with lens-shaped aggregates of small granular feldspar, and subordinate quartz grains. Some of the amphibole grains mould on to one another, and some have splintery edges. Where jagged needles of opaque iron mineral occur they too conform with the alignment of the other mineral grains. The original feldspar grains are partly or completely sericitized, whereas most of the recrystallized feldspar is fresh. Both relict laths and reconstituted feldspar range in composition from andesine to oligoclase. Accessory minerals are quartz, biotite, sphene and, less commonly, epidote. The granular opaque iron mineral (0.5mm.) is mostly ilmenite.

The granulites are probably products of metamorphism and metasomatism (Edwards & Baker, 1954). Most of the rocks are massive, but in some the hornblende crystals are sub-parallel and the rocks have a poor schistosity, despite the equidimensional form of the plagioclase grains. Pyroxene, where present, forms both small, well-cleaved, stout crystals and xenoblastic grains. The grainsize ranges from 0.5 to 1 mm. Minor constituents include quartz, scapolite, sphene, opaque iron mineral, and apatite.

Granite has intruded Group III metadolerites both in the Selwyn-Kuridala area and elsewhere. Some metadolerites as well as being metamorphosed and metasomatized are veined by red soda feldspar of later metasomatic or hydrothermal origin (see p. 175); others, such as the ortho-amphibolites at Duchess, are impregnated with feldspar in flecks and stringers, giving them a migmatitic appearance.

Many of the Group III intrusives in the Corella Formation have been intensely altered, as have the calc-silicate rocks, and they have formed ortho-amphibolites, whose alteration is more extensive than that shown by the older Group II intrusives in the lower formations. But where they occur near one another in the lower formations, they show similar alteration.

The sills of Group III uniformly show low regional metamorphism. White (1960) considers that their remarkably uniform thickness at Kuridala, regardless of their position within the syncline, indicates that they were emplaced before folding. In support of this, he has noted that the intrusives consistently show marginal deformation, and metamorphism. Carter, on the other hand, believes that the intrusives in the Staveley Formation were intruded after folding because some intrusives to the south-west of Kuridala show apparent thickening in the noses of folds which he believes they intrude. The chemical properties of the sills (Walker, 1958, unpubl.) add support for this belief: chemically they are similar to the intrusives in the next group. If the sills were emplaced after folding, they fall into Group IV. Their precise age, however, is unresolved.

Group IV: This group consists of stocks, radial dykes and sill-like and small irregular-shaped intrusives. The intrusives (*dl*) are widely distributed in the eastern belt, but none has been recorded in rocks younger than the Eastern Creek Volcanics in the western belt. Most have been seen in the Corella, Soldiers Cap, and Argylla Formations, and in the Eastern Creek Volcanics. They have been studied mostly where metamorphic unconformities important to the geological history are found; for example, at Duchess, Dajarra, near Mount Isa, Longara, Rosebud copper mine, and the Soldiers Cap area. In the Snake Creek area the radial dykes are metamorphically unconformable with the regionally metamorphosed pelitic country rocks they intrude.

Where Group III and Group IV intrusives occur near one another, Group IV are identified by their lesser alteration, more massive outcrops, and structural relationships. They commonly occupy faults, and noses of pitching folds. The contrasting metamorphism between the rocks of the two groups marks the sites of numerous metamorphic unconformities. For example, at Duchess, the Group III intrusives in the Corella Formation are commonly closely jointed and have a granular texture (Pl. 30, fig. 1); they obviously have been more intensely metamorphosed and metasomatised than the slightly altered Group IV intrusives (Pl. 30, fig. 2). Some of them have become migmatitic. For these reasons Group IV intrusives are considered to be younger than the first main Lower Proterozoic deformation. Along the western part of the metamorphic belt the intrusives have distinctive banded outcrops, many of which are elevated above the country rocks and the older basic igneous rocks.

The intrusives are fine-grained to medium-grained dolerite and metadolerite. Outcrops are massive and jointed and blocky. Banding is common in large and small intrusives. Some of the large intrusives are gabbroic; these include multiple stocks, and some that contain rafts of intensely altered calc-silicate or para-amphibolitic rocks. The stocks are a few feet to half a mile in diameter.

In the stocks at Duchess the surface of the weathered metadolerite is brown, whereas the freshly broken rock has a resinous lustre and is scattered with pale, cloudy, green feldspar phenocrysts. Banding is prominent and distinctive: alteration along microfractures has given rise to bands rich in amphibole. The fractures are probably incipient joints in the rocks, as some of them intersect. The rocks have a blastophitic texture, and although they are mostly even-grained, a few large feldspar laths (2.4mm.) are visible. The thin sections consist mainly of labradorite laths (0.5 to 2mm.), relict pyroxene grains with uralitic margins (0.5 to 1.5mm.), biotite (0.2 to 0.5mm.), opaque iron minerals (up to 0.5 mm.), and scapolite. The iron minerals are present in minor amounts and the scapolite is rare. In these rocks feldspar is normally about twice as abundant as the ferromagnesian minerals. Some of the more basic rocks, however, contain roughly equal amounts of the feldspar and ferromagnesian minerals, as well as hypersthene and olivine, and have a gabbroic texture. They are probably accumulative, and related to the dolerite in the stocks.

The metadolerite shows low-grade to moderate-grade thermal alteration; biotite is more abundant in the moderate than in the low-grade rocks.

In the Snake Creek area, south of Cloncurry, 'sills' roughly conform with the strata in a north-pitching anticline and thus have concentrically arranged outcrops in the andalusite-garnet-mica schists of the Soldiers Cap Formation. Transgressing this structure are radial dykes, probably of the same age. Small irregular-shaped intrusives are also numerous and widespread in the Soldiers Cap Formation.

The 'sills' and dykes bulge and pinch along their length and crop out continuously over ten miles. Both dip at steep angles. The 'sill' outcrops are up to 500 feet and the dykes up to 100 feet thick.

The metadolerite in the Snake Creek area is similar in both the dykes and the 'sills'. It is dark, massive, fine and even-grained, and consists mainly of dark green hornblende and feldspar. Amphibole is about twice as abundant as feldspar. Thin sections of metadolerites show blastophitic texture, except in areas of local deformation. The amphibole is green hornblende, which forms individual grains and aggregates, up to 1mm. long. In the undeformed rocks plagioclase occurs as laths (up to 2mm.); the deformed rocks are partly or completely reconstituted. The recrystallized feldspar is fresh, whereas much of the original feldspar is extensively sericitized. Relict laths of plagioclase show normal zoning, with a range in composition from labradorite to oligoclase. The reconstituted feldspar is generally oligoclase or andesine. The minor constituents are opaque iron mineral, quartz, and less commonly epidote. Some of the opaque iron mineral is granular or skeletal, and is associated with sphene.

Both the 'sills' and the dykes show similar low grade, mainly thermal, metamorphism, and are probably coeval. Local shearing and faulting have produced hornblende schist.

In the Duchess, Kuridala, and Snake Creek areas the metadolerites are locally impregnated with red feldspar produced by regional metasomatism or general hydrothermal alteration (p. 175); they are also veined by aplitic granite. In zones of mineralization, they show hydrothermal alteration. Although some Group IV metadolerite contains scapolite, scapolitization has not been as intense as in metadolerites and amphibolites of Groups I and III.

Group V: Intrusives or flows (no symbol and *dl?)* occur in association with the Mount Isa Shale and Judenan Beds; they have been referred to by other workers as 'greenstones', along with chlorite schists of sedimentary origin. The 'greenstones' crop out west of the Black Star orebody, and have been encountered in mine drill holes, near and south of the mine. Those in the Judenan Beds were found in No. 5 Tailings Dam Tunnel.

Other bodies of low-grade rocks of basaltic appearance occur within higher-grade rocks, one mile east of Dajarra, and another in the Carioca copper mine area at lat. 20°35′10″S, long. 139°53′30″E. These occurrences are probably relics of basaltic rocks erupted after the surrounding rocks were regionally metamorphosed.

Undeformed basic rocks of this group from the Mount Isa Shale, examined in thin section, show abundant feldspar laths (0.5mm.), mostly albite, between which chlorite, sericite, calcite, epidote, opaque iron mineral, and, in some cases, biotite and amphibole occur. The texture is intergranular. Some rocks are porphyritic, with feldspar phenocrysts up to 3mm. long.

The deformed basic igneous rocks have become greenschists, which are widespread and characteristic of brittle-zone deformation. They consist mainly of chlorite, albite, and lesser amounts of quartz and opaque iron mineral.

About four miles slightly west of south of Mount Isa, basaltic rocks crop out in the Biotite lease, between Lena and Mica Creeks. Two opinions are held on the origin of these. Knight (1953) and E. K. Carter have mapped them as infaulted blocks of Eastern Creek Volcanics, and Carter extends this explanation to include the 'greenstones' near the Mount Isa Mine. On the other hand, Rheinhold (1957, unpubl.) mapped the many basaltic outcrops in the Mica Creek area as conformable with the grain of the country, though some appear to be outcrops of very broad lenses.

The relationships of the 'greenstones' to the Mount Isa Shale are therefore in doubt. Carter has suggested (p. 110) that their present position is due to faulting during and after deposition of the Mount Isa Shale. On the other hand, the basic igneous rocks could be flows within the Mount Isa Shale and Judenan Beds, or some could be intrusives. In any case, they have been involved in the deformation of the Mount Isa Shale and are of a comparable metamorphic grade. The structure and the texture of the igneous portion of the 'greenstone' are typically basaltic.

Group VI: This group consists of a few widely separated linear dykes, which, with Group VII intrusives, are marked *do* in the maps. Because some of the intrusives into country rocks and granite of the eastern geosyncline are somewhat deformed and altered, they have been provisionally separated from the unmetamorphosed intrusives of Group VII.

Dolerite dykes of Group VI have been observed near and south-east of Kuridala, and near and south of the Mary Kathleen mine. The dyke 1 mile south of Kuridala cuts the sills (*ds*) in the Kuridala Formation at right angles and intrudes the Williams Granite to the east of Kuridala. It occupies a series of progressively stepped east-west joints, and is up to 100 feet wide and from 8 to 10 miles long. Dykes farther east of Kuridala invade the Soldiers Cap Formation. The dykes at, and near, the Mary Kathleen mine strike roughly north-east; they intrude the Corella Formation and the Wonga Granite. Farther south-south-east they occur at the Rita uranium lease and at Mount Burstall.

Exposures are of spheroidally weathered brown boulders up to a foot across; the boulders break with a conchoidal fracture to reveal light grey dolerite. Small black grains of pyroxene and light facets of feldspar can be recognized. The thin section has an average grainsize about 1mm. It consists mostly of ophitically arranged pyroxene (1mm.) and feldspar (1mm.), with lesser amounts of a serpentine-like mineral, quartz, and opaque iron mineral (0.5mm.). Light and dark

minerals occur in the ratio of 3:2. The pyroxene is mostly colourless augite but includes rare grains of pigeonite. The small amount of fresh feldspar that remains is labradorite. Although ilmenite is abundant in places, sphene is rare; other accessories are quartz, chlorite, and epidote. Extensive sericitization of the feldspar and the development of uralite from pyroxene are probably the result of strong autometamorphism.

The age of the dykes in this group cannot be conclusively established. The alteration of most dykes can be attributed to autometamorphism; but some, at Mary Kathleen and Mount Burstall, are slightly deformed and veined by soda feldspar (Walker, 1956, unpubl.). The veining could be due to granite action during the second Lower Proterozoic orogeny, but it could equally well be attributed to Upper Proterozoic or Lower Palaeozoic tectonic movements.

Group VII: The intrusives in this group are single linear dykes *(do)* that invade the Mount Isa Shale and other folded rocks.

Knight (1953) recorded two east-striking dolerite dykes in the Mount Isa Shale, 3¼ and 4 miles north of Mount Isa, and a third farther north-east which strikes a little east of north, only slightly transgressing the bedding. Another east-striking dyke occurs in the 'Undifferentiated Lower Proterozoic' rocks, east of the Calton Hills track, 28 miles north of Mount Isa.

The dykes in the Mount Isa Shale are up to 50 feet wide and 1,000 feet long. They are thoroughly weathered and crop out as rounded, buff-coloured boulders. Weathered feldspar laths and a pale green mineral can be recognized in hand-specimen. The thin section of the rock is even-grained (1.5mm.) and shows patches of relict ophitic texture. It consists mainly of sericitized feldspar (1.5mm.), biotite, opaque iron mineral (1.5mm.), quartz (0.5mm.), and rare sphene. The feldspar is too much altered for its composition to be determined. Little trace remains of the original ferromagnesian minerals, which have been replaced by pleochroic gold to green-brown biotite and less commonly by chlorite. Quartz forms small interstitial grains. The rock is a much weathered dolerite; however, some of its alteration may have been caused by slight hydrothermal activity.

A dyke in the Ploughed Mountain Beds, in the Fiery Creek area 28 miles north-west of Mount Oxide copper mine, may also belong to this group. A specimen from the dyke is a dark basic rock whose minerals cannot be recognized in hand specimen. The thin section is porphyritic and consists mainly of sericitized feldspar laths (1mm.) and phenocrysts (4mm.), and chlorite derived from feldspar and ferromagnesian minerals. A few relict pyroxene crystals (3mm.), together with the feldspar laths, form ophitic texture. The grainsize of the base ranges from 0.5 to 2mm. Calcite is a common secondary mineral and there are a few interstitial grains of quartz. Opaque iron mineral is a minor constituent, forming blades up to 1mm. long.

Ungrouped: Some of the unaltered dolerite dykes, like that found ¼ mile south of the Mount Isa-Oban road crossing on Mica Creek, may be younger than Lower Proterozoic. The dolerite is very fresh and consists mainly of labradorite,

augite, hypersthene, and opaque iron mineral, and has ophitic and porphyritic textures.

Plutonic Rocks

Nine bodies of granite have been formally named: the Kalkadoon, Ewen, Wimberu, Naraku, Williams, Sybella, Wonga, Weberra, and Nicholson Granites. Their distribution is shown in Figure 13.

Most of the granites are composite, containing rocks of different ages and compositions; indeed, although all the bodies are designated 'granites', petrologically they are not all true granites. Their petrological and age relationships are discussed below, after the consideration of each as a geographical entity.

Kalkadoon Granite

The name is derived from the Kalkadoon Copper Mine. The granite crops out in the Dobbyn, Cloncurry, and Duchess 4-mile Sheet areas (Atlas, Pls. 7, 8, and 9).

The Kalkadoon Granite crops out discontinuously from St Pauls Creek, 10 miles north of Dobbyn, to Sulieman Creek, 20 miles south of Dajarra, a distance of about 160 miles. In the north the average width of outcrop is 4 miles, but the southern end of the mass is considerably wider, and increases from 10 miles at Kurbayia railway siding to 25 miles at Dajarra.

The Granite is bounded mostly by the Leichhardt Metamorphics, but in the south-eastern corner by the Corella Formation. It intrudes the Mount Guide Quartzite 10 miles west of Butru siding and the Argylla Formation near the Crusader mine. At Sunday Gully it is overlain by the Surprise Creek Beds, but also in this area Jensen (1940) has observed that a granite invades them, a fact that can only be explained by recognising that the mass is a composite one.

Granodiorite is the main type in the composite mass; minor intrusions are of granite, adamellite, and, to a lesser extent, microadamellite, potash-rich microgranite, pegmatite, aplite, and albitite.

Most of the *granodiorite* is fairly uniform in mineral composition, although relative mineral abundances vary somewhat over its length, and in places it is strongly foliated. In some places it is locally hybridized by basic material, for example west of Bushy Park Homestead, where it is also strongly dislocated (Joplin, 1955, p. 56). The granodiorite is coarse-grained and commonly porphyritic. At the southern end of the body, the phenocrysts are of white or grey feldspar in a grey groundmass, whereas in the northern part pink feldspar forms both phenocrysts and part of the groundmass. The phenocrysts measure up to 5 cm. long; they are of microcline and plagioclase, and are set in a hypidiomorphic granular groundmass of quartz, plagioclase, microcline, and biotite, whose grain-size ranges from 0.5 to 6mm. Some of the plagioclase phenocrysts are subhedral; others are corroded and may be enclosed by microcline. The microcline is generally fresher than plagioclase, but both are turbid from alteration and contain sericite flakes. The microcline also is slightly albitized in places. Quartz grains have undulose extinction and may be partly granulated, whereas feldspar

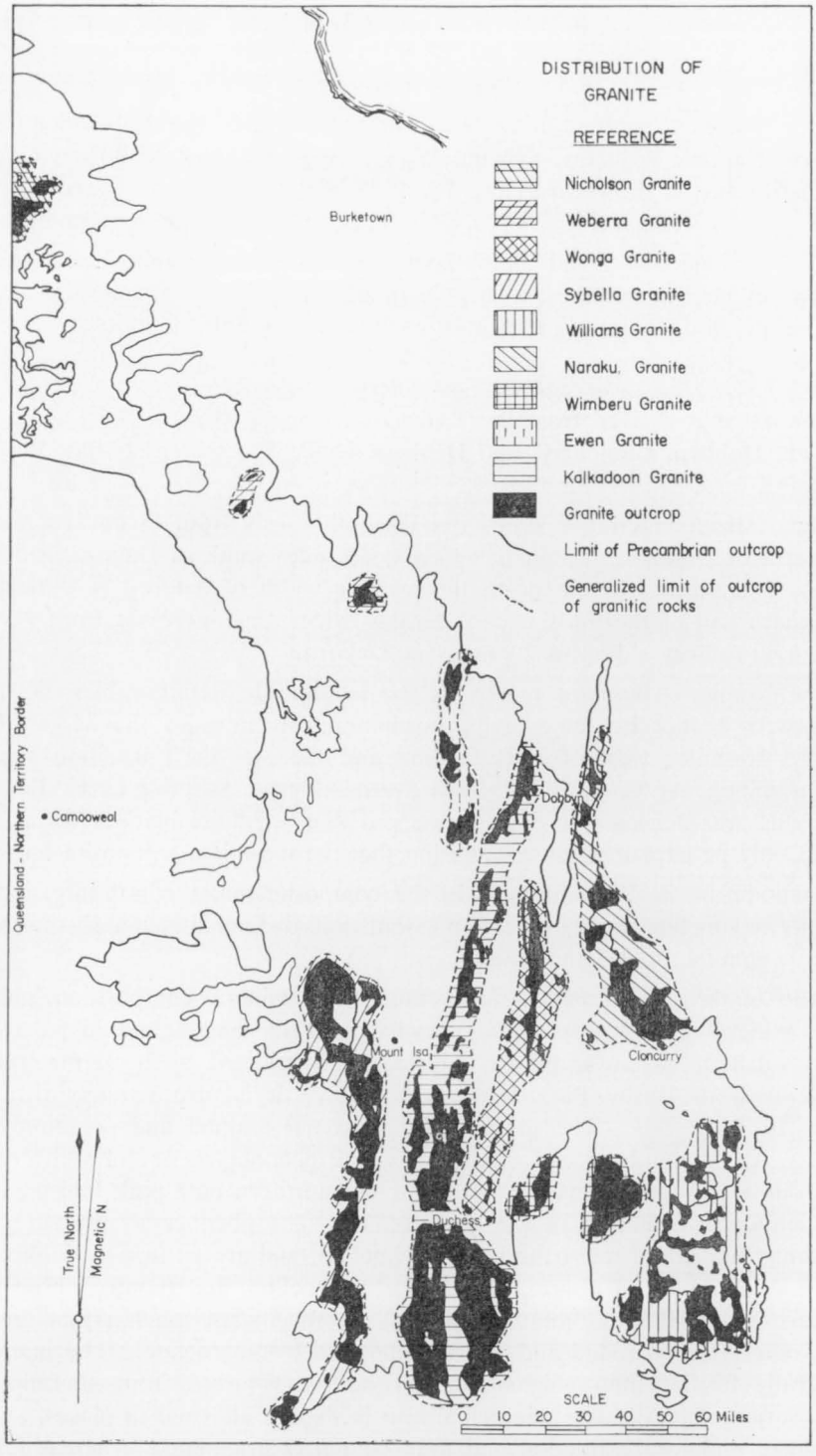
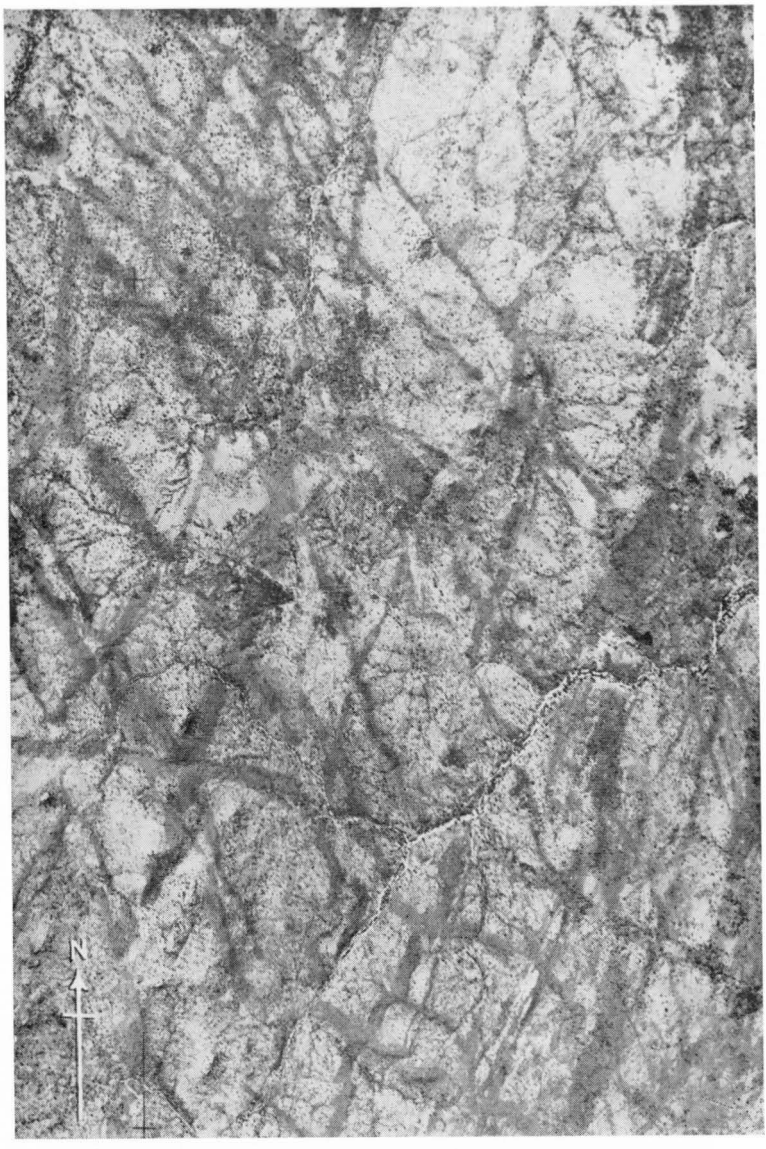


Fig. 13. Distribution of named granite bodies



Metadolerite dyke swarm in the Leichhardt Metamorphics, north of Mount Isa-Cloncurry road, about 18 miles from Mount Isa. Scale about 1:24,000.

—Air photograph by Adastra Airways Pty Ltd, for the Surveyor-General of Queensland.

N

Fig. 1. Xenoliths in the Kalkadoon Granite, east of Rifle Creek Dam.

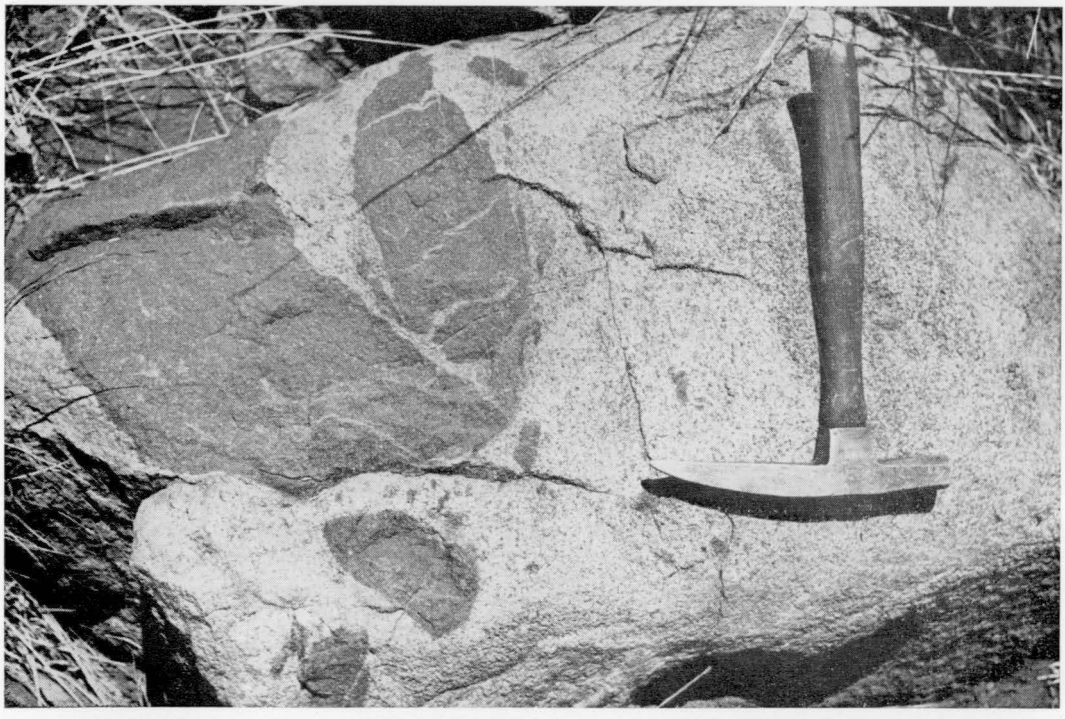


Fig. 2. Xenoliths in fine-grained Sybella Granite, about 13 miles north-north-west of Mount Isa.

—Photograph by Dr G. A. Joplin.

Fig. 1. Large porphyroblasts of microcline in granitic gneiss at the eastern margin of the Sybella Granite, 2 miles south of Mackellars Well.

Fig. 2. Fine-grained granite cutting the older coarse-grained porphyritic granite. Wonga Granite south of Cleanskin Creek.

Photographs by Dr G. A. Joplin.

Fig. 1. Relict structure shown by orientation of feldspar phenocrysts in the Sybella Granite, 3½ miles west-south-west of Gap Bore, Yaringa Creek area.

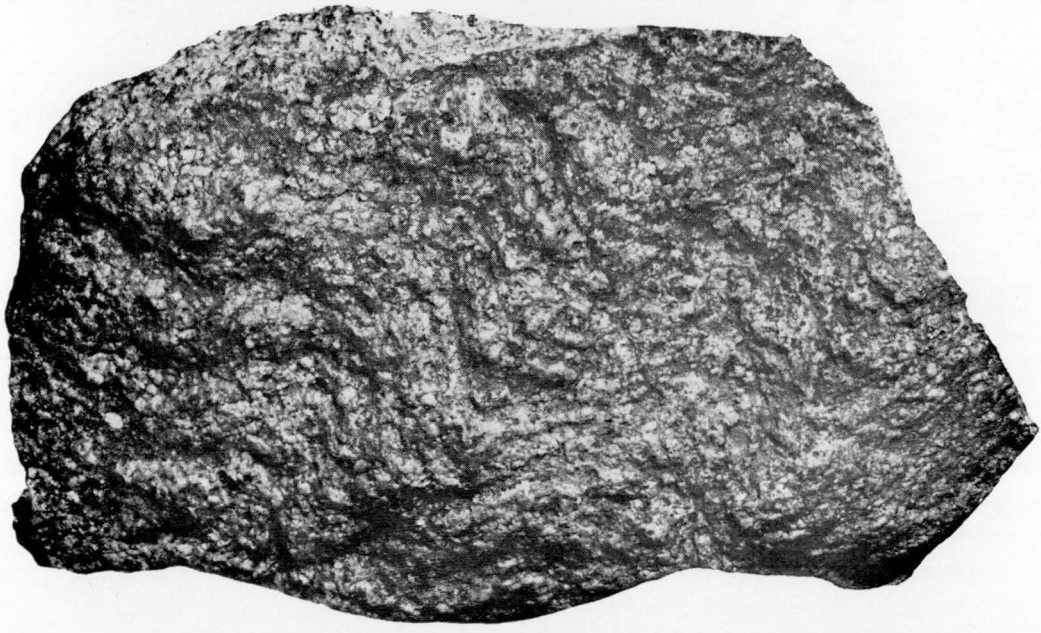


Fig. 2. Relict sedimentary crenulations in Wonga Granite, 10 miles east of the Lady Fanny copper mine. Natural size. Note that the banding in this rock is produced by layering of leucocratic and melanocratic minerals, in contrast to the crystal orientation in the figure above.

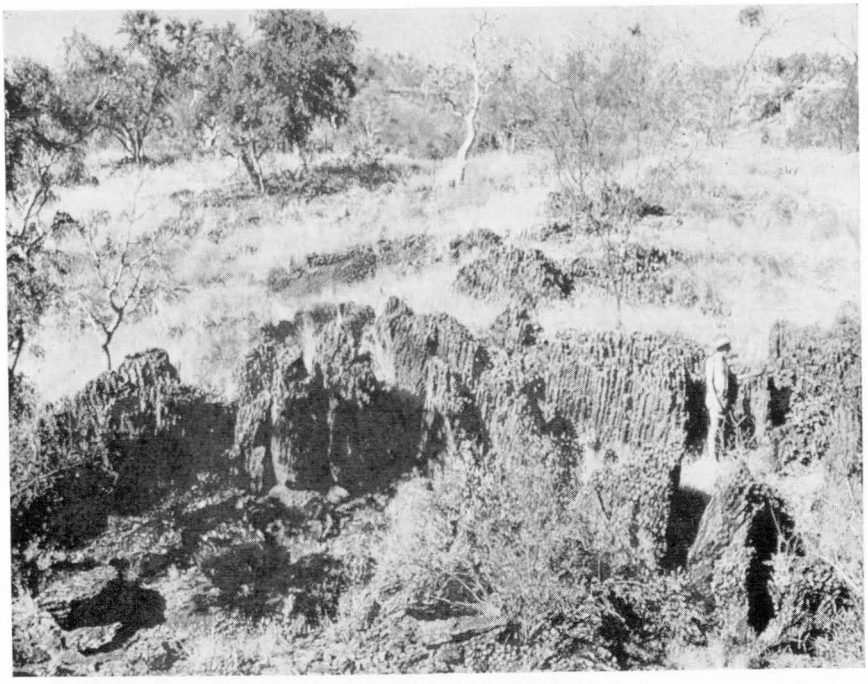


Fig. 1. Colonial stromatolites in the Paradise Creek Formation, Paradise Creek area.

Fig. 2. 'Cylindrical' stromatolites near Paradise Creek, plan view; part of colony shown above.

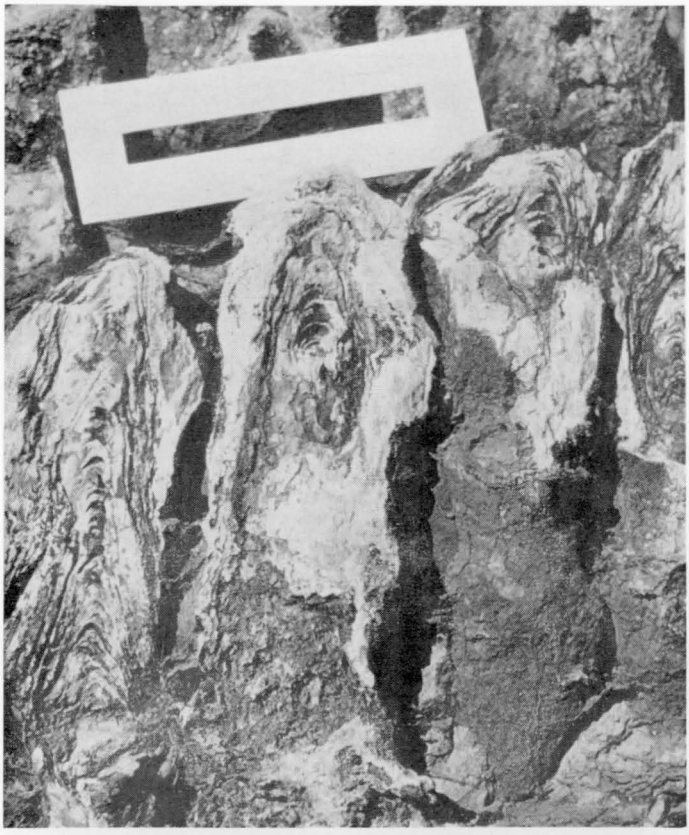
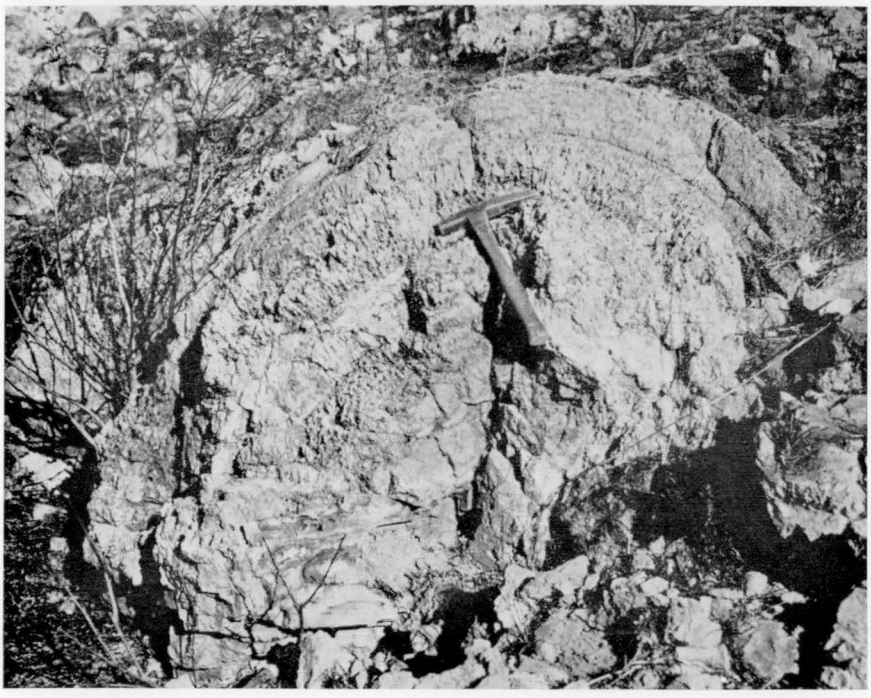


Fig. 1. Close-up view of individual 'cylindrical' stromatolites. Protractor is 6 inches long.

Fig. 2. Compound hemispherical stromatolite, west side of Pandanus Creek, about one mile from junction with Fiery Creek.



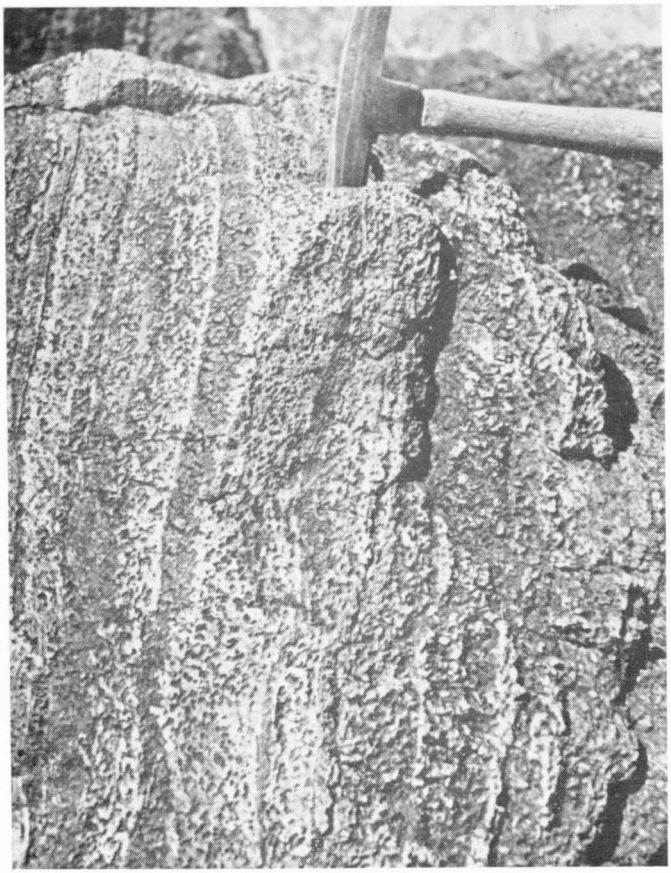
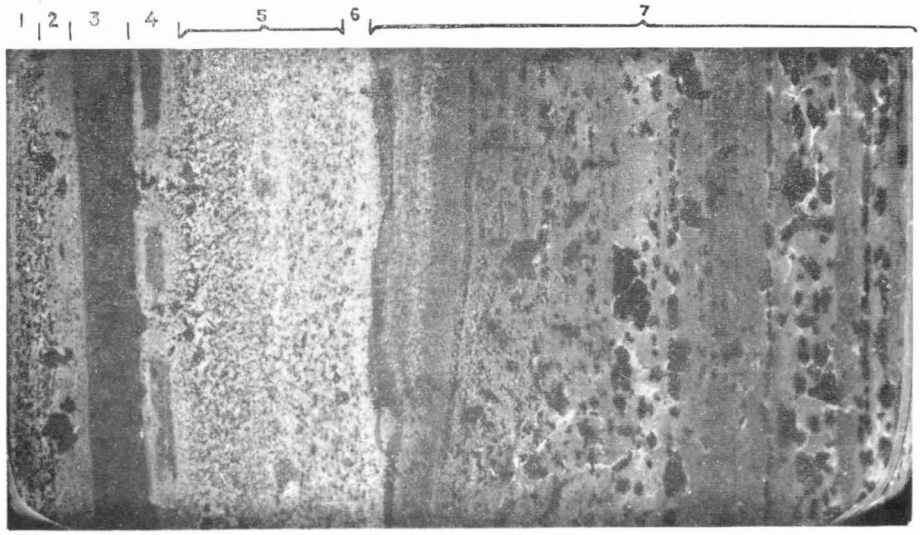


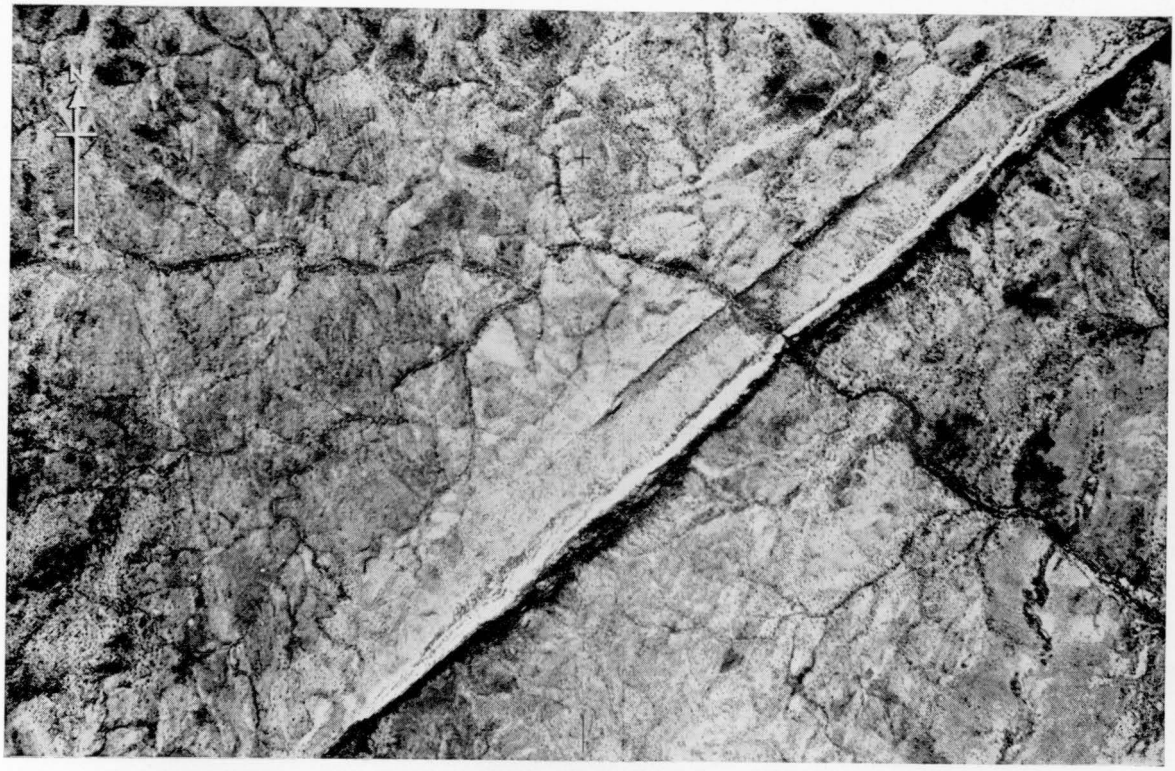
Fig. 1. (Left) Granulite in the Corella Formation, near the Dugald River silver-lead-zinc prospect.

Fig. 2. (Below). Banded metamorphic rock in the Corella Formation, from the upper Cattle Creek area. Petrological determination by Dr G. A. Joplin.

Band 1. Quartz-mica-garnet schist with abundant magnetite and scapolitized feldspar.

2. Same as 1, with large porphyroblasts of staurolite.
3. Same as 1, with larger proportion of magnetite.
4. Lighter bands have little magnetite and feldspar; the darker contain much scapolitized feldspar. Garnet and mica present in both.
5. Coarser mosaic of same minerals as 4. Staurolite is absent and dark spots are concentrations of magnetite and micas.
6. Pink garnet band with some quartz and trace of altered feldspar.
7. Quartz garnet mica, staurolite and magnetite. Turbid feldspar is almost absent. The darker bands contain concentrations of euhedral magnetite crystals and the larger dark areas are ragged porphyroblasts of biotite and/or staurolite. Differences in grain-size produce further banding but without marked differences in mineral composition.





Fountain Range Fault, one of the prominent strike - slip faults of the region. The quartz reef and silicified fault material stand up to 700 feet above the general level of the country. Mount Philp iron deposit appears in the lower right of the photograph. Scale about 1:35,000.

—Air photograph by Adastra Airways Pty Ltd, for the Surveyor-General of Queensland.

Fig. 1. Folding in the Soldiers Cap Formation, east of Cloncurry. Calc-silicate rocks of the Corella Formation unconformably overlie the Soldiers Cap Formation in the top left of the photograph. Scale about 1:75,000.

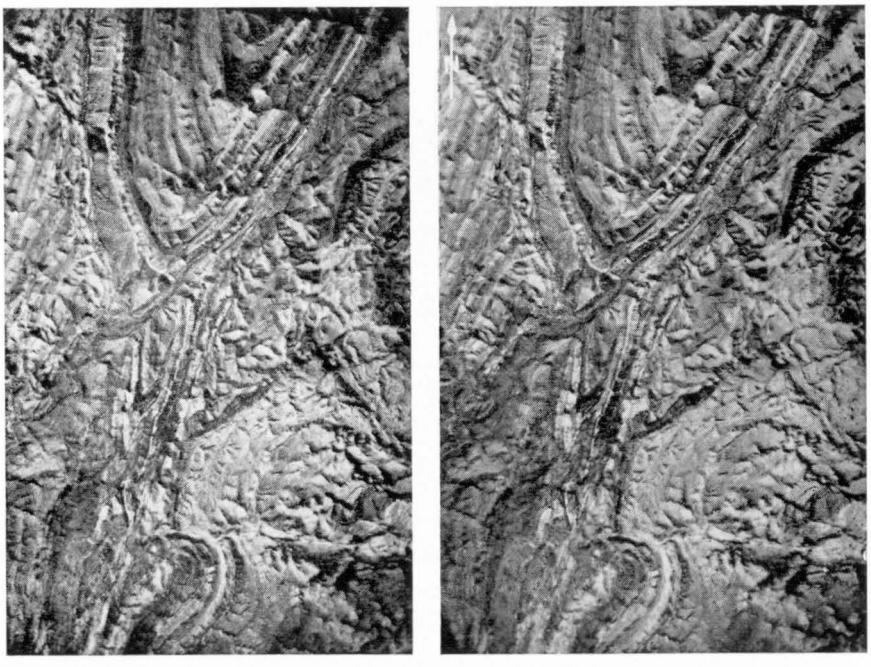
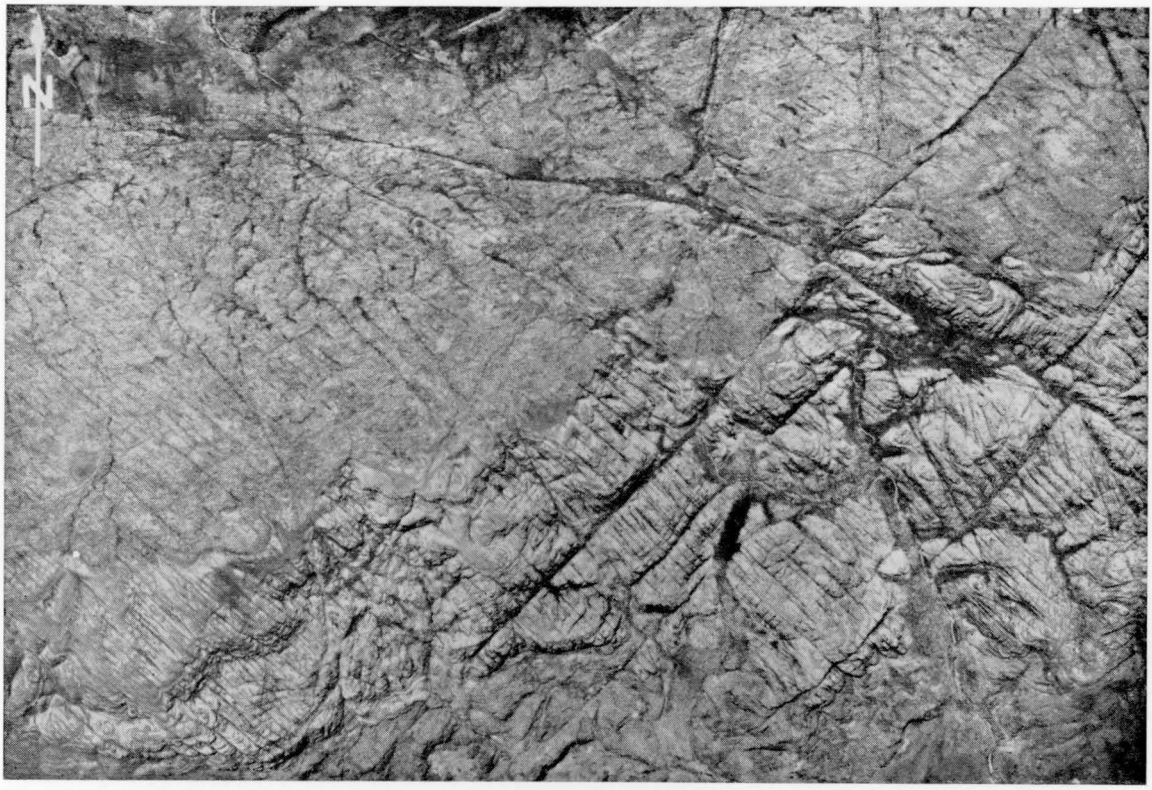


Fig. 2. Stereoscopic pair of air photographs showing folding in the Lower Proterozoic strata about 16 miles north-north-west of Mount Oxide. Mount Gordon Fault may be seen in the centre of the photograph. Stratigraphical units involved are the Myally Beds, Ploughed Mountain Beds, and Gunpowder Creek Formation. Scale about 1:120,000.

—Taken from portions of official R.A.A.F. photographs: not to be reproduced without authority.



Air photograph showing jointing in the Westmoreland Conglomerate. Movement has taken place on some joints. Scale about 1:75,000.

—Taken from portion of an official R.A.A.F. photograph: not to be reproduced without authority.

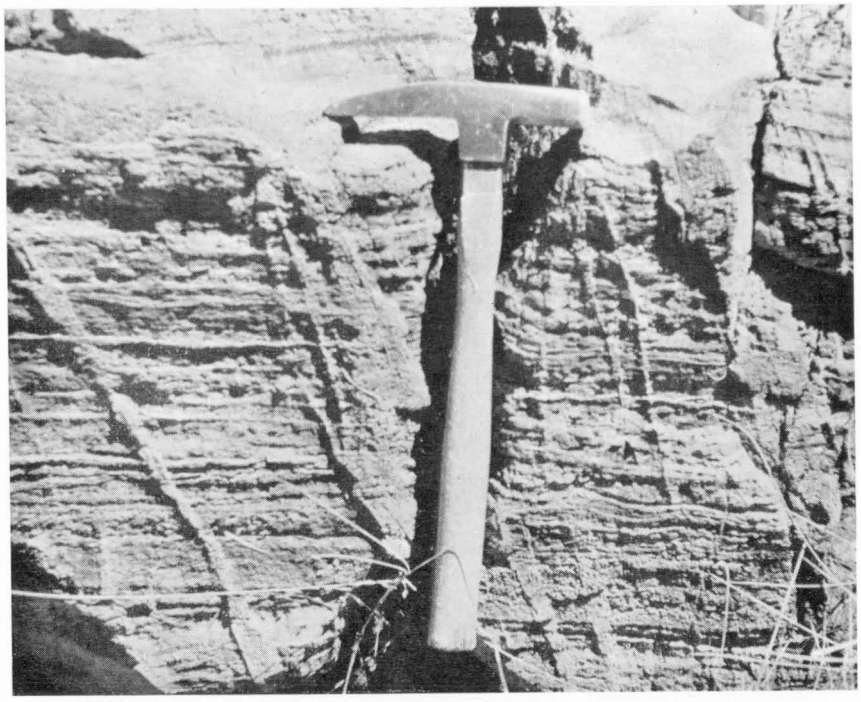


Fig. 1. Red soda feldspar replacement veins cutting finely banded calc-silicate hornfels of the Corella Formation. About 4 miles north of the Trekelano copper mine.

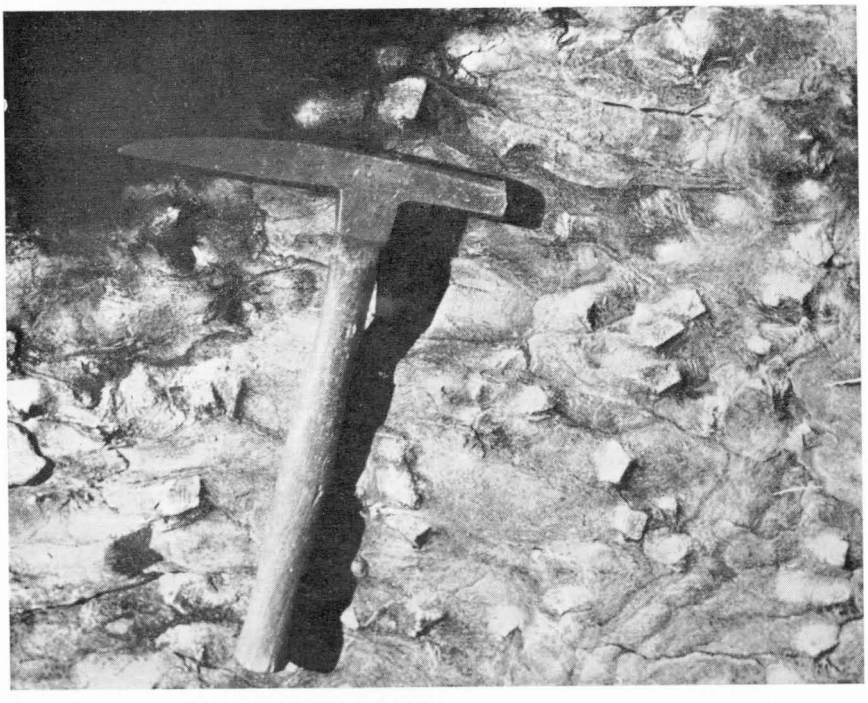


Fig. 2. Crystals of andalusite in andalusite-garnet-mica schist, Soldiers Cap Formation, about 2 miles south-west of Mount Norna.

—Photograph by Dr G. A. Joplin.

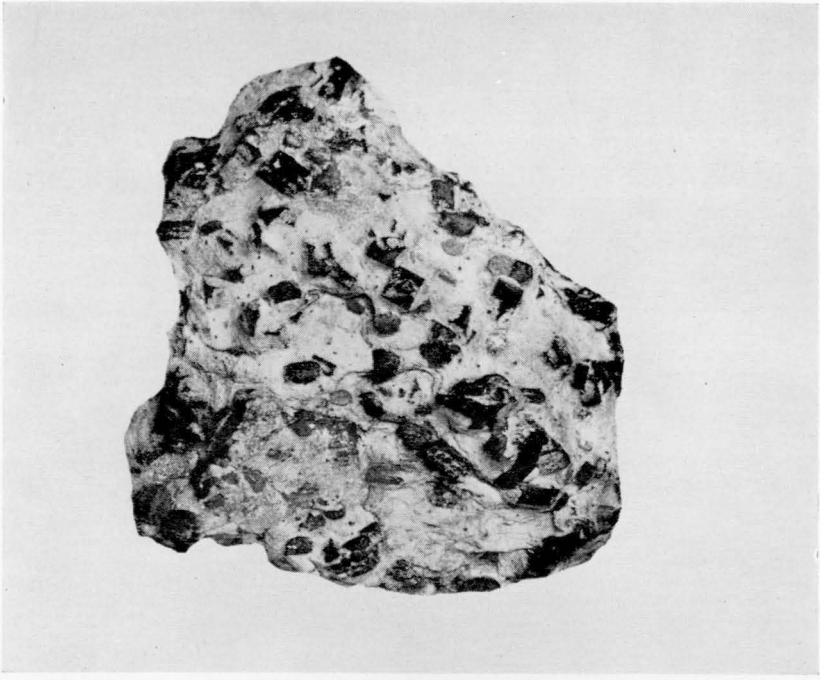


Fig. 1. Staurolite, biotite, and garnet porphyroblasts set in a fine micaceous base. From Corella Formation, upper Cattle Creek area.

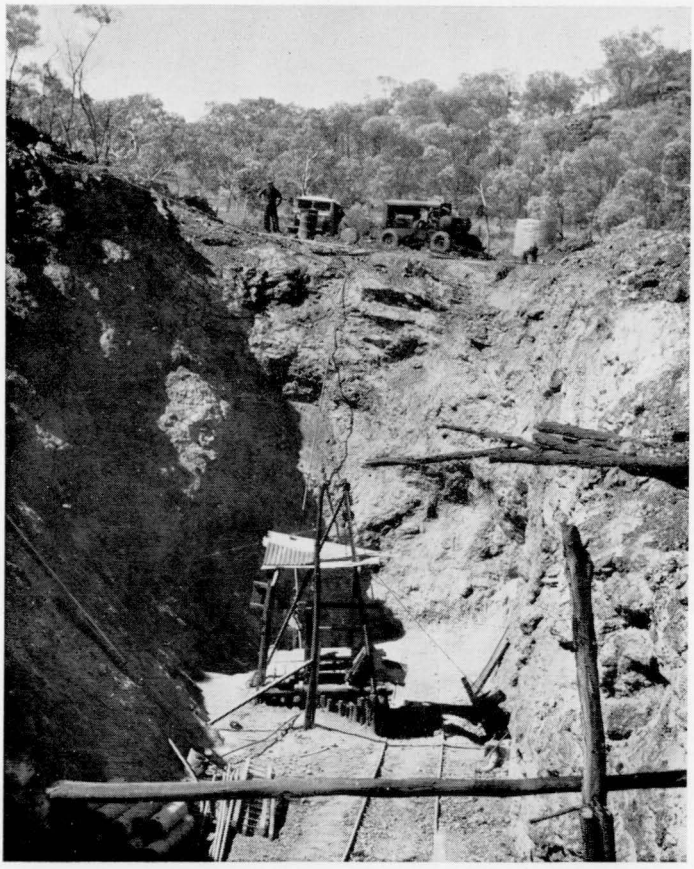


Fig. 2. Lady Annie copper mine, Paradise Valley, 1957. An example of a small mine of the region.

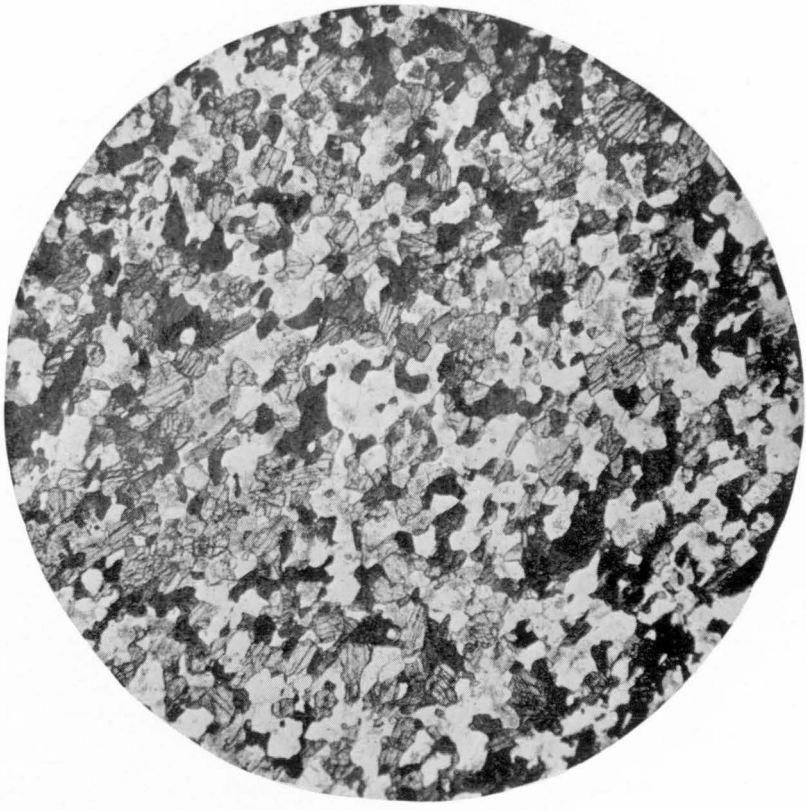


Fig. 1. Pyroxene-plagioclase-hornblende granulite with stout grains of pyroxene set amongst plagioclase and darker hornblende grains. The plagioclase shows patchy clouding. Accessory minerals are scapolite, apatite, sphene and opaque iron oxide. Plane-polarized light, magnification X 27. Specimen R.7080. Near Duchess.

Fig. 2. Medium-grained dolerite, mainly of tabular labradorite crystals and slightly uralitized pyroxene. Small inclusions form parallel trains along the cleavage, particularly of the central lath. Accessory minerals are quartz, biotite and opaque iron oxides. Crossed nicols, X 27. Specimen R.7249. Near Duchess, within 50 feet of specimen R.7080 above.

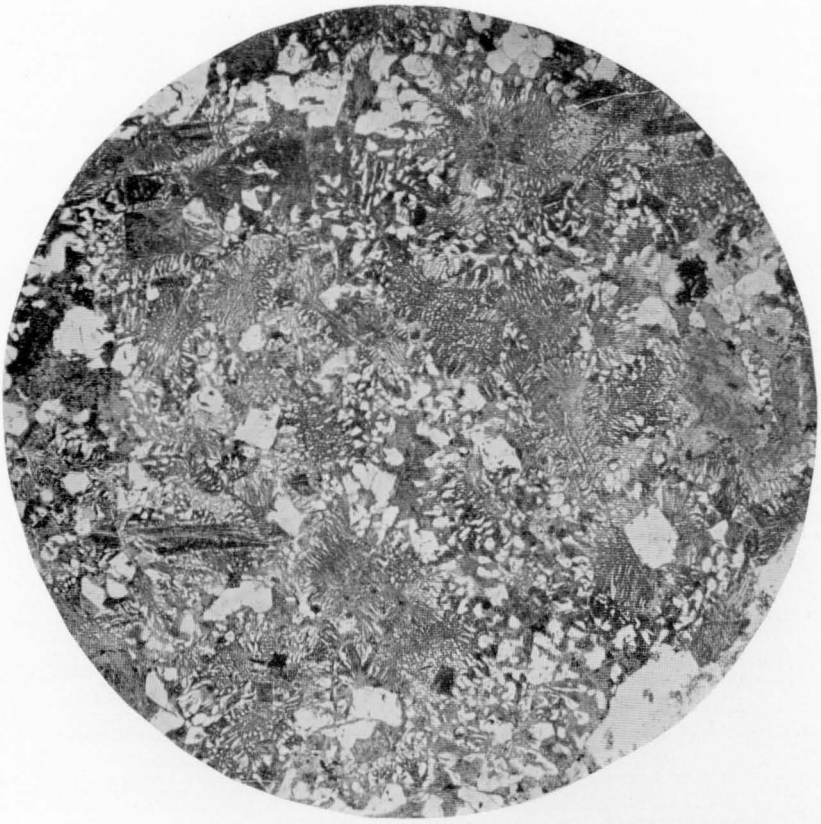


Fig. 1. Granophyre showing texture; quartz and feldspar phenocrysts are optically continuous with the corresponding minerals in the groundmass of intergrown quartz and feldspar. Plane-polarized light, X15. Specimen R.3225. Eastern margin of Weberra Granite.

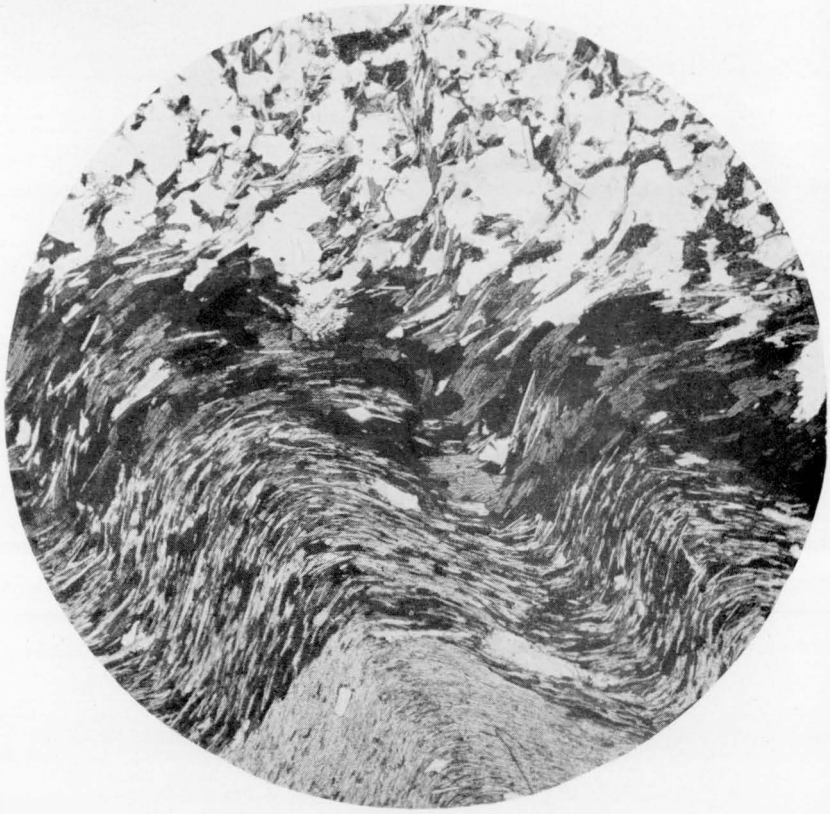


Fig. 2. False-cleaved quartz-biotite-muscovite schist. Biotite and muscovite form alternate bands. Plane-polarized light, X 15. Specimen R.6927, Soldiers Cap Formation.

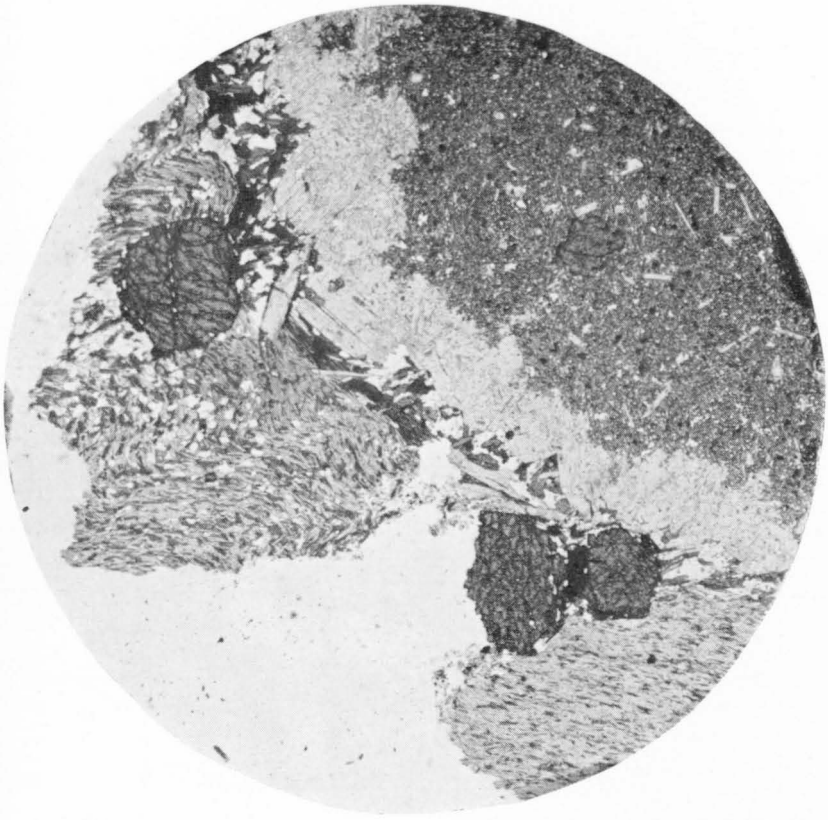


Fig. 1. Garnet-andalusite-biotite-muscovite schist. A large andalusite grain, with abundant small inclusions, is rimmed by muscovite flakes. The dark crystals are of garnet and are surrounded by false-cleaved bands of muscovite and biotite. Plane-polarized light, X 15. Specimen J.680. Soldiers Cap Formation.

Fig. 2. Staurolite and garnet porphyroblasts in a base of quartz, biotite and muscovite. The staurolite has a narrow outer zone free of inclusions. Plane-polarized light, X 15. Specimen R.6928, Corella Formation, upper Cattle Creek area.

Fig. 1. Cordierite-anthophyllite schist, showing radiating sheaves of anthophyllite and poikiloblastic cordierite, with abundant inclusions of quartz, feldspar and opaque iron mineral grains. Plane-polarized light, X 15. Specimen R.6935. North-west of Mary Kathleen airstrip.

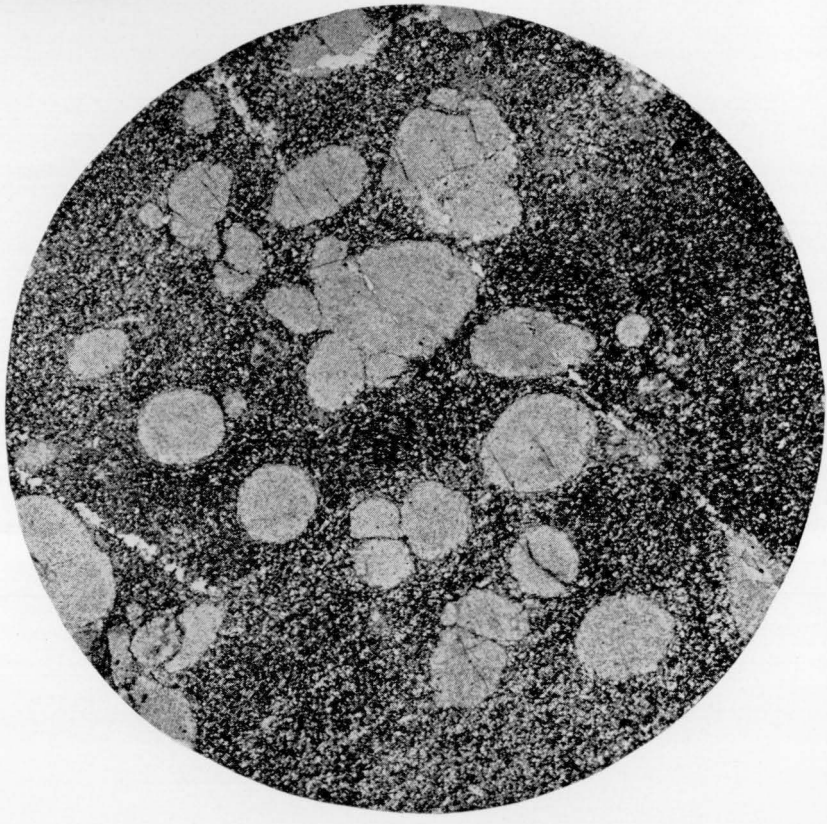


Fig. 2. Scapolite spotting a low-grade calc-schist of small biotite flakes and fine calcite and quartz grains. Plane-polarized light, X15. Specimen R.6932. Charley Creek Formation.

shows no signs of stress except for a few bent twin lamellae. Biotite (2.5mm.) is the main dark mineral, and small amounts of hornblende are present in some thin sections. Clots of biotite pseudomorph hornblende; biotite flakes are generally arranged linearly. Accessory minerals are muscovite, apatite, sphene, and opaque iron minerals. Secondary muscovite and epidote may be found in altered feldspar, and epidote also replaces hornblende or biotite.

Modal analysis shows that plagioclase and quartz each form 30% and microcline 20% of the rock. The remainder is essentially biotite, with some hornblende, sphene, and apatite, and rarely epidote, muscovite, and opaque iron mineral.

Granite intrudes the Mount Guide Quartzite near Broadhurst Bore at lat. 21°23′50″S, long. 139°34′30″E; it is not unlike that observed 12 miles south-south-east of Mount Isa and in the Dobbyn area. A fresh xenolithic granite crops out near the road to Mount Cuthbert from Oona railway siding; it is adjacent to an older, deformed and weathered granitic rock.

The granite consists of pink microcline phenocrysts (up to 12mm.) in a granular groundmass (grains about 0.1mm.) of quartz, plagioclase, microcline, biotite, and hornblende. Microcline phenocrysts enclose smaller quartz grains (2.5mm.) and subhedral corroded plagioclase crystals. Fluorite is intergrown with some of the quartz and replaces feldspar along its cleavages. The rock contains about 25% each of potash feldspar and plagioclase and about 30% of quartz; biotite forms about 15% and hornblende, epidote, sphene, and fluorite constitute the remaining 5%.

An *adamellite* intrudes the Argylla Formation near the Crusader mine. It is allotriomorphic granular and is fairly even in grainsize; grains average about 3mm. Small veins of granular quartz and feldspar, and also of chlorite, cut the rock. Xenomorphic oligoclase, microcline, and quartz each makes about 30% of the thin section. Altered biotite forms the remainder; it is completely chloritized and is commonly associated with small crystals or granules of apatite, sphene, and opaque iron mineral.

The potash-rich *microgranite* that invades the basic dykes north of the Kings Cross copper mine shows a wide range in grainsize, from 0.1 to 3mm. It contains large, irregular, independent crystals and graphically intergrown grains of quartz and potash feldspar, and sericitized remnants of subhedral plagioclase. Biotite, partly chloritized, occurs with numerous grains of sphene.

Aplitic and *pegmatitic* veins penetrate the Kalkadoon Granite in places. They have been observed near the Referee mine and east of Broadhurst Bore. The aplite is light grey or flesh-coloured, and has a typical aplitic texture; it consists mainly of microcline and quartz (about 40% each) with lesser amounts of biotite (about 8%). The grainsize ranges from 0.1 to 1mm., with a few grains reaching 3mm.

Ewen Granite

The name of the granite is derived from Ewen Creek. The granite crops out in the Dobbyn 4-mile Sheet area, intrusive into Argylla Formation (Atlas, pl. 7). It is overlain by Myally and Surprise Creek Beds and is older than the Eastern

Creek Volcanics; at lat. 19°28′S, long. 139°39′E, these volcanics overlie the granite.

The granite is exposed in a belt up to 4 miles wide from Mosquito Creek in the north to Surprise Creek in the south, a distance of about 35 miles.

A number of granitic variants have been collected from the Ewen Granite. The main mass ranges from adamellite to granite. Potash microgranite appears to intrude the main granitic body.

The *adamellite* in hand specimen is light grey and fine-grained. Milky feldspar and colourless quartz and biotite can be recognised; some segregations of biotite flakes measure up to 10mm. across.

In thin section the rock is seen to range from allotriomorphic to hypidiomorphic granular, and has a grainsize of 0.5 to 3mm. The main minerals are microcline, quartz, plagioclase, and biotite, and minor constituents are epidote, zircon, and opaque iron mineral. Myrmekitic and perthitic intergrowths occur; in fact, much of the potash feldspar is perthitic microcline, in which patches of typical gridiron twinning can be seen. Plagioclase is zoned basic andesine; it is altered more extensively than the microcline, to sericite and rarely to chlorite. The xenomorphic quartz grains are commonly cracked and strained and some contain grains of minute inclusions. The biotite is well cleaved and partly altered to pale green chlorite; small inclusions of possible zircon grains are surrounded by pleochroic haloes.

A modal analysis shows that the rock contains 34% each of potash feldspar and quartz, 26% of plagioclase, 5% of biotite. Accessory minerals make up the remainder.

The *granite* specimens contain red feldspar phenocrysts up to 3 cm. in a finer-grained groundmass of quartz, feldspar, and chlorite. They have the appearance of a red granite porphyry.

In thin section the granite can be seen to have an allotriomorphic granular texture in which microcline phenocrysts, and the surrounding smaller grains of plagioclase, microcline, quartz, and flakes of chlorite, are partly granulated. Strained grains, undulose extinction, and turbid brown feldspar alteration products, are common. The phenocrysts in the thin section measure up to 10mm., whereas the groundmass grains range from 0.1 to 1mm. The accessory minerals are zircon, sphene, opaque iron minerals, and secondary epidote and sericite. Most of the phenocrysts are patch perthite, and microcline shows coarse gridiron twinning. The plagioclase is basic oligoclase. Turbid brown alteration characterizes all feldspar grains, and opaque iron mineral occupies cracks and cleavages in them. Quartz grains are mostly cracked and have undulose extinction. Chlorite flakes are pleochroic from pale yellow-green to bright lettuce-green and occur in bundles which probably pseudomorph biotite. Granular epidote occurs along their cleavages. Mauve-blue birefringence colours suggest that the chlorite is penninite. Small inclusions, possibly zircon, are surrounded by pleochroic haloes.

Modal analyses indicate a wide range in mineral percentages; the granite can contain between 40 and 50% potash feldspar, 20 and 30% plagioclase, 10 and

35% quartz, and 5 and 10% chlorite. The spread is partly due to the porphyritic character of the rock, and perhaps partly to the potash metasomatism and the replacement of original plagioclase by microcline—a possibility in keeping with the general alteration that characterizes the rock.

Intrusives of *potash microgranite* occur within the main body of adamellite or granite. Hand specimens are flesh-coloured and contain feldspar phenocrysts, up to 30mm. across, in a fine-grained groundmass. They show greenish, opaque patches or outlines of euhedral feldspar and bundles of chlorite, but are generally poor in ferromagnesian minerals.

Thin sections show phenocrysts of euhedral quartz and potash feldspar (including patch perthite) in an allotriomorphic granular groundmass. Corrosion embayments occur in some quartz grains. Granophyric material occupies grain interstices and abuts some phenocrysts. The other main mineral is albite. Accessory minerals are biotite, sericite, and opaque iron mineral. The phenocrysts of potash feldspar measure up to 30mm. and those of quartz up to 8mm. The grainsize of the groundmass ranges from 0.1 to 1mm. Myrmekitic intergrowth surrounds some of the potash feldspar phenocrysts. The potash feldspar is mostly perthitic microcline or patch perthite with indistinct gridiron twinning. The quartz phenocrysts and grains commonly show undulose extinction.

Modal analyses indicate that the potash microgranite contains 46% potash feldspar, 37% quartz, 15% plagioclase, and 2% accessory minerals.

Wimberu Granite

The Wimberu Granite, named from Wimberu Holding, Parish of Kenton (Dep. Public Lands Map 4M84), crops out in the Duchess 4-mile Sheet area (Fig. 13) and consists of three bodies within a large anticline between Kuridala and Duchess. The bodies may be continuous below Cambrian sediments that separate the outcrops. The eastern body is 20 miles long and 12 miles wide; the two western outcrops are each 4 miles wide, but 10 and 6 miles long.

The Wimberu Granite intrudes the Argylla Formation, Marraba Volcanics, Mitakoodi Quartzite, and Answer Slate. Specimens have been examined from near the Malbon-Kuridala Road 13 miles from Malbon, and about 1 mile west of Dronfield railway siding; but insufficient specimens have been examined to establish whether the main granitic type is granite or adamellite. The largest body is invaded by microgranite, microadamellite, and aplite.

The granite is coarse-grained and flesh-coloured in hand specimen, and contains microcline and plagioclase phenocrysts up to 10 mm. long. The plagioclase phenocrysts are slightly the more abundant. The groundmass is allotriomorphic granular and consists of quartz and feldspar, through which flakes of biotite (0.5 to 1mm.) are evenly distributed; quartz and feldspar grains are up to 3mm. long and a small amount of graphic intergrowth has developed. The plagioclase is more altered than microcline and has developed a turbid brown surface, which, together with zoning, prevents the determination of the composition of the plagioclase. Biotite is mostly coloured green, and altered to chlorite. Hornblende and fluorite are also present. Pyrite and other opaque iron minerals

(0.5 to 1mm.) are found in association with the ferromagnesian minerals. The opaque iron mineral is partly rimmed by sphene.

The mineral composition was visually estimated as about 25% quartz, 40-30% plagioclase, 30-40% microcline, 2% biotite-chlorite, and about 2% mostly opaque iron mineral, but also hornblende and fluorite.

The aplite that invades the granite consists mainly of saccharoidal microcline and quartz with a range in grainsize up to 2mm., but includes abundant patches of graphic intergrowth and also some chlorite.

Naraku Granite

The name is derived from the Naraku Railway Siding. The Naraku Granite crops out in the Cloncurry and Dobbyn 4-mile Sheet areas (Atlas, Pls. 8 and 7) and forms a series of outcrops from a point 18 miles north of Coolullah Homestead south to Cloncurry, a distance of 82 miles. A few small outcrops have also been mapped in the vicinity of the Robar copper mines, about 15 miles south-south-east of Cloncurry. The granite is entirely bounded by the Corella Formation. The width of the outcrops increases from about a mile at Coolullah Homestead to 5 miles immediately north of Cloncurry. The Naraku Granite is covered by soil and Mesozoic strata east of the Precambrian belt. It has been described by Joplin (1955, pp. 58, 59, Table 5).

Hand specimens are fine-grained; most grains measure from 0.5 to 3mm. They are massive or slightly foliated and consist of pink feldspar (1 to 5mm.), quartz (1mm.) and biotite (1mm.). They are not distinctly porphyritic; their grey colour varies according to the abundance of biotite.

In thin section, it can be seen that the texture is mostly hypidiomorphic granular and less commonly allotriomorphic granular. Plagioclase (acid andesine) controls the distinctive texture and forms subhedral crystals that consist of corroded sericitized cores surrounded by clear rims of plagioclase. Both microcline and quartz form large and small grains. Some quartz grains have undulose extinction. Olive-green biotite is the main dark mineral; the small flakes are associated with sphene and a small amount of epidote. Opaque iron mineral occurs in small amounts, and rare accessories recorded include hornblende, apatite, and muscovite.

The main body is probably adamellite, or more accurately microadamellite, but proportions of plagioclase, potash feldspar and quartz vary in different parts of the Naraku Granite. In general, plagioclase (45 - 30%) is much more abundant than microcline (15 - 30%); quartz forms 30% to 40%, biotite 4% to 6%, and various accessories less than 1%.

Williams Granite

The name of the granite is derived from the Williams River. The Williams Granite forms several outcrops in the eastern part of the Duchess 4-mile Sheet area (Atlas, Pl. 9). Scattered outcrops extend from Soldiers Cap in the north to the south of Squirrel Hills on Bustard Creek in the south, where the exposures are larger and more extensive. The Williams Granite crops over 60 miles and

increases from 15 miles width of scattered outcrops in the north to 35 miles width in the south. It invades the Soldiers Cap, Staveley, Corella, and Kuridala Formations and the Answer Slate. No younger strata, other than Mesozoic, overlie it.

Fine and coarse-grained granite or adamellite has been recognized; and in the northern part of the Williams Granite, microadamellite forms a marginal phase to the coarser-grained variety and occurs as dykes and small irregular intrusives. Furthermore, dykes and veins of a more microcline-rich variety have been observed, and also sills, dykes and minor intrusions of pegmatite, soda aplite, and albitite (Joplin, 1956), many of which cut the main bodies of granite or adamellite. About 4½ miles south-south-east of Kuridala, medium-grained microcline granite preserves relict crenulated bedding and fold structures. In some of the more southerly outcrops also, for example near Squirrel Hills and Mount Doré, more relict sedimentary structures are preserved in the granitic rocks. Such features are characteristic of granitized rocks. Microcline-bearing pegmatitic and aplitic rocks apparently have also formed by granitization (p. 174). The Corella Formation and contemporaneous calcareous rocks are the rocks most commonly transformed to granite.

Very few specimens are available for description, and most of these are the fine-grained type. However, one coarse-grained rock from Squirrel Hills Station has an allotriomorphic granular texture and consists of oligoclase, microcline, quartz, and hornblende, and rare apatite, sphene, and opaque iron mineral.

The *microadamellite* ranges from red to flesh-coloured and is commonly associated with cream soda aplite, into which it grades by decrease in the amount of potash feldspar. It is allotriomorphic to hypidiomorphic granular with a range in grainsize from 0.4 to 3mm., and consists mainly of microcline, plagioclase, and quartz. The feldspars form roughly a third each of the thin sections, and quartz about a quarter. Biotite is the main ferromagnesian mineral, but it is generally partly chloritized. Accessory minerals are muscovite, sphene, apatite, fluorite, calcite, and opaque iron mineral.

Fine-grained *potassic granite* is widespread and consists of flesh-coloured feldspar and clear quartz grains. The arrangement of biotite flakes gives the rock a poor foliation but in places the texture approaches granoblastic. Grain-size ranges from 0.3 to 2mm., and the thin section consists of quartz, microcline, plagioclase, and biotite, with accessory apatite and opaque iron mineral. Microcline is the predominant feldspar; it forms grains up to 2mm. across and shows typical gridiron twinning. The plagioclase (1.5mm.) is oligoclase-andesine; it contains some twin lamellae or sericitized cores. Quartz, commonly strained, occurs as single grains or as a mosaic of grains up to 2mm. across. Some quartz forms inclusions in the microcline, with which it is also graphically intergrown. Biotite is partly altered to chlorite.

Sybella Granite

The name is derived from Sybella Creek. The granite crops out in the Mount Isa and Urandangi 4-mile Sheet areas (Atlas, Pls. 5 and 6). It extends

almost continuously from a point east of Mingera Creek and 4 miles south of the Barkly Highway, to Smoky Creek 30 miles south of Ardmore Homestead, a distance of 110 miles. Its greatest width is in the Mount Isa 4-mile Sheet area, where the outcrop tapers from 18 miles across in the north to 6 miles in the south. In the Urandangi area it has a fairly constant width of about 5 miles.

Country rocks that surround or are close to the Sybella Granite include the Eastern Creek Volcanics, the Mingera Beds, the Mount Isa Shale, and the Judenan Beds. The Eastern Creek Volcanics are intruded by the granite and raised to a moderate to high grade of metamorphism. The contact with the Mingera Beds is probably faulted; if so, they probably overlie the granite. No contacts have been found with the Mount Isa Shale, which is separated from the granite by the Mount Isa Fault, and it is not affected by contact metamorphism. The Judenan Beds in general have been little affected, if at all, but some rocks mapped as Judenan Beds have been greisenized; their identity with the Judenan Beds is not beyond doubt.

The western boundary of the Sybella Granite is for the most part concealed under Cambrian rocks or alluvium.

Four distinct types of granite — a weathered core, a foliated porphyritic granite, a massive porphyritic granite and a microgranite — have been recognized in the Sybella Granite, as well as pegmatite, soda aplite, and albitite. There may also be some minor instrusions of microadamellite and potash-rich microgranite.

A weathered core appears to occupy the northern central part of the Sybella Granite, flanked on Mingera Creek by a coarse-grained porphyritic granite that has altered and granitized it (Joplin, 1955, p. 42). No other contacts have been mapped. The oldest granitic rock recognized in the region occurs as pebbles in the Argylla Formation (it is therefore probably older than the Kalkadoon granodiorite): these pebbles may well be related to the weathered core and to the granite near Yaringa Creek, which intrudes Yaringa Metamorphics. The pebbles were referred to by Joplin (1955, p. 38-9); they include medium-grained and coarse-grained pink and cream granitic rocks, allotriomorphic granular and consisting of microcline, plagioclase, quartz, muscovite, biotite, and a small quantity of sphene and opaque iron mineral.

In hand specimen the *weathered granite* of the core is cream to flesh-coloured and iron-stained. Generally it has a granitic appearance, but it grades, in places, into a rock which, though now silicified, looks as if it may have been an arkose. The old granite was probably either deeply weathered or partly resorted before the porphyritic granite intruded it.

The rock consists of large irregular grains of quartz which interlock with chalcedony, pseudomorphing feldspar. Amorphous silica that appears to contain some chloritic material surrounds these grains. Further silicification is indicated by cross-cutting veins of clear secondary quartz.

The second type in the Sybella Granite is a foliated *porphyritic granite*. It appears to extend from its northern outcrops on May Downs southward nearly

to Jayah Creek, where it passes, in places, into a more massive type. The boundary between the massive granite and the migmatites south of the latitude of Ardmore Homestead has not been mapped and possibly the porphyritic granite grades into them. Both foliated and massive varieties are intersected by small bodies of microgranite, which are particularly numerous in the northern outcrops.

The foliated porphyritic granite has been described and analysed by Joplin (1955, p. 56, Table IV). It is a red granite with patches of pink microcline (15mm.) which are not individual grains but aggregates of smaller grains which measure from 3 to 0.5mm. The colour of the rock, and the degree of foliation, differ from place to place with the biotite content.

In thin section the granite is seen to be porphyritic and allotriomorphic granular; some of the phenocrysts interlock with the granular groundmass. Some microcline phenocrysts and grains are fringed by myrmekite, and contain albite intergrowths and small subhedral, tabular, and corroded inclusions of plagioclase. The plagioclase in the groundmass is oligoclase; it forms interlocking grains with the other minerals. Some crystals are subhedral or corroded or both. On Waverley Creek such phenocrysts are enveloped by microcline. Other grains consist entirely of microcline, and it is suggested that these are possibly xenoblastic porphyroblasts. Quartz (up to 3mm.) and the ferromagnesian minerals occur mostly in the groundmass. Biotite is the main dark mineral and is commonly dark olive-green, but in some specimens it is bleached to golden-yellow; alteration to chlorite and epidote is common. Green hornblende forms subhedral and irregular grains in many rocks, and, especially, granular clusters with small flakes of biotite and tiny granules of sphene. Apatite occurs, in particular, along foliation planes. Fluorite is a constant accessory; it tends to replace feldspar along cleavages.

The rock contains 35-40% microcline, 25-35% quartz, and 15-25% plagioclase. Biotite is a little more abundant than hornblende, and together they constitute most of the remainder.

The third type of granitic rock is more massive than the foliated porphyritic type. It forms part, at least, of the southern Sybella Granite mass. On Rocky Creek 6 miles north-west of Sulieman Bore it is a coarse-grained *porphyritic granodiorite* containing abundant de-oriented xenoliths. It is mineralogically a granodiorite, and looks very similar to the Kalkadoon granodiorite. The rock, in places, has pink phenocrysts in a fairly dark groundmass; they are microcline and plagioclase, and those of microcline measure up to 20mm. Grains in the groundmass range from 0.5 to 2mm.

The thin sections show that the xenomorphic microcline grains are commonly fringed by myrmekite and that the subhedral plagioclase crystals are sericitized. The groundmass, of average grainsize 0.5mm., consists of quartz, microcline, plagioclase, biotite, hornblende, sphene, apatite, and opaque iron mineral. Apatite is unusually abundant. The mineral percentages are 25-35% of plagioclase and quartz, 15-20% of microcline, and 10-15% of biotite. Of the remaining minor constituents, hornblende and sphene are the most common.

Microgranite forms a lobe in the north-eastern part of the granite, and small bodies, mainly dykes, which intersect the other types within the Sybella Granite and have characteristics of high-level intrusives. It has been described and analysed by Joplin (1955, pp. 55 and 60, Table V). The outcrops of microgranite are, in places, rich in basic xenoliths (Pl. 19, fig. 2), particularly in the northern part of the Sybella Granite outcrop, and especially on Kitty's Plain, 12 miles north-north-west of Mount Isa.

Soda aplite and albitite are marginal to, or cut, the microgranite, and mica pegmatite also cuts the microgranite on the north-eastern margin of the Sybella Granite in areas of greisenization (Joplin, 1955).

The microgranite is a massive, fine-grained to medium-grained, pink or reddish rock. It contains small quantities of mica or chlorite, or both, but the ferromagnesian mineral differs from place to place; there is a wide range in grainsize (0.4 to 1.5mm.) within individual rocks. The thin sections are allotriomorphic granular and consist of microcline, together with plagioclase or quartz, or both. Quartz commonly forms granular aggregates. Some microcline is fringed by myrmekite, and plagioclase is generally extensively sericitized. The common variety of biotite is olive-green; but some is golden-yellow or completely bleached and in part altered to chlorite. Minor accessories are muscovite, sphene, apatite, and opaque iron mineral.

The microgranite is composed of about 40% microcline, 35-40% quartz, 15-20% plagioclase, and 2-5% biotite and minor accessories.

Wonga Granite

The name is taken from Shepherd (1946) (see Table IV). The granite crops out in the Cloncurry and Duchess 4-mile Sheet areas (Atlas, Pls. 8 and 9). The main part of the granite is continuous, and stretches from a point about 8 miles south-south-west of Kajabbi to about 5½ miles south of Mary Kathleen township. North of the Wonga Fault the average width is about 5 miles; south of the fault it is about 2 miles. In the Duchess Sheet area are numerous small elongated exposures from 1 to 3 miles long and about a mile wide. They crop out discontinuously from 5 miles south-west of the abandoned township of Ballara to the Trekelano copper mine. The Wonga Granite mainly intrudes the Corella Formation, but also has contacts with the Leichhardt Metamorphics and the Argylla Formation.

The Wonga Granite on the western side of the eastern geosynclinal area has been displaced by a series of north-east faults. The adjoining granite has been deformed, but the fault-plane is filled with aplite. The faults therefore were active after the emplacement of the main granite, but before the end of the episode.

Within the area of outcrop of the Wonga Granite numerous small dykes or veins, which are exceptionally rich in microcline, cut the granite. Examples of such potash-rich microgranite can be seen in the Dugald River area, where they have sharp contacts with the granite (Joplin, 1955, fig. 11B). Abundant potash-rich pegmatitic and aplitic dykes have been observed in granite between

the Lady Fanny and Trekelano copper mines — particularly around Duchess; and a mica pegmatite dyke cuts rocks near the Old Man Waterhole which are believed to be Deighton Quartzite.

Crenulations and plications, believed to be sedimentary, are preserved in the Wonga Granite at Duchess and at lat. 21°13′30″S, long. 140°08′10″E — a point about 10 miles east of the Lady Fanny copper mine. They suggest that the granite is a product of granitization (Pl. 21, fig. 2), and if so it has been derived from calc-silicate strata of the Corella Formation. The process involved in this transformation is discussed on pp. 173-5. However, not all the Wonga Granite can be confidently attributed to this mode of formation; some outcrops show features more typical of magmatic origin.

In the main outcrop the granitic rock is predominantly coarse-grained, and includes massive and foliated types which may be either porphyritic or porphyroblastic. Migmatite and banded gneissic structure are well developed, in places, from highly contorted calc-silicate rocks. Thus, in the northern area as well, it is difficult to decide whether the gneissic rocks are of sedimentary origin or whether they are strongly foliated magmatic granites, or possibly formed by lit-par-lit injection of migma or magma.

The typical mineral assemblage of the Wonga Granite is microcline, quartz, plagioclase, and hornblende. Large microcline grains (up to 10mm.) occur in a medium-grained groundmass (0.3mm. grains) of microcline and quartz, with lesser amounts of sericitized plagioclase, and hornblende or biotite, or both.

The Wonga Granite has many textural varieties and slight mineralogical variants, and none can be described as typical. It is rich in microcline (45-50%); quartz forms 20-25%, and plagioclase 15-20%. Biotite and hornblende vary in inverse proportions, though hornblende is the more common.

In the southern exposures of Wonga Granite, it typically appears to be finer-grained, and perhaps more massive, than in the northern outcrops. A thin section contains microcline and quartz and lesser amounts of plagioclase, biotite, and hornblende. The texture is allotriomorphic granular, though the rock is almost granoblastic. There is a wide range in grainsize from 0.5 to 3mm., but some larger feldspar and quartz grains (up to 5mm.) occur amongst the abundant smaller grains. Some of the microcline grains (up to 3mm.) are microperthitic, and many are fringed by myrmekite or contain small inclusions of rounded quartz grains. Quartz grains commonly occur in bands; individual grains may be cracked or show undulose extinction. Irregular andesine grains (up to 2mm.) are heavily sericitized and complex twinning is absent. Although the microcline is turbid it is less extensively altered than the andesine. Green-brown biotite flakes and hornblende grains are evenly distributed throughout and form flakes and grains up to 1mm. long. Commonly hornblende is slightly more abundant than biotite. Apatite and opaque iron mineral are rare accessories. The relative percentages of minerals, by visual estimation, are about 40-50% microcline, 25-35% quartz, and 15-20% plagioclase. Biotite and hornblende make up the remainder.

Weberra Granite

The name is derived from the Parish of Weberra (Dep. Public Lands Map 4M92). The granite crops out in the Lawn Hill and Camooweal 4-mile Sheet areas (Atlas, Pls. 3 and 4). Only two occurrences have been recorded on the maps. The more southerly is the main body and appears to occupy a small dome in the Ploughed Mountain Beds between the upper reaches of Fiery and Sandy Creeks. It is roughly concordant and is about 4 miles across. The northern occurrence consists of several small outcrops north of the Gregory River at lat. 18°47′50″S, long. 138°51′40″E and lat. 18°40′40″S, long. 138°49′20″E. Soil cover masks most contacts, though two outcrops may occur along faulted contacts between Myally and Ploughed Mountain Beds. The main body of granite was probably emplaced at a high level, because it has only a narrow metamorphic aureole.

Dykes of fine-grained granitic rock, and late-stage quartz-feldspar porphyry and granophyre, are associated with the main body. Pegmatites are associated with the northern outcrops, and the adjacent sediments have been greisenized to some extent.

Only a few specimens are available for description and none is very fresh; furthermore, they are dissimilar petrographically.

The rock from the southern exposure is slightly porphyritic fine-grained massive red granite composed almost entirely of feldspar and quartz. The thin section has a granitic fabric that includes some patches of graphic intergrowth; it consists of potash feldspar, quartz, and smaller quantities of plagioclase and ferromagnesian minerals. The grainsize of the groundmass is fairly even and averages about 0.4mm. The potash feldspar is mostly orthoclase (3mm. and some grains up to 5mm.) and includes some grains which are fringed by small, altered, tabular crystals of plagioclase; some of this feldspar is perthitic. Plagioclase is altered to turbid brown products in which are included clinozoisite, chlorite, calcite, sericite, and some secondary quartz. The ferromagnesian content is limited to interstitial alteration products, which are chlorite and golden-brown biotite. Accessories are a few grains of sphene and opaque iron mineral.

Half the thin section is alkali feldspar and another third is quartz; of the remainder most is plagioclase, but small amounts of clinozoisite, chlorite, and biotite are also present.

The rock from the northern occurrence is massive, medium-grained, pinkish grey, muscovite granite. Quartz, pink feldspar, and muscovite can be recognized in hand specimen. Under the microscope the rock is allotriomorphic granular and is fairly even-grained; in the thin section are grains that measure up to 6mm., but the grainsize averages about 3mm. It consists of potash feldspar, plagioclase, quartz, and muscovite. Irregular quartz grains (3mm.) appear unstrained. Potash feldspar (up to 6mm.) is about as abundant as plagioclase and only some of it shows poorly developed microcline twinning. Plagioclase grains (1.5mm.) are brown and turbid through alteration. Muscovite flakes (2mm.) are a pale greenish

yellow, and are abundant; they form inclusions along cleavages in plagioclase. There are no ferromagnesian minerals.

Quartz forms 40% of the thin section, plagioclase and potash feldspar each make up about 25%, and muscovite 10%.

The granophyre and quartz-feldspar porphyry associated with the Weberra Granite are similar to those found in the Nicholson Granite, and have not been found associated with the other granite masses. The porphyry has been described on p. 133. The granophyre ranges from flesh-coloured to brick-red and contains flesh-coloured feldspar phenocrysts. The thin sections have a dominant granophyric texture and are porphyritic (Pl. 31, fig. 1). The phenocrysts are quartz (2mm.) and euhedral feldspar (2mm.). The minerals of the granophyric intergrowth and any included quartz and feldspar phenocrysts are in optical continuity. Where the granophyric intergrowth is patchy, finely granular quartzo-feldspathic material occurs between the patches. The grainsize of the base averages 0.1mm., but the base, in some cases, includes a number of feldspar laths up to 1mm. The feldspathic phenocrysts are mostly of altered potash feldspar and are turbid brown. Sericite and calcite, which are probably derived from this alteration process, form small interstitial grains in the granophyric base. Opaque iron mineral occurs and heavy iron staining affects most of the specimens examined.

Nicholson Granite

The name is derived from the Nicholson River. The granite crops out in the south-west of the Westmoreland 4-mile Sheet area (Atlas, Pl. 2) and in the adjoining part of the Northern Territory. The outcrop forms an east-west belt, and covers an area of about 130 square miles, 30 square miles of which are in Queensland. Minor intrusions of granophyre are associated with the main granitic body.

Two granitic types have been observed in the Nicholson Granite. One is a coarse-grained pinkish grey granodiorite, fairly rich in biotite, and associated with more basic types, whereas the other is medium-grained, massive, porphyritic, red quartz-mica diorite, associated with granophyre. Both intrude the Cliffdale Volcanics, but are overlain by the Westmoreland conglomerate. Jensen (1941) considers that the diorite occurs as a laccolith in the Cliffdale Volcanics (with which it may be co-magmatic), but its relationship with the granodiorite is unknown. Only one specimen of each is available for description.

The quartz-mica diorite is a hypidiomorphic granular rock which consists of plagioclase, biotite, hornblende, and quartz. The plagioclase, slightly sericitized basic andesine, forms subhedral tabular crystals about 5mm. long and shows well developed albite and pericline twinning. Biotite flakes measure up to 1.5mm. and occur both independently and intergrown with light green, subhedral prismatic crystals of hornblende of about the same size. Quartz grains measure up to 4mm., and show slight undulose extinction.

The granodiorite or adamellite is a coarse, fairly even-grained, hypidiomorphic granular rock which is similar to the quartz-mica diorite except that it

contains orthoclase. Plagioclase forms tabular crystals up to 6mm. and is euhedral against orthoclase, suggesting a tendency towards monzonitic fabric; sericitization prevents determination of its composition. Orthoclase forms grains up to 10mm.; some contain tabular inclusions of plagioclase and others are microperthitic. Although quartz forms grains that measure up to 6mm., it is normally interstitial; it has undulose extinction and some grains are irregularly cracked. Biotite flakes (up to 3mm.) and clots (up to 4mm.) of smaller flakes (1 to 1.5mm.) are strongly pleochroic from deep sepia to golden-yellow. Flakes are commonly bent and contain lenses (1.5mm. long) which are optically positive and probably of zircon. Some flakes are partly altered to chlorite and epidote. Small pleochroic haloes surround possible zircon grains; inclusions of apatite are also common. Plagioclase forms about one-third of the thin sections and orthoclase and quartz average one-quarter each. Biotite is the other primary mineral and forms one-eighth of the thin section.

As with the Weberra Granite, granophyric rocks are associated with the Nicholson Granite and probably represent a late phase of the original granitic emplacement. The granophyre is a light grey rock that weathers pink. It contains white feldspar phenocrysts and translucent quartz grains which are equally abundant and both range in size from 1.5 mm. to 6 mm. The thin sections show that part of the groundmass has a delicate, but perfect, granophyric texture, and the remainder is spherulitic and consists of needles of quartz and feldspar which fringe phenocrysts and grow out from them to form stellate bundles. There is optical continuity between mineral components of the granophyric intergrowth and the corresponding phenocrysts. The quartz phenocrysts are mostly euhedral and contain pseudo-inclusions, and the feldspar phenocrysts are subhedral. The plagioclase is andesine or oligoclase which is generally heavily stained with hematite. Also included in the groundmass are aggregrates (1 to 2 mm.) of interlocking quartz grains, some chlorite, and subordinate granular epidote and calcite (2 mm.). Chlorite (0.5 mm.) pseudomorphs some of the original biotite.

Age Relationships and Mode of Emplacement

The granites described above all probably contain components of various ages; and field contacts and petrogenetic considerations enable many of these to be distinguished. The postulated sequence of granitic events, with those of the basic igneous and metasomatic events, are given in Table VI. All events are considered in relation to the orogenic episodes. A detailed study of the petrogenetics and tectonics of granitic emplacement has not been possible, but present knowledge and ideas on these problems are summarized.

Five ages of granitic rocks are recognized. All the granitic rocks, with the possible exception of the old granite that forms a core in the northern part of the Sybella Granite, are thought to be of Lower Proterozoic age. Probably the members of at least two granite series (Read, 1955) are represented by these Lower Proterozoic granites.

Field Relationships

The existence of a granite older than the Kalkadoon granodiorite has been indicated by the presence of granite pebbles in the Argylla Formation, as the granodiorite would not have been exposed at the time of their deposition. Also, contact relationships established by Joplin (1955, p. 42) between masses of Sybella Granite on May Downs indicate an old granite core. So, perhaps, an early granitic basement is here represented.

The Ewen Granite is overlain by the Eastern Creek Volcanics, and thus is the earliest granite established by incontrovertible field evidence; but the Kalkadoon granodiorite may be as old or even older. Near the northern end of the Kalkadoon Granite at the head of Sunday Gully the granodiorite is overlain by the basal conglomerate of the Surprise Creek Beds, indicating that it was exposed in Lower Proterozoic time. Elsewhere it is intruded by dyke swarms which, in turn, are invaded by potash-rich microgranite that probably accompanied the first main orogenic deformation. Furthermore, if the dyke swarms are feeders to the Eastern Creek Volcanics, again the granodiorite is older than the first orogenic deformation. Further support for the antiquity of both the Ewen Granite and the Kalkadoon granodiorite is given by their alteration, and by the fact that the granitic masses are composite bodies whose younger components intrude to higher stratigraphical levels than the granodiorite. The granodiorite appears to be regionally metamorphosed in places.

Possibly the Kalkadoon granodiorite and Ewen Granite are contemporaneous, both being emplaced during initial orogenic movements affecting the Leichhardt Metamorphics, and during or after the outpouring of the acid volcanics in the Argylla Formation. An alternative suggestion has been made by Joplin & Walker (in press) that the granodiorite is coeval with the acid volcanics in the Leichhardt Metamorphics and the granite with the volcanics in the Argylla Formation, each granitic type intruding its own lavas. The more basic composition of the granodiorite gives some support for this latter suggestion.

Most of the named granitic bodies contain rocks believed to have been emplaced during the first main orogenic deformation. They include the Wimberu adamellite, Naraku microadamellite, Williams adamellite and microadamellite, Kalkadoon granite, and the Sybella granite and granodiorite. All these granitic rocks, except the Sybella granite and granodiorite, intrude strata in the eastern geosynclinal area as high as the Corella and Kuridala Formations.

The various microgranitic and aplitic phases that invade many of these granitic rocks were emplaced somewhat later than the main bodies, probably at a later stage in the granitic sequence accompanying the first main deformation. They are commonly massive and marginal to the bodies, cut them with sharp contacts, and thus are considered to be high-level intrusives. The Sybella microgranite in the Sybella Granite is an example. This and the microgranite in the Wonga

Granite form fairly numerous outcrops compared with the few intrusives seen in the Kalkadoon, Ewen, and Williams Granites.

The microadamellites have been found in various granitic bodies, but soda aplite and albitite have been observed only in the Kalkadoon, Williams, and Sybella Granites. Joplin (1955, and 1956, p. 81) considers that the albitite intrudes the Sybella microgranite, and Joplin & Walker (in press) have observed that the Williams adamellite and microadamellite have been albitized in places as well as intruded by the soda aplite, and have suggested that the regional soda metasomatism may have been related to this. The metasomatism appears to have accompanied the first main deformation, as metasomatic products have not been found in the Myally or Judenan Beds, which were little affected by the first deformation, whereas they are widespread in the eastern geosynclinal area (which was strongly deformed) particularly in the Corella Formation.

Muscovite-rich pegmatite occurs in the Kalkadoon Granite, but is mainly found marginal to the Sybella granite and microgranite, and the Williams Granite, particularly south of Fullarton River.

The greisenized rocks around the Sybella Granite are so changed that, except for the Eastern Creek Volcanics, they cannot be identified with any particular formation, and their age, and hence that of the greisenizing granite, remains unknown. For this reason, Table VI shows alternative ages for the granite.

The Wonga Granite presents another problem, as granitization has played an important part in its formation. Many microcline-rich veins with a pegmatitic or aplitic appearance are associated with it, and probably formed as part of the same process (p. 173). The preservation of fold structures in granite formed *in situ* indicates that granitization occured at a late stage in the first orogenic deformation, after regional folding, metamorphism, and metasomatism (see p. 174). Palimpsest sedimentary structures have also been recorded in the Kalkadoon, Williams, and Sybella Granites. The effects of granitization are more localized in the Williams and Sybella Granites than in the Wonga. Granitization of calc-silicate rocks 4½ miles south-south-east of Kuridala produced a similar suite of rocks to those at Duchess, and appears to have been locally important.

The Weberra Granite intrudes strata laid down after the first orogenic deformation, and thus probably accompanied the second. It is at least 30 miles farther north-west than the nearest outcrop of other Lower Proterozoic granite, and this may indicate that the centre of granitic activity was moving in this direction when the later Lower Proterozoic granites were emplaced. A pegmatite dyke, believed to be in the Deighton Quartzite, and small occurrences of granite intruding the Myally and Surprise Creek Beds along the eastern margin of outcropping western geosynclinal rocks, have been recorded, but their significance is not understood.

The Nicholson Granite invades the Cliffdale Volcanics. Smith & Roberts (1960, unpubl.) have demonstrated that the Carrara Range Volcanics in the Mount Drummond 4-mile Sheet area (Northern Territory) are of upper Lower Proterozoic

age, and they believe that the volcanics are equivalent to the Cliffdale Volcanics. The Nicholson Granite, therefore, is best considered to be Lower Proterozoic, overlain by Upper Proterozoic Westmoreland Conglomerate.

Petrogenesis

The early granitic rocks in the region appear to be more basic than most of the younger granites, which become progressively richer in soda, silica, or potash. Such differences could be explained by successive injections during the differentiation of a normal granitic magma. The large time intervals between successive granitic emplacements, and the tectonic complexity of the region, do not support, however, the postulate of the formation of the various granitic rocks from a single differentiation series. Indeed, at least two granite series (Read, 1955) appear to exist. In each, differentiation gave rise to progressive enrichment in soda or silica, and in one potash enrichment was probably accompanied by the generation of hydrothermal solutions during late stage differentiation and crystallization (see Joplin & Walker, in press). These solutions made potash metasomatism and granitization possible.

The composition of injected magma at any stage in differentiation may have been modified locally by the assimilation of country rocks, which resulted in the formation of the many hybrids observed. Widespread variations caused by this, as Joplin (1955) originally postulated, now seem improbable (though the Sybella granodiorite may be an exception), because many of the granitic rocks of the first orogenic deformation are less basic than the Kalkadoon granodiorite; yet they were emplaced in country rocks richer in both basic igneous and calc-silicate rocks. Moreover, Kalkadoon granodiorite has a fairly constant chemical and mineralogical composition throughout. Further, the Naraku microadamellite and the Wonga granite intrude similar calc-silicate country rocks; the more sodic and basic character of the microadamellite can be attributed to petrogenetical causes. The microadamellite appears to have been magmatic, whereas it is recognised that the Wonga Granite includes many patches of granitized country rock, and is, to that extent at least, of metasomatic origin.

An example of basification by assimilation, however, is possibly illustrated by the Sybella granodiorite (see p. 151), which is probably coeval with, but more basic than, the Sybella granite. Numerous xenoliths observed in the outcrops north-east of Sulieman Bore, as well as tectonic considerations discussed below (p. 160) support this explanation.

After studying the micrometric and chemical analyses of the various granitic rocks, Joplin & Walker have suggested that the Kalkadoon granodiorite and Ewen granite represent the end of the first granite series; earlier members have not been detected. The granite, although probably co-magmatic, may have been slightly later than the granodiorite, as it is the more acid of the two.

Further, they suggest that the Wimberu adamellite, with its fairly high soda content, was the initial member of the second granite series and thus the earliest granite introduced during the first orogenic deformation. Possibly, it differenti-

ated along three different trends according to the prevailing water-pressure conditions. The most siliceous differentiate gave rise to the Naraku microadamellite. Differentiation towards soda enrichment resulted first in the Williams adamellite and finally in the formation of soda aplite and albitite. The third trend was towards potash-rich varieties, of which the Wonga granite is typical.

The Sybella granite appears to follow both siliceous and sodic trends, accordingly culminating in the development of either microgranite, or albitite similar to that found in the Williams adamellite.

The relationship of the Sybella to the other granites is not satisfactorily established. It may be contemporaneous with the Wonga Granite: both are invaded by very similar microgranites. If so, there must have been two periods of soda metasomatism; first because it is postulated that the Wonga Granite was formed by the potash metasomatism of scapolite granulite, which was itself the product of soda-enriched calcareous sediments; and secondly because the microgranite which invades the Sybella Granite appears to be invaded by albitite.

Alternatively, the Sybella may be contemporaneous with the Williams Granite, and both older than the Wonga: both Sybella and Williams Granites appear to be magmatic, though small sporadic areas of granitized rocks occur; both are partly fringed with greisenized rocks with mica pegmatites; and both are associated with albitites and possibly with a later soda metasomatism. If this is so, we need postulate only one period of soda metasomatism, and the Wonga Granite is younger than the Sybella (and their microgranites are not contemporaneous).

The mica pegmatites in the Sybella and Williams Granites possibly resulted from late hydrothermal and pyrometasomatic activity in the region. The microcline pegmatites, as seen in the Wonga Granite, are closely related to potash metasomatism and granitization.

The intrusion of the Weberra Granite possibly marks the close of the second cycle, and that of the Nicholson Granite, about 90 miles away, may be either related or belong to a third.

Tectonics

Possibly high level intrusive types are represented by the Kalkadoon granodiorite, Ewen Granite, and Nicholson Granite, which invade lavas with which they are possibly co-magmatic.

The Sybella microgranite is also massive and fine-grained, and it forms small, marginal high-level intrusives in the Sybella Granite, producing only slight contact effects in the adjacent country rocks.

The physical features of the high-level intrusives are consistent with their having been emplaced at relatively shallow depths, but those of the other granites do not appear to correlate with their apparent depth of emplacement (Joplin & Walker, in press). As Joplin and Walker have shown, present evidence would appear to indicate that the intensity of folding at the time of emplacement, and the

competence of the strata invaded, have a bearing on the structural features developed in the granite. The Sybella Granite, for example, probably received some protection during emplacement from quartzites and basalts in the margin of the orogenic belt; these strata were relatively competent compared with the yielding calcareous sediments in the centre of the belt, where the Wonga Granite was emplaced. Consequently, the Wonga Granite has the appearance of a deep emplacement because much of it is metasomatic and replaces rocks which would have yielded plastically. Thus, if the Sybella and Wonga Granites are contemporaneous, differences in the physical features of each may have resulted from their different positions in the orogenic belt and the competencies of the terrain they invade, rather than from depth of burial.

Most of the granites accompanying the first orogenic deformation were not necessarily deeply buried; they were probably emplaced at moderate depths. For example, the Wonga and Naraku and portions of the Kalkadoon and Williams Granites, have large outcrops in the stratigraphically high formations, such as the Corella.

One particular tectonic problem is the origin of the foliation in the Sybella Granite. Elsewhere, foliation is mainly found in the Wonga Granite, particularly in the northern outcrops, where it largely resulted from migmatitic development. In the Sybella Granite strong foliation is found in its northern outcrops, but fades as the granite passes into granodiorite in the south, and outcrops become massive. Thus it is possible that the Sybella Granite was emplaced along north-south shears flanking an old granitic block and compressed during consolidation. In the absence of such fractures farther south more stable conditions may have prevailed, enabling assimilation and differentiation to take place; here the massive, xenolithic Sybella granodiorite developed.

Metamorphism and Metasomatism

The recurrent orogenic and igneous events have been accompanied by various metamorphic and metasomatic processes, though not all of these are necessarily directly related to igneous activity. Regional metamorphism is widespread and shows marked thermal effects; it could be called a regional thermal metamorphism. Contact and dislocation metamorphism are common locally. Possibly slight metasomatism accompanied metamorphism; but metasomatism that occurred after some of the metamorphic epochs, and involved additions of soda and chlorine, is referred to as 'regional metasomatism'. Another process, which followed the regional metasomatism, has been called the 'general hydrothermal alteration'. It strongly leached many of the rocks affected by the regional metasomatism. The term metamorphism, as used, implies alteration in textures and minerals, with only slight, if any, bulk chemical change, whereas metasomatism can involve chemical as well as textural changes.

A study of the basic igneous rocks has revealed a number of localities where adjoining rocks show contrasting metamorphism; these are sites of 'metamorphic unconformities'.

The reader is referred to Appendix I for petrographic descriptions of typical metamorphic and metasomatic rocks.

Metamorphism

Field work has not been adequate, nor are specimen collections sufficient, to permit mapping of metamorphic zones or to relate all metamorphic processes to particular orogenic events or igneous bodies; for this reason, conventional classifications, particularly for contact metamorphism, have not been used. The pelites and basic igneous rocks are the best indicators of metamorphic environment, and have been used to illustrate the general aspects of the regional and contact metamorphism. Only the basic igneous rocks are widespread. After the discussion of individual occurrences a broad metamorphic sub-division of the region is attempted. This roughly indicates the metamorphic state of the major rock groups.

The metamorphic study has proved important in the analysis of the geological sequence of events. The study of some areas, in slightly greater detail than was possible for the regional survey, has shown a number of places where metamorphic unconformities exist.

Regional Metamorphism

Except for the Eastern Creek Volcanics the Upper Proterozoic and the Lower Proterozoic rocks north and north-west of Mount Isa are uniformly very low grade or unmetamorphosed. Details of their alteration need not be referred to further. However, some rocks, including the basic rocks in the Mount Isa Shale, range up to the biotite-chlorite subfacies of the greenschist facies.

Suites of basic igneous, pelitic, and carbonate rocks have been selected to indicate the metamorphism found in rocks of the Lower Proterozoic metamorphic belt, and remarks are confined to them. Pelites, though of great value in metamorphic zoning, are not sufficiently abundant to serve as indicators of detailed zoning; basic igneous rocks, on the other hand, are widely distributed, and serve as good indicators of metamorphic grade, particularly the lower grades.

The regional metamorphism is characterized by a dominant thermal factor. Despite this characteristic, the metamorphism is essentially of regional type, showing a regional distribution. The various aspects of the regional metamorphism of the basic igneous and pelitic rocks are discussed in the order low-grade to high-grade.

Alteration of the basaltic rocks of the Eastern Creek Volcanics, 1½ to 5 miles east of Mount Isa, may be attributed to autometamorphism, or to subsequent hydrothermal alteration, or to low-grade regional metamorphism. These rocks consist entirely of low-temperature mineral assemblages and their fabric shows little sign of stress (Appendix 1, p. 289. Specs. R6970, R6974). Despite the general alteration, the feldspar remains fresh in some rocks and retains a lath-form; its composition ranges from albite to andesine. These features suggest that alteration is not entirely metamorphic.

Narrow shear-zones cut the Eastern Creek Volcanics in many places; in thin section the deformation is shown by distortion of feldspar laths and the growth of oriented chlorite and actinolitic amphibole. The effects of shearing may also be seen widely in the Marraba Volcanics; their overall metamorphic grade and degree of shearing are greater than in the Eastern Creek Volcanics.

The metamorphism of the pelites in the Soldiers Cap Formation between the latitudes of Cloncurry and the upper McKinlay River ranges from low grade to moderate grade. South of the Fullarton River pelites are more abundant, but are commonly pneumatolytically altered. Here this alteration has masked many of the metamorphic effects, though, amongst the greisen and secondary muscovite, andalusite porphyroblasts remain and suggest a moderate metamorphic grade for these rocks.

The pelites that crop out 12 to 15 miles east-south-east of Cloncurry are in the greenschist facies; assemblages include quartz-chlorite-muscovite and quartz-biotite-muscovite (Appendix 1, p. 285). Neither garnet nor chloritoid has been found in this area, but near the Gilded Rose gold mine colourless garnet, probably rich in the almandine molecule, appears, and the assemblage includes garnet, quartz, biotite, and muscovite. The presence of these minerals suggests that the albite-epidote amphibolite facies has been reached in this area.

Ten to fifteen miles farther south, near Soldiers Cap and Upper Snake Creek, the andalusite-garnet-biotite-muscovite assemblage is common in the pelites (Appendix 1, p. 285). Another assemblage, cordierite-anthophyllite-garnet-mica, has been found in a few places. Joplin (1955, pp. 40, 41) has described kyanite-garnet schist from this area, but kyanite has not been found in the course of the present work, and it is considered that the rocks concerned are the cordierite-anthophyllite-garnet rocks (Appendix 1, p. 286, Spec. J482B).

Assemblages containing either andalusite or anthophyllite are fairly typical of rocks in the cordierite-anthophyllite sub-facies of the amphibolite facies, particularly in thermally altered rocks, but garnet is not common. The garnet in the Soldiers Cap Formation is an iron-magnesia garnet (Appendix I, pp. 285-6) with a pink tint, and is rich in the almandine molecule, but its presence in such an assemblage is unusual according to Turner & Verhoogen (1951), because its place is normally taken by cordierite in this subfacies; however, they state (p. 449) that 'isomorphous substitution of iron for magnesium in cordierites of this type is limited; conversely, in almandine substitution of magnesium for iron is possible only to a small extent. Thus if the $\frac{FeO}{MgO}$ ratio in the bulk composition of the rock exceeds a certain value, MgO and FeO must be considered as separate components, and almandine and cordierite may crystallize side by side. Similarly, the presence of MnO allows the appearance of spessartine and almandine in rocks from which garnet would otherwise be absent'. Even so, the association andalusite-biotite is unstable.

Where grades corresponding to the amphibolite facies have been reached in the rocks of the Soldiers Cap Formation, schistose structures (andalusite-garnet-mica schist) are accompanied by granoblastic and poikiloblastic structures (cordierite-anthophyllite-garnet-mica rocks). These textural features, in conjunction with the mineralogical assemblages developed, suggest that temperature has been an important factor in the metamorphism of the rocks. Therefore, in the same formation, the schists 12 miles east-south-east of Cloncurry are in the greenschist facies, and, by contrast, the rocks of the Snake Creek area are in the amphibolite facies. The schists show strong schistosity and false cleavage, which demonstrate the importance of stress in the lower grades of metamorphism. Whether stress persists in the higher grades cannot be readily assessed as temperatures appear to have had the greater influence on mineralogical and textural features.

Tilley (1935, p. 191) has described thermally metamorphosed basic rocks from Botallack containing almandine and biotite, and attributes the garnet in these rocks to the metasomatic introduction of K_2O, FeO, and SiO_2, under wet low-temperature conditions. Harker (1932, p. 327) quotes the case of an area studied by Müller (1891) where metamorphism of a garnetiferous mica schist by the granite of Schneekoppe in the Riesengebirge resulted in a rock composed largely of andalusite and biotite, with new-formed garnet in well-shaped crystals. Analyses show that the garnet is fairly normal almandine. Harker quotes this assemblage as resulting from regional following thermal metamorphism.

In the Soldiers Cap area the Group IV basic igneous rocks intruded the pelitic succession after it was folded and metamorphosed (see p. 140), and show from low to moderate grade thermal metamorphism. This shows that a second metamorphism has affected the Soldiers Cap rocks, but it is not known whether it was of sufficient intensity to change the imprint of the first. The sequence of metamorphic events in this case appears to be the reverse of that found by Müller.

High-grade metamorphic rocks are mostly in the Corella Formation and their outcrops have a roughly linear distribution between lat. 20°23′30″S, long. 140°03′15″E (that is, immediately south of Cleanskin Creek) and Mount Philp. Other high-grade rocks have been observed in the Eastern Creek Volcanics bordering the Sybella Granite from the Old Slaughter Yards in the north to Sulieman Bore in the south.

Interesting rocks, from the zonal point of view, occur south of the Inkerman copper mine on Cattle Creek, in the Rosebud mine area, and in the Cleanskin Creek area. Joplin (1955, pp. 40, 41) has referred to some of these rocks, and in those from Cleanskin Creek she has recorded kyanite, though in the course of the present work on rocks from this area, sillimanite was the only index mineral found. The sillimanite occurs with micas but no cordierite, whereas the occurrences of high-grade rocks in the Eastern Creek Volcanics referred to below contain cordierite, micas and, less commonly, andalusite with sillimanite.

In the sillimanite-biotite-muscovite schist (Appendix I, p. 291, Spec. J421B) from Cleanskin Creek sillimanite occurs in conjunction with muscovite, constituting a disequilibrium assemblage. In the thin section it can be seen that some of the sillimanite developed from muscovite, but also that there are stout discrete prisms of sillimanite. Possibly the formation of the stout sillimanite grains can be attributed to metasomatism related to nearby granite.

Staurolite-garnet-biotite-muscovite schist (Appendix I, p. 290, Spec. R6928) crops out on Cattle Creek; it has an equilibrium assemblage of the staurolite-kyanite subfacies. It is interbedded with a rather unusual garnet-mica schist rich in biotite idioblasts (Pl. 29, fig. 1). In the field andalusite has been recorded from this area. These rocks, like the thermally metamorphosed rocks from the Rosebud Mine area and the Mount Philp area, reach the amphibolite facies, but the latter are in the cordierite-anthophyllite subfacies. All these rocks are within the Corella Formation.

Another staurolite-bearing rock has been reported by White (1960). The staurolite occurs in muscovite-biotite schist near the base of the Mount Elliott Slate Member of the Kuridala Formation, near the Mount Elliott copper mine. No garnets have been seen in this rock, so it need not necessarily have formed by regional metamorphism.

The presence of apparently high-grade metamorphic rocks which form scattered outcrops along the eastern margin of the Urandangi 4-mile Sheet area and the south-eastern part of the Mount Isa 4-mile Sheet area, is an interesting metamorphic feature of the central western part of the region. These rocks have been observed at the Old Slaughter Yards 8 miles north-west of Mount Isa: on one of the Mothers Day uranium leases (lat. 20°40′10″S, long. 139°25′30″E); on the headwaters of Mica Creek; on Rocky Creek, 6 miles north-west of Sulieman Bore; and on Yaringa Creek. At the northernmost occurrence, the rock is mainly cordierite-sillimanite-muscovite-biotite schist, and the rocks from Rocky Creek appear to be of higher grade still: they contain a similar cordierite-sillimanite-muscovite-biotite assemblage, but may also include small amounts of andalusite, garnet, tourmaline, or rutile. Quartz, and commonly plagioclase, occur in these rocks (Appendix I, pp. 288-9).

Joplin (1955, p. 39) suggests that these rocks are windows or small inliers of high-grade regionally metamorphosed ?Archaean basement within the Lower Proterozoic country rocks, which form metamorphic unconformities. She has pointed out (personal comment) that their textures are very different from those of other nearby rocks; and they may have been buried under high confining pressure and rising temperature. However, mapping has failed to detect any structural discordance in either area (see p. 76), and the small patches of high-grade rocks could be interpreted as localized metasomatic occurrences related to granitic rocks emplaced during metamorphism. The presence of tourmaline, and the apparent structural continuity of the country rocks, lend support to this alternative.

Some instructive textural and mineralogical features are shown by the thin sections of these apparently high-grade rocks. The cordierite porphyroblasts are coarsely poikiloblastic, and hence probably grew at depth. Sillimanite, and rarely andalusite, form large prisms, and the accessory minerals tourmaline, apatite, and rutile form stout idioblasts, which are also characteristic of rocks recrystallized under high confining pressure.

The presence of sillimanite is generally taken to indicate that stress accompanied high-grade metamorphism. However, Turner & Verhoogen (1951, p. 442) have suggested the possibility 'that sillimanite is the truly stable form of Al_2SiO_5 in this [pyroxene-hornfels] facies and that andalusite, though highly characteristic, is in fact metastable'. Possibly, therefore, the stress implication of sillimanite may be ignored. Sillimanite may have formed during high-temperature metamorphism accompanied by slight metasomatism (removal of potash) during synchronous granitic emplacement. Such an environment is reasonable because of the presence of andalusite, and would have resulted in the direct replacement of micas by sillimanite, particularly under metasomatic conditions when equilibrium would be rapidly reached.

Contact Metamorphism

The contact effects of the Nicholson Granite on the Cliffdale Volcanics have not been studied. Field observations on the Weberra Granite show that silicification and probably some hornfelsing occur at the contact with the main granite body. Near its north-western margin calc-silicate rock has been recorded, derived apparently from a dolomitic shale. North-west of the Gregory River, mica schist is associated with a muscovite-rich phase of the Weberra Granite.

In the Lower Proterozoic metamorphic belt, only a few low-grade contact-altered rocks—other than those regionally metamorphosed—have been recognised; they include the spotted scapolite-calcite-biotite rock described by Joplin (1955, p. 43): a similar rock is described in Appendix I, p. 294, Spec. R6932. In the basic igneous rocks, other low-grade assemblages are found. Some rocks retain most of their high-temperature minerals, but original pyroxene grains may be rimmed by hornblende and there may be a slight diminution in the lime content of the original basic feldspar. In the other rocks, particularly where a low-temperature mineral assemblage existed at the time of metamorphism, the contact metamorphism is shown by biotite replacing sericite and some of the chlorite, calcite, and opaque iron mineral; the original texture is preserved. The original basic plagioclase had already given rise to albite and epidote, and generally some calcite and chlorite had been formed, in part, from the ferromagnesian minerals. Fine dusting with opaque iron mineral is also common, particularly in rocks which originally had a glassy base. Such thermally altered rocks as these may be found in scattered outcrops penetrating the Leichhardt Metamorphics between Dobbyn and Dajarra. Examples may be seen one mile east of Dajarra and in the Carioca copper mine area.

Moderate-grade rocks containing assemblages typical of contact metamorphism occur in the Rosebud and Mary Kathleen mine areas and farther south, near Mount Philp. All are in the Corella Formation and their metamorphism is typical of the cordierite-anthophyllite subfacies of the amphibolite facies, but unlike the rocks (pp. 163-5) whose assemblages are attributed to regional metamorphism, these rocks do not contain garnet. Whether they are genetically related to the nearby granite has not been established. An example is the cordierite-anthophyllite rock (Appendix I, p. 291, Spec. R6935), which was probably derived from a magnesia-rich sediment; possibly magnesia-iron metasomatism also contributed to its formation. The presence of silica suggests that complete equilibrium has not been reached. Another rock, from Mount Philp, is a thermally-altered basic igneous rock that retains its original ophitic texture. Mineralogically, however, the rock has been changed to a diopside-hornblende-andesine assemblage, with which smaller amounts of biotite, sphene, and apatite occur. This assemblage is also typical of the amphibolite facies.

Other evidence of moderate-grade contact metamorphism has been observed east of the Mount Cobalt mine, where andalusite has been recorded in the field in mica schists of the Kuridala Formation; andalusite has also been recorded one mile east of Duchess. Garnet has not been reported in these rocks.

Metamorphic Subdivisions and Unconformities

The region is broadly divisible into two major metamorphic units; one is the metamorphic belt corresponding to the rocks of the eastern geosynclinal area and the metamorphic rocks south of Mount Isa to Smoky Creek, and the other consists of the little-altered sediments of the western geosynclinal area to the north and north-north-east of Mount Isa. The rocks in the first unit are complexly folded, moderately metamorphosed and strongly deformed in places; further, they are affected by widespread regional metasomatism and extensively intruded by granite. By contrast, the rocks in the second unit are simply folded, little metamorphosed although locally dislocated, and, as far as is known, they are unaffected by regional metasomatism; only one granitic mass is known to occur (Weberra Granite). There is a strong metamorphic unconformity between these two units where the western geosynclinal strata overlap on to the Leichhardt Metamorphics and Kalkadoon granodiorite along Gorge Creek and north to St Pauls Creek.

In less general terms the region has been tentatively divided into six metamorphic units, which essentially correspond to the major stratigraphical and tectonic divisions. A wide range of metamorphic effects may be found within each unit, though in each some features are sufficiently distinct to make possible a general metamorphic division of the region. The following units are recognized:

1. A belt of rocks of moderate metamorphic grade extends from north of Dobbyn south to Dajarra and beyond; the overall metamorphic grade increases from north to south. The belt coincides with the outcrop of the Leichhardt Metamorphics. Field relations of basic intrusives to granite, and of basic intrusive

to basic intrusive or country rock, particularly microscopic evidence of metamorphic unconformities, show that the Leichhardt Metamorphics have been involved in at least three diastrophic episodes, some or all of which included intrusion of granite. As a result, the rocks show the effects of regional (or thermal) and dislocation metamorphism or both. However, regional metasomatism masks, in places, the earlier metamorphism, whereas dislocation may mask the products of the earlier metamorphism and metasomatism.

2. (a) A group of rocks of low-grade metamorphism forms the central portion of the metamorphic belt; it surrounds an axial zone (b) of moderate-grade rocks. It is bounded in the west by the eastern margin of the Leichhardt Metamorphics, and in the east by the 'Cloncurry Overthrust', and it extends the full length of the metamorphic belt. Much of the Marraba Volcanics and the Marimo Slate are in the greenschist facies; Edwards & Baker (1954, p. 31) believe that the rocks near Duchess are in the biotite zone; and White (1960) has shown that most of the rocks in the Kuridala-Selwyn area, forming the Answer Slate, Staveley, and Kuridala Formations, have undergone only low-grade metamorphism.

(b) The axial zone of moderate-grade rocks extends from Cleanskin Creek at lat. 20°23′30″S, long. 140°03′15″E in the north, through Mary Kathleen, Cattle Creek, and Mount Philp, to near Green Creek well in the south. The rocks in this zone are in the amphibolite facies.

Metamorphic unconformities occur in the metamorphic rocks of both (a) and (b). Numerous examples can be found at Duchess between the basic igneous intrusives of Groups III and IV, and in the Rosebud copper mine area between cordierite-anthophyllite rocks of the Corella Formation and the low-grade Group IV basic igneous rocks.

Regional metasomatism, whose effect is most marked in the Corella Formation, and dislocation metamorphism, mask earlier metamorphic changes in many places. Again, there is evidence that strata have been affected by more than one diastrophic episode.

3. Low-grade to moderate-grade rocks, found only in the Soldiers Cap Formation and east of the 'Cloncurry Overthrust', include garnet-andalusite-mica and garnet-cordierite-anthophyllite assemblages: these suggest a strong thermal factor caused by either deep burial or abnormally high temperatures.

Metamorphic unconformities occur in the Snake Creek area between low-grade Group IV basic intrusives and moderate-grade regionally metamorphosed strata. Both have been intruded by granite. Whether or not granite accompanied the initial regional metasomatism of the strata has not been determined. Regional metasomatism affects the rocks in places.

4. A unit that is characterized by moderate-grade metamorphism, and, as a result of faulting over wide areas, by dislocation metamorphism, comprises the Mount Guide Quartzite and portions of the Eastern Creek Volcanics, which crop out mainly along the western margin of the Duchess, the eastern margin of the Urandangi, and the south-eastern part of the Mount Isa 4-mile Sheet areas.

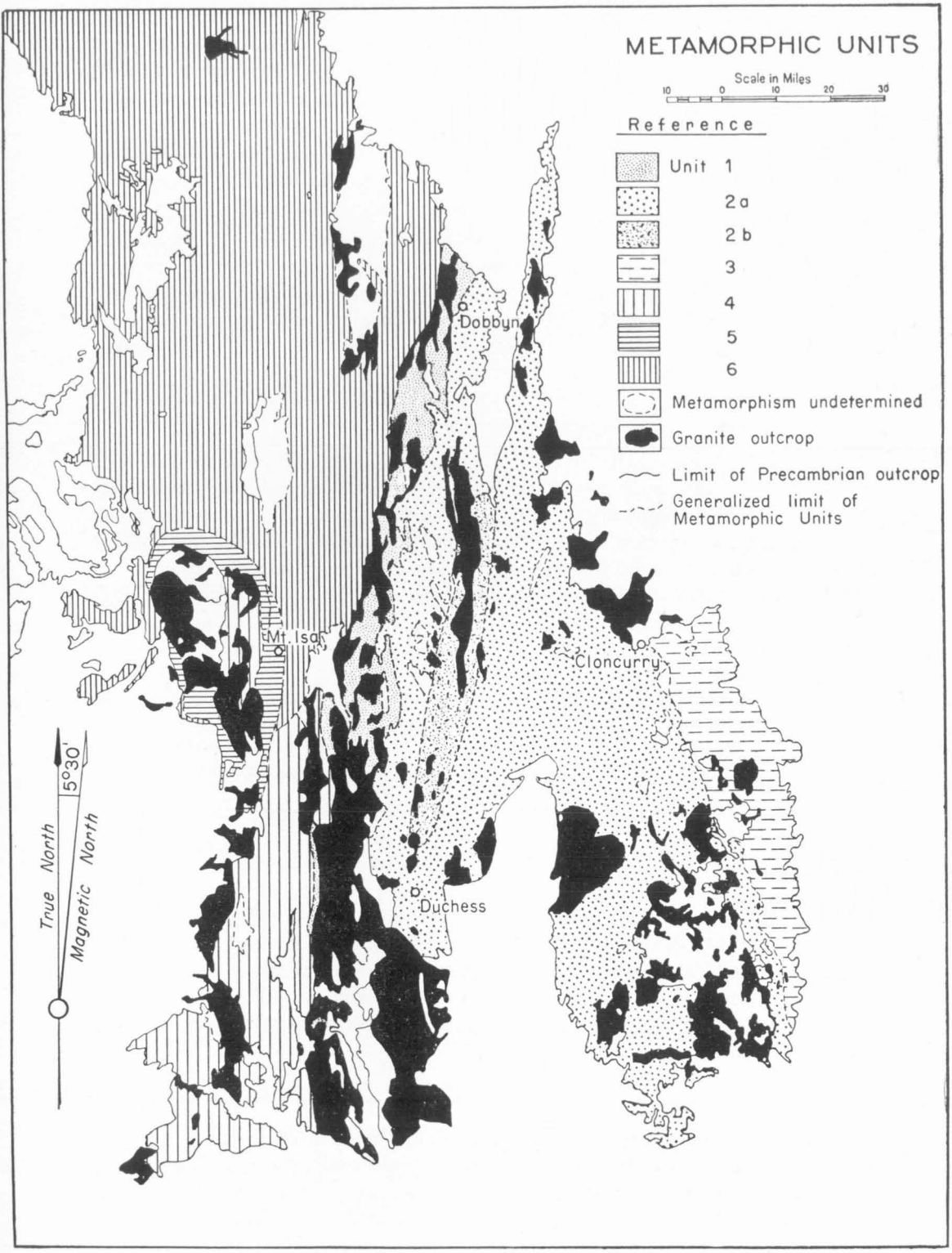

METAMORPHIC UNITS
Scale in Miles
10 0 10 20 30
Reference
Unit 1
2a
2b
3
4
5
6
Metamorphism undetermined
Granite outcrop
Limit of Precambrian outcrop
Generalized limit of Metamorphic Units
Dobbyn
Mt Isa
Cloncurry
Duchess
True North
Magnetic North
5°30'

Fig. 14.

Metamorphic unconformities have been observed on Kittys Plain, about 11 miles north-west of Mount Isa, between basic igneous rocks of Groups II or III and the low-grade rocks of Group IV. The genesis of apparently high-grade rocks in moderate-grade strata of the Eastern Creek Volcanics, between the Old Slaughter Yard in the north and Sulieman Bore in the south, has been discussed. Further, many outcrops of basaltic rocks north and north-west of Dajarra are apparently low-grade, yet they are surrounded by moderate-grade amphibolites. The relationships in this area are not fully understood.

5. Low-grade schists and dislocated rocks form a belt along the east and north of the Sybella Granite in the Mount Isa Sheet area. The Judenan Beds peripheral to the Sybella Granite demonstrate the metamorphic characteristics of this unit: pelites, and acid and basic volcanics, show strong dislocation metamorphism. The unit was probably metamorphosed during the final Lower Proterozoic orogenic deformation; the granite may have acted as a rigid block around which strata of the western belt were wrapped.

6. This division includes all the little-altered Lower Proterozoic rocks of the western belt; in general terms it embraces the Myally Beds and contemporaneous and younger strata north of the Barkly Highway, and the Mount Isa Shale and Mingera Beds. The most highly metamorphosed strata of this division display mineral assemblages found low in the greenschist facies. Much of the alteration shown, however, particularly that of some of the basic lavas (Appendix I, p. 289, 296), is best attributed to hydrothermal migration of carbonates, iron, and silica.

Metasomatism

Soda and potash metasomatism, and hydrothermal alteration, superimposed on many of the metamorphic and igneous rocks in the Lower Proterozoic metamorphic belt, have added greatly to the diversity of rock types in the region. So far as is known the Myally Beds and younger rocks were not affected.

Soda and chlorine metasomatism, that is, the regional metasomatism, have affected many hundreds of square miles. Edwards & Baker (1954) have described the scapolitization and formation of 'red rock' in some detail, particularly in the Duchess-Trekelano and Dugald River areas, which are 75 miles apart. Joplin (1955) has described similar rocks from the Cleanskin Creek and Mount Burstall areas. The present work has shown that the regional metasomatism, to which the scapolite-bearing rocks are attributed, extended over wide areas, including the intervening areas between the localities previously studied. The rocks in the Corella Formation and some of the basic igneous rocks were particularly affected by the regional metasomatism, and show most of the changes caused by it.

The effects of potash metasomatism and general hydrothermal alteration have been widespread and their products are found in the same country rocks as those of the regional metasomatism; each process can, therefore, be studied in the same areas, as the products of each are sufficiently distinct. There are, however, areas where the products of one process are evident without those of the others. Although the regional investigation has supplied enough data to enable

the effects of the processes to be readily recognized, products representing all stages in the processes are not available for detailed study.

The present investigation has shown that soda metasomatism followed the main regional metamorphism (which is attributed to the first main Lower Proterozoic orogenic deformation), and was followed, in turn, by potash metasomatism, with granitization, and hydrothermal activity. A suggested scheme of events is set out in Table VI, and the following discussion is presented according to the sequence of events postulated. Although the events are tabulated as in sequence many are probably protracted and overlap with others.

Soda and Chlorine Metasomatism

Edwards & Baker (1954) have described scapolite-pyroxene granulite, scapolite marble, scapolite-biotite and hornblende-biotite schist, and scapolite-albite-hornblende schist. The general description of the rocks given in their abstract is:

'The characteristic rocks are banded scapolite-pyroxene granulites, in which the banding corresponds to bedding of original fine-grained sediments, thought to have been calcareous shales. The granulites consist essentially of a dipyre, $Ma_{75}Me_{25}$, and a bright-green ferriferrous augite, with abundant accessory pink sphene. Some of the granulites contain albite in place of the scapolite, and hornblende or biotite in place of the pyroxene. In places the scapolite granulites are interlayered with the metamorphic equivalents of shales, or grade into scapolite marbles. Elsewhere they appear interbedded with amphibolites.'

In Appendix I (pp. 292-4) descriptions are given of representative metasomatic rocks. The hornblende-diopside-plagioclase-scapolite granulite probably had a similar genesis to the rocks examined by Edwards & Baker. The spotted scapolite-biotite-calcite rock (p. 294) is typical of the low-grade calc-silicate rocks from the Corella and Charley Creek Formations.

Edwards & Baker believe that the formation of either pyroxene, or hornblende, or biotite, was determined by the amount of lime available for combination with magnesia and iron oxides in the rocks, in excess of that required for the formation of scapolite and albite; pyroxene formed where lime was in considerable excess, whereas biotite was produced where there was little or no excess of lime. Thus they conclude (p. 30) that 'the fine interleaving of biotite-albite schists with scapolite-pyroxene granulites . . . . can be explained in terms of soda-metasomatism of finely interbedded calcareous, slightly calcareous and non-calcareous shale bands'. They also indicate that such conditions of soda-chlorine metasomatism, affecting these bands, and also dolomitic beds, could give rise to scapolite granulites, scapolite-albite granulites and albite granulites. Moreover, they believe (p. 31) that the presence of abundant pyroxene does not imply a high temperature of formation, or a high grade of metamorphism, but that the biotite in the metamorphosed non-calcareous shales is probably the best indicator of the grade of metamorphism.

Joplin (1955, p. 45), on the other hand, has compared some of the para-amphibolites from the Duchess area to hornfelses of Classes 7 and 8 (Goldschmidt, 1911), particularly those containing a diopside-plagioclase assemblage; those

with diopside-hornblende-plagioclase and hornblende-plagioclase assemblages possibly represent Class 6, or were formed under conditions of wet contact metamorphism (Joplin, 1935). Joplin was also impressed by the close similarity in hand specimen between the Dugald River and Duchess rocks, and she thus considers that the scapolite-bearing granulites described by Edwards & Baker from the Duchess area are scapolitized representatives of such hornfelses.

Joplin has observed other para-amphibolites on Cleanskin Creek in close association with apparently high-grade regionally metamorphosed rocks; the assemblage quoted includes kyanite and sillimanite, with textures attributed to high-grade regional metamorphism. She also records that quartz and calcite co-exist in the vicinity; this excludes the possibility that the rocks resulted from high-grade contact metamorphism. This conclusion appears to conflict with the views expressed by Edwards & Baker, who believe that the rocks are essentially products of metasomatism.

During the present examination of rocks from the same locality on Cleanskin Creek kyanite was not observed (p. 163). The rocks from this area include sillimanite-biotite-muscovite schist (Appendix I, p. 291, Spec. J421B). Sillimanite may form from mica during metamorphism supplemented by metasomatism (p. 165). Furthermore, para-amphibolites containing assemblages with quartz and calcite in co-existence have not been observed in close proximity to the sillimanite-bearing rocks, but are known to occur in the Mount Burstall area.

Possibly, therefore, the rocks with pyroxene-hornblende-plagioclase assemblages, containing quartz and calcite, could be metasomatic products, as at present there is no evidence to necessitate a contrary view.

Although Edwards & Baker (1954, p. 31) do not suggest a source for the sodic emanations, they consider that metasomatism was contemporaneous with regional metamorphism. They have noted the similarity between the metasomatic products of the Kiruna district of Sweden (Sundius, 1915) and those of Duchess. In the Kiruna district, the scapolitization is considered to be genetically related to the intrusion of basic magma during regional metamorphism, which resulted in 'regional-pneumatolytic metamorphism'.

Group III and Group IV basic igneous rocks (p. 134) have been observed at Duchess, but the distribution of neither appears to coincide with regional metasomatism. In this respect, much depends on whether scapolitization was a short single event or a protracted one, and whether a second, less intense, scapolitization occurred. Commonly the degree of scapolitization shown by rocks appears to depend on their metamorphic and structural conditions before metasomatism. Rocks whose grains had been internally fractured, resulting in larger granular surface areas, are more intensely altered by metasomatism than are undeformed rocks. At Duchess many of the Group III basic igneous rocks are intensely metasomatized, having been previously metamorphosed and deformed during the first orogenic deformation. By contrast, the Group IV basic igneous rocks show only slight scapolitization along incipient joints. These rocks did not undergo intergranular fracturing as they were emplaced after the regional folding and

metamorphism. If the soda and chlorine metasomatism was a single, short-lived, event it must therefore have occurred after the emplacement of the younger basic igneous rocks, and would then be unrelated to basic igneous activity.

If further slight scapolitization followed the main regional metasomatism, the main scapolitization could have accompanied the emplacement of the Group IV basic igneous rocks. At Duchess there does appear to be a fairly close association between Group IV basic rocks and areas where the para-amphibolites show most intense metasomatism, but regionally this association does not appear to hold; the effects of regional metasomatism are more widespread than the Group IV basic igneous rocks. In fact, a closer coincidence exists between the soda-rich granitic rocks and the products of metasomatism. Therefore, returning to the original proposition of a single metasomatic event, this alternative has much to commend it.

Granitic rocks are known to intrude the first four groups of basic igneous rocks. Joplin (1956) has already suggested that albitite in the region represents a late differentiate of granitic magma, and is thus unrelated to basic igneous activity. On chemical grounds, therefore, the soda and chlorine necessary for regional metasomatism may have been related to granitic emplacement and may have been concomitant with the formation of the albitite (Table VI). This interpretation is discussed in greater detail in Joplin & Walker (in press).

Potash Metasomatism and Granitization

Potash metasomatism and granitization have affected the country rocks over wide areas. They followed the regional metasomatism and have affected, in particular, the scapolite-bearing para-amphibolites in the Corella Formation and the basic igneous rocks of the first four groups. They are related to and probably concomitant with the general hydrothermal alteration discussed below.

The products of potash metasomatism are widespread and include potash feldspar porphyroblastic rocks (Appendix I, p. 283) and granitic rocks in addition to rocks with the appearance of aplite and pegmatite. Another product described in Appendix I (p. 292) is a hornblende-plagioclase-microcline-scapolite granulite from the Corella Formation.

Granitization has been observed in granitic rocks, acid lavas, psammitic rocks, ortho-amphibolites, and para-amphibolites. Joplin (1955, p. 42) and Joplin & Walker (in press) have recorded microcline porphyroblasts in granitic rocks from the Waverley Creek area (Urandangi Sheet) and in acid lavas. Joplin (p. 47) suggests that some of the large quartz and microcline grains of irregular outline in acid lavas on the Leichhardt River may be porphyroblasts grown as a result of static granitization.

An examination of rocks from the Mount Cuthbert, Crusader, Edna May, and Lady Fanny mine areas, and from the old Mount Isa-Cloncurry Road, about 25 miles from Mount Isa, shows that the acid lavas and interbedded metasediments of the Leichhardt Metamorphics and Argylla Formation have undergone, to various degrees, both soda and potash metasomatism, as some of the

original feldspar has been albitized, and some of the albite pseudomorphs of microcline are cut by microcline veins. Further, in some rocks two generations of microcline occur. The second generation microcline forms discrete grains showing coarse gridiron twinning and has irregular, typically porphyroblastic, margins, in contrast with the partly-replaced original microcline, which displays fine cross-hatched twinning. As a result of the potash metasomatism the rocks affected are much richer in microcline than is normal for such types. Some of the rocks are almost completely reconstituted.

The Argylla Formation also includes some formerly argillaceous quartzites, and some conglomeratic beds, which illustrate porphyroblastic development very clearly. Similar porphyroblastic rocks have been observed in the Corella Formation, 4½ miles east of Duchess, and half a mile north of Chumvale Homestead, and in the Ballara Quartzite half a mile north-east of the Wee MacGregor copper mine. In these rocks palimpsest structures are generally absent, except for the rounded pebbles of the conglomerate. The conglomerates in the Three Threes (Argylla Formation) and the Wee Macgregor mine areas contain abundant rounded quartzite pebbles, and that from two miles west-south-west of the Rifle Creek dam contains sparsely distributed rounded quartzitic and granitic pebbles. The matrices of these conglomeratic rocks have the appearance of an acid volcanic in hand specimen, as they contain porphyroblasts of feldspar and quartz. However, an examination of the thin section shows that the porphyroblasts grew in their matrices, the matrix being more susceptible to metasomatism than the relatively inert pebbles.

This differential metasomatism raises the possibility that the main rock types were affected differently by the same metasomatic process. For example, the calc-silicate rocks of the Corella Formation commonly show 'red rock' development and granitization, whereas, during their metasomatism, only feldspar-porphyroblastic rocks appear to have developed in the Argylla Formation.

Some country rocks were completely transformed to granite during the potash metasomatism, and though granitization effects occur in many parts of the region they are, with the exception of the Wonga Granite, commonly localized at the margins of granite masses. Examples of granitization of metasediments can be seen in the Corella Formation about 10 miles east of the Lady Fanny copper mine, at lat. 21°13′30″S, long. 140°08′10″E, (Pl. 21, fig. 2), and in the Staveley Formation 4½ miles south-south-east of Kuridala, where the granitic rocks preserve structures of the original sediments. At these localities, and in the Duchess area, aplite-like and pegmatite-like rocks also resulted from the granitizing process. The pegmatite-like dykes and veins at Duchess range from a few inches to tens of feet wide.

The occurrence east of the Lady Fanny mine is the most impressive, as granite has formed from the thinly banded and puckered para-amphibolites, composed of alternating bands rich in leucocratic and ferromagnesian minerals. The para-amphibolites are mineralogically similar to those described from Duchess (Edwards & Baker, 1954); they grade imperceptibly into a microcline granite composed of

microcline, quartz, and plagioclase, and roughly equal but lesser amounts of biotite and hornblende (p. 153).

Petrographical examination of the para-amphibolites and granitized rocks east of the Lady Fanny mine shows that they carry microcline in the leucocratic bands; it appears to have replaced much of the plagioclase and all of the scapolite, as scapolite is not preserved in the derived microcline granite. This replacement was accompanied by an increase in the amount of quartz (Joplin & Walker, in press). Where the para-amphibolites have been almost completely converted to granite, much of the original ferromagnesian minerals has disappeared, and, except for relict banding, the rocks have become fairly homogeneous biotite-hornblende-plagioclase-microcline granite. Nevertheless, some scapolite grains persist in the ferromagnesian-rich bands until a very late stage in the granitization of the rock, apparently having escaped alteration by a preferential shielding effect of the ferromagnesian minerals.

The formation of granite *in situ* from para-amphibolite would involve the redistribution of large volumes of material. Much of the MgO, CaO, and FeO would have to be removed and large volumes of K_2O, Al_2O_3, and SiO_2 added in order to produce a granitic rock of the type described on p. 153. Production of granite by a metasomatic process is supported further by the fact that the metamorphic grade of the granitized rocks does not appear to have been high; in fact, granitization affected rocks in the low to moderate grades.

General Hydrothermal Alteration

Hydrothermal alteration may have accompanied or immediately followed potash metasomatism; but it clearly followed the soda metasomatism. Edwards & Baker (1954, pp. 15, 32) note the formation of 'red rock' from para-amphibolite by hydrothermal alteration, and (p. 23) observe that in bore cores and other specimens from Trekelano 'the veins and associated bands of "red rock" cut across the foliation of the hornblende schists and scapolite granulites at various angles'. Half a mile west of Duchess a similar sequence can be observed: a stratified breccia has been homogeneously scapolitized and has formed a para-amphibolite in which outlines of breccia fragments are preserved; red feldspar veins cut both matrix and breccia fragments, and were therefore emplaced after scapolitization.

The distinction between the general hydrothermal alteration and the potash metasomatism with granitization, however, is not so clearly defined. In areas of extensive 'red rock' development, including replacement veins (for instance, in the Duchess area), distinctly aplitic and pegmatitic rocks are abundant, apparently cutting the 'red rocks' in places, grading into them elsewhere, or forming large masses within them. The relationships between the various rock types are not fully understood, but the potash metasomatism and the general hydrothermal alteration may have been related, and contemporaneous, processes.

As a result of the general hydrothermal alteration, segregations of feldspar, epidote, hornblende, silica, calcite, and hematite, together with some sulphide

minerals, occur in many of the country rocks, notably in the Corella Formation. Intrusive and replacement veins (Pl. 28, fig. 1) of feldspar (mostly albite) also formed as a result of feldspathization during this alteration.

Areas affected by intense hydrothermal activity are widespread; notable examples occur at Duchess, 2 miles north-east of Mount Philp, and 4½ miles south-south-east of Kuridala.

Edwards & Baker (1954) have described 'red rocks' from the Duchess, Trekelano, and Dugald River areas. They state: 'The "red rock" appears to consist chiefly of recrystallized albite, and scapolite, together with secondary quartz.' Descriptions of 'red rocks' from Duchess and near the Gilded Rose mine are given in Appendix I (p. 293, Specs. R7209, R7210).

In the Duchess area and elsewhere, many cubic miles of para-amphibolitic country rocks surrounding some of the north-south fractures and shears have been converted to 'red rock'. Strongly reactive hydrothermal solutions apparently exploited faults, small fissures, and foliation planes in the ortho-amphibolites and the para-amphibolites and other metasediments. They leached some of the constituents from the wall rocks and redistributed and replaced other material, particularly feldspar and silica, to form the vast volume of 'red rock' and the replacement veins and dykes which cut the country rocks. The bedding planes of the original para-amphibolites can be traced undisturbed through many of the dykes. The veins and dykes (Pl. 28, fig. 1) range from a fraction of an inch to many feet wide.

Edwards & Baker (1954, pp. 15 & 32) have shown that the formation of 'red rock' involved the leaching of most of the MgO, and much of the CaO and FeO, from the para-amphibolites of regional metasomatic origin. They note that magnetite is present in segregations and deduce from the presence of finely intergrown ilmenite and hematite that these minerals 'have unmixed from solid solution, so that presumably such segregations formed above 500°C'.

Where large tracts of para-amphibolites have been transformed to 'red rock', relict fold structures in the original amphibolites are commonly preserved, indicating that hydrothermal alteration took place without structural deformation; this suggests that the process was accompanied by little volume change, if any. Around some of the 'red rock' zones at Duchess are para-amphibolites which are more basic than most in the region. Possibly they are enriched in ferromagnesian minerals formed from material expelled during the development of 'red rock' that formed nearby. Moreover, on a regional basis, the same mineral assemblages have been produced by general hydrothermal alteration, and show the same relationships in widely separated areas of calc-silicate rocks in the Corella and Staveley Formations. This seems to suggest that the process is one of redistribution of material in the country rocks; the degree and extent of the alteration depend only on the intensity of the hydrothermal activity at each locality.

As mentioned, the other results of this hydrothermal process include the concentration of calcite, epidote, amphibole, silica, and opaque iron minerals. These can be seen associated intimately with 'red rock'.

Calcite is locally concentrated in many places in the para-amphibolites and other lime-rich metasediments. It forms both narrow lenses concordant with the bedding and large transgressive bodies, in favourable structural positions. It is coarsely crystalline and commonly is very pure; some bodies also contain crystalline dolomite and others have disseminated copper minerals. The larger bodies are mined for use as smelter flux at Mount Isa (see p. 246).

Epidote is conspicuous in the Corella Formation, Eastern Creek Volcanics, and Marraba Volcanics, but also occurs in other formations. At Duchess and along the Edna May road, 16 miles east of Mount Isa, epidote can be seen concentrated in silicified patches, particularly where north-south fractures cut basic rocks. The widespread basaltic rocks which show deuteric, or slight hydrothermal, alteration contain much epidote or chlorite. With more intense alteration, epidote formed in fractures and segregations, and became finely disseminated through interbedded psammitic strata in some basaltic successions, forming epidote quartzites.

Amphibole segregations are common in the Corella Formation; they developed with the formation of 'red rock'. The amphibole is not as dark as the hornblende in the para-amphibolites; much of it is fibrous and is probably a tremolitic variety.

Silicification of faults and fissures has occurred repeatedly throughout the geological history of the region. Fractures have been filled wtih massive vein quartz, or the wall rocks have been replaced by silica, resulting in a broad silicified band with a quartzitic appearance. Many of the outcrops weather to form banded ridges. The Fountain Range Fault (Pl. 25) is a conspicuous example, but similar outcrops abound in the Lower Proterozoic metamorphic belt. Other siliceous outcrops, however, are unrelated to structural features; they occur mainly on the inland drainage fall, on ridges. The silica, which is grey to white, is probably of supergene origin, and marks an early Tertiary or older land surface. Examples are the silicified residuals that cap sericite and chlorite schists near Mount Isa. These outcrops form hills with a massive quartzitic appearance, but a tunnel into one hill has revealed only soft schists.

Iron minerals, including hematite and magnetite, are concentrated in several places. Segregations occur close to 'red rock'; but larger exposures include Mount Philp, Mount Leviathan (Black Mountain, near Cloncurry) and sill-like ironstone bodies south of Selwyn (Carter & Brooks, 1955). At Mount Philp, ironstone forms a long irregular outcrop, 11,000 feet long and of average width 85 feet, which strikes a little east of north and transgresses para-amphibolite. Possibly the Mount Philp iron ore represents iron oxides expelled during the extensive hydrothermal alteration which gave rise to the 'red rock' in the Mount Philp Agglomerate. The iron oxides may have replaced a pre-existing fault zone as Carter & Brooks (1955, p. 7) have indicated that the deposit is younger than the metamorphism and metasomatism and have shown in one place in the deposit that 'the pre-existing rock has been partially replaced by iron, and weathered surfaces are very similar in appearance to those of the unreplaced calc-silicate rocks'.

Pneumatolysis

Joplin (1955, pp. 42, 51) has referred to the products of pneumatolysis which are common at the margin of the porphyritic foliated granite (i.e. Sybella Granite) and elsewhere in the region. Locally schorl and biotitite have been developed.

Greisenization is particularly noticeable in the vicinity of the Sybella and Williams Granites, and mica and feldspar pegmatite dykes are common in the same localities. Muscovite is the most common mineral developed; tourmaline and fluorite are also widespread. Red garnet and beryl, and less commonly topaz, occur in a pegmatite at the Big Beryl Mine (Mica Creek area), and muscovite and beryl have been mined elsewhere in the Mica Creek area (see p. 249).

Garnetization of noteworthy extent is known only in the Mary Kathleen mine area and a few miles north-east, east, and south of it. Matheson & Searl (1956) state that iron garnet grew along joint planes in the para-amphibolites at the Mary Kathleen uranium mine.

STRUCTURE

The outcropping strata of the region fall into four distinct stratigraphical or structural divisions:

1. Upper Proterozoic.
2. Lower Proterozoic eastern belt (see Fig. 4).
3. Lower Proterozoic western belt, east of the Mount Gordon Fault-zone.
4. Lower Proterozoic western belt, west of the Mount Gordon Fault-zone.

All but the Upper Proterozoic strata are considered to have undergone orogenic deformation. Fold-axis trends in the Upper Proterozoic units are generally west to north-west, folding is open and of moderate intensity, and commonly lacks strong linearity. Faulting is common, with displacements of several thousand feet in some cases, and appears to be for the most part normal faulting. Some of the faults affecting the Precambrian rocks also displace Ordovician sediments and are therefore Lower Palaeozoic or younger.

The Lower Proterozoic strata have, with some interesting exceptions, a general meridional trend. West of the Mount Gordon Fault-zone folds tend to be irregular and to be of the basin-and-dome type. The older strata, including most of those in the eastern geosynclinal belt, have been twice subjected to orogenic deformation. Compressive stresses acted from the east and west in each orogeny. Folding is strong to intense. Folds range in size from minor crenulations to regional structures, particularly in the eastern belt. The most numerous faults are transcurrent strike-slip faults, but high-angle reverse faulting, and probably strike faulting, are important, and some normal faults have been observed.

Faults played an important part not only in the final deformation of the orogenic belt, but also in its evolution. Faults can be recognised which date from the extrusion of the Eastern Creek Volcanics; others affect Middle Cambrian and

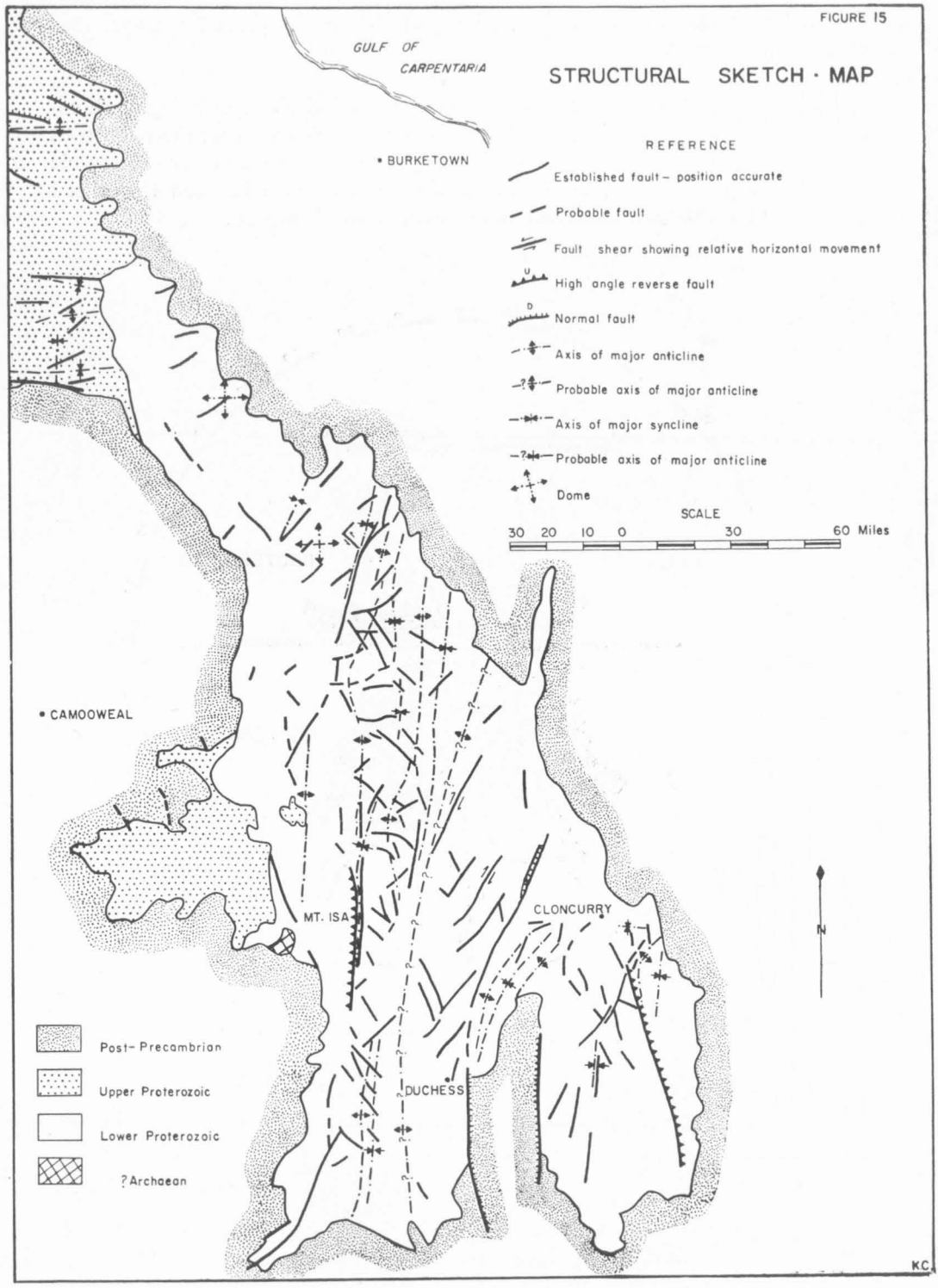


FIGURE 15
STRUCTURAL SKETCH · MAP
GULF OF CARPENTARIA
• BURKETOWN
REFERENCE
Established fault – position accurate
Probable fault
Fault shear showing relative horizontal movement
High angle reverse fault
Normal fault
Axis of major anticline
Probable axis of major anticline
Axis of major syncline
Probable axis of major anticline
Dome
SCALE
30 20 10 0 30 60 Miles
• CAMOOWEAL
MT. ISA
CLONCURRY
DUCHESS
N
Post- Precambrian
Upper Proterozoic
Lower Proterozoic
?Archaean
KC

Q2

Ordovician strata. Practically all faults dip at high angles, generally steeper than 65°.

Fold axes and faults of mappable size (recognised by either mapping or photo-interpretation) are shown in Plate 34, at the back of this volume; the main ones are shown in generalized form in Figure 15. An analysis of the Lower Proterozoic faults is presented in Figures 16-18. The marked contrast between Upper and Lower Proterozoic fault-directions is apparent from Figure 16.

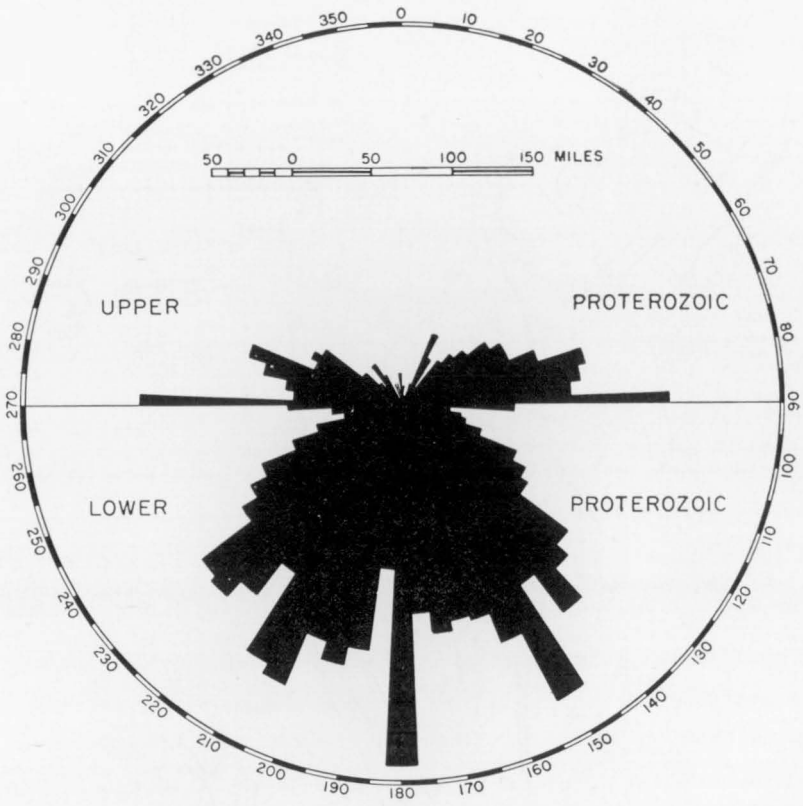


Fig. 16. Fault directions in the Precambrian.

Cleavage is absent from the Upper Proterozoic strata, and through most of the western geosynclinal sediments axial-plane cleavage is developed only in the least competent rocks. In the eastern belt axial-plane cleavage and schistosity are well developed.

The rocks that form the basement to the Lower Proterozoic are not well enough known to interpret their structures.

Folding

Many types of rock are found in the Lower Proterozoic sequence and the history of folding is complex. For these reasons the fold structures differ from place to place. The largest structures—the main anticlinoria and synclinoria—are relatively simple and open; they developed as arches while sedimentation was in progress and determined the later pattern of folding. Fold axes generally strike roughly north-south; a marked divergence from this direction is described below. In addition, there is a zone of pitch change about the latitude of Cloncurry, where roughly east-west fold axes have been recorded (see Pl. 26, fig. 1, and Pl. 34).

There is no evidence of nappes or autochthonous folds, but many minor folds are overturned, to dip west in the west of the outcrop area and east in the east. Lower Proterozoic strata in the western geosynclinal basin are only locally overturned. Folds generally pitch at steep angles, commonly over considerable distances.

Clear evidence of two periods of strong folding of the Lower Proterozoic rocks is given by the Deighton Quartzite, which dips up to 80°, but lies with a pronounced unconformity on older Lower Proterozoic rocks (see also p. 96).

A major north-east-pitching anticlinorium occurs south-west of Cloncurry. It extends over a meridional distance of 60 miles and the extremities of the limbs are up to 32 miles apart. It is a compound structure with two anticlinal areas separated by a narrow syncline (Fig. 11). The Argylla Formation, Marraba Volcanics, and Mitakoodi Quartzite crop out in the structure. The Mitakoodi Quartzite on the eastern limb of the fold displays an intricate secondary fold pattern, with fold axes striking and pitching about north-east, at a large angle to most of the folds in the region (Fig. 10).

The detail of folding in the Marraba Volcanics and the underlying Argylla Formation is not apparent, but a strong lineation, which cuts across the major fold axes, and also the minor fold axes in the Mitakoodi Quartzite, can be seen in the air photographs. Examination in the field indicates that the pattern is produced by close jointing, probably with some fault movement. In places, particularly in the Argylla Formation, dolerite dykes which have been sheared and regionally metamorphosed follow the fractures; elsewhere they cut across them.

It is suggested that the intricate folding in the Mitakoodi Quartzite has been produced by shear-folding, not at right angles to the compressive stress but parallel to the north-east component of the conjugate strike-slip fault system produced by the compression. Tuff, shale, and limestone underlie and overlie the Mitakoodi Quartzite. These rocks would readily yield to permit the complex folding of the sandstone (quartzite). The folding may have taken place during the first Lower Proterozoic orogenic phase, and the fracture-pattern may have been superimposed during the second.

Elsewhere the folding of the more competent strata is generally quite simple except in mineralized zones and near granite. The Corella Formation, on the other hand, displays great complexity of minor structures with intricate plastic

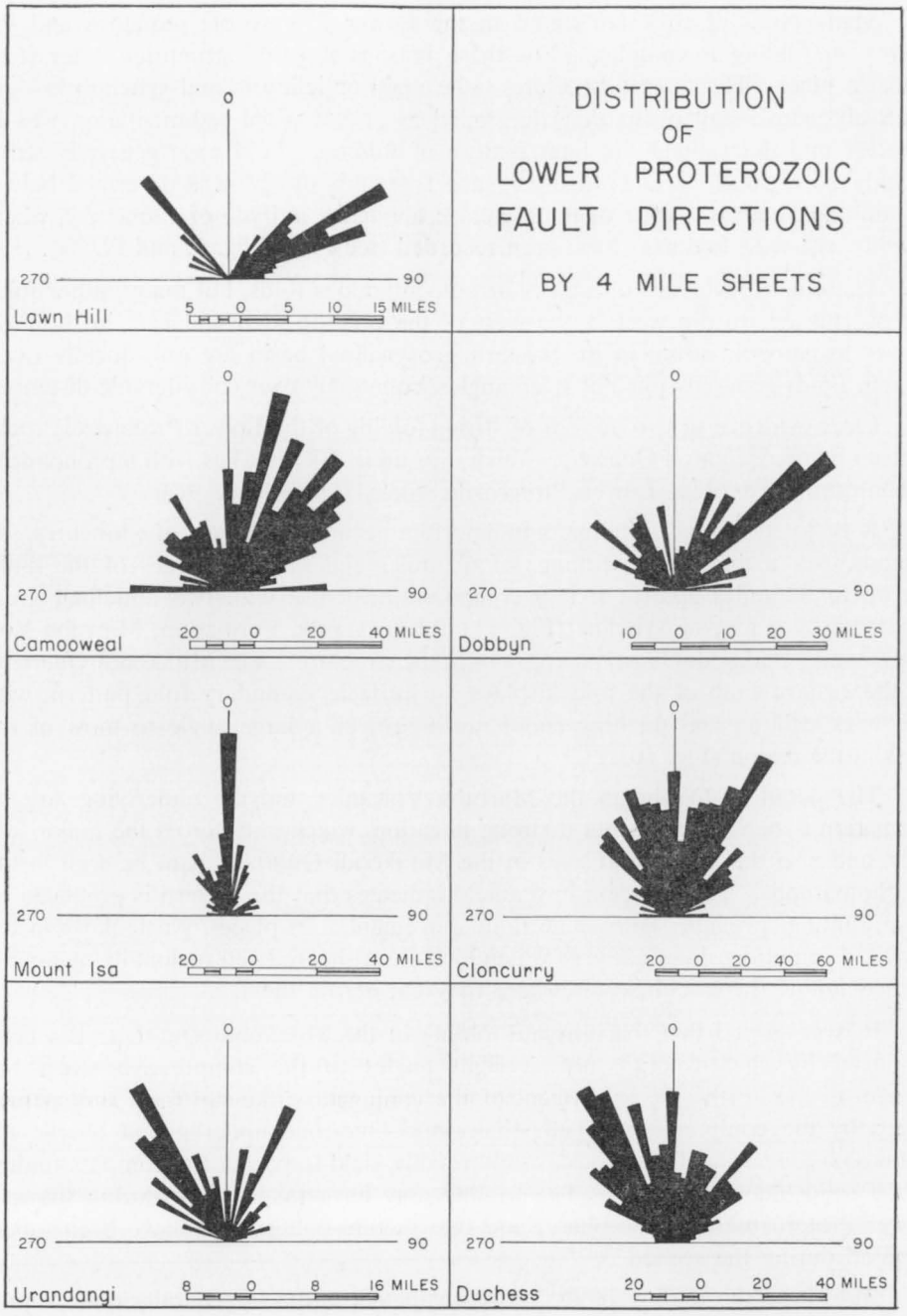

DISTRIBUTION
OF
LOWER PROTEROZOIC
FAULT DIRECTIONS
BY 4 MILE SHEETS
0
270
90
Lawn Hill
5 0 5 10 15 MILES
Camooweal
20 0 20 40 MILES
Dobbyn
10 0 10 20 30 MILES
Mount Isa
20 0 20 40 MILES
Cloncurry
20 0 20 40 60 MILES
Urandangi
8 0 8 16 MILES
Duchess
20 0 20 40 MILES

Figure 17

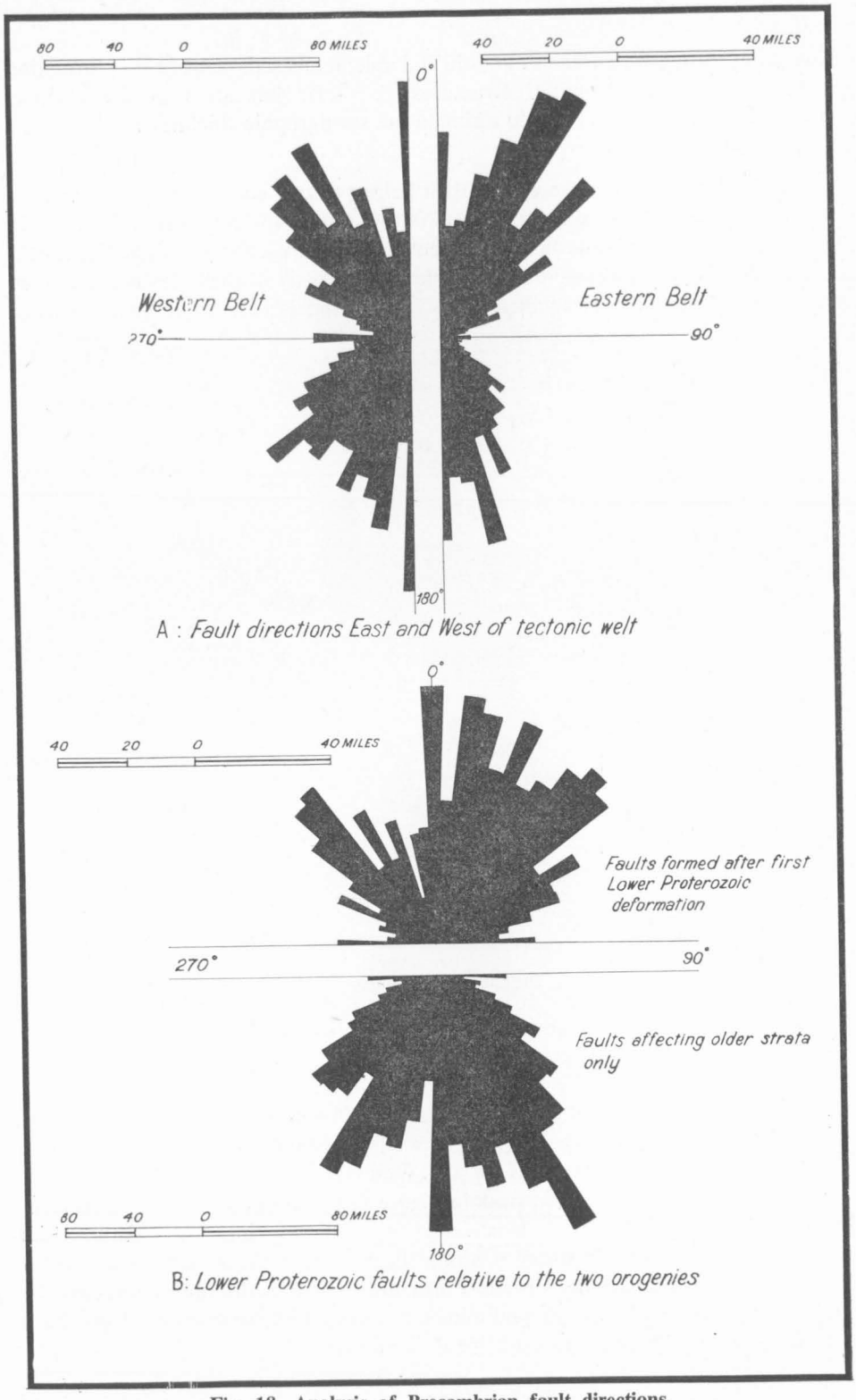


Fig. 18. Analysis of Precambrian fault directions.

deformation throughout. The dolomitic and calcareous sediments of this formation were quite incompetent; minor structures give little indication of the regional structures and it is very difficult to estimate the stratigraphic thickness.

Faulting

Many of the faults in the eastern belt belong to two conjugate strike-slip fault systems with major strike directions of 030-150° and 045-130° (see the 'peaks' in Fig. 18a). Many show movement consistent with east-west compression. The north-east direction is best developed in the eastern belt; many of these faults are infilled by massive quartz veins or silicified zones. Some show at least two generations of

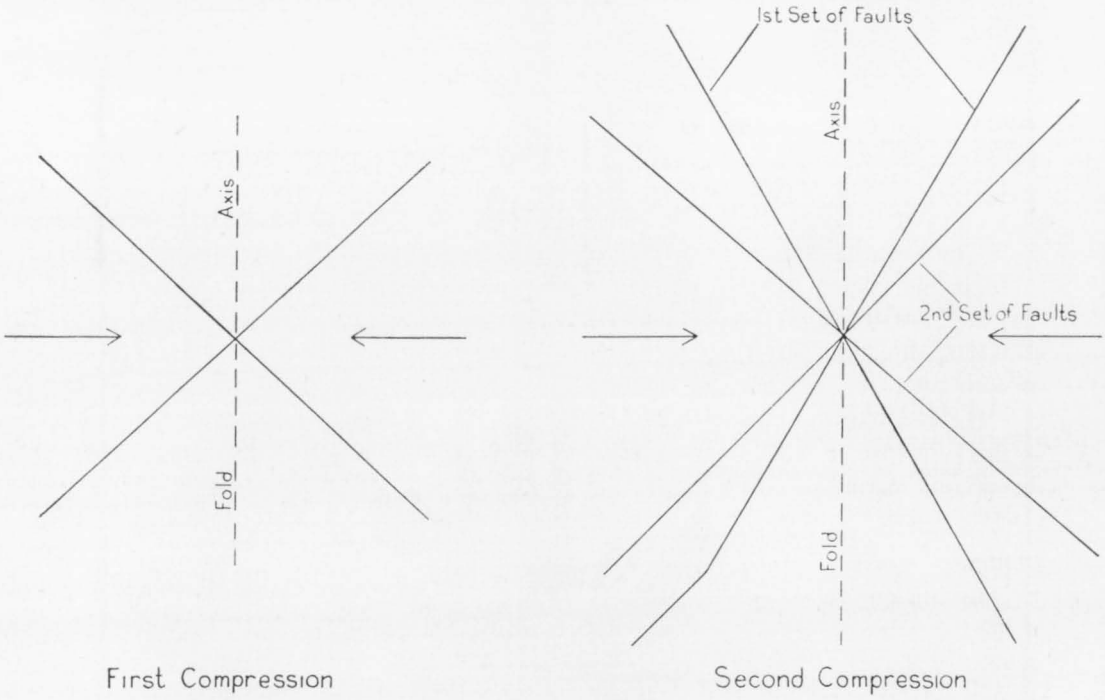


Fig. 19. Distortion of the Lower Proterozoic conjugate fault system by the final folding.

silicification. Owing to the complexity of the region few reliable measurements or estimates of fault displacements could be obtained. An example of a probable large horizontal displacement is given by the Mount Remarkable Fault (Atlas, Pl. 8) along which the displacement appears to be about 16 miles. The Wonga Granite is displaced, north block to the north-east, a short distance by the Cameron Fault and may be displaced three miles by the Wonga Fault (Atlas, Pl. 8); the fault lines are filled by aplite. The 165° peak in Figure 18a is due largely to the 'Cloncurry Overthrust' of Honman (1939). It is a high-angle east-dipping reverse fault, south and south-south-east of Cloncurry. Along the fault line the Soldiers Cap Formation has been thrust over the Corella Formation. Where the fault-zone cuts the Corella Formation, faults are discontinuous, probably because movement has been partly or completely taken up by plastic deformation.

Strike faulting has been observed in many places and is probably a very important factor in the deformation of the region. However, it is difficult both to recognise and to evaluate in such a highly deformed region. Silicification and deformation can be seen at the contact of nearly all rock masses with different physical properties, but whether movement has been slight or large cannot readily be determined. The high incidence of north-south faults in Figure 16 is due partly to strike faults and partly to high-angle faults, both normal and reverse, in the Selwyn-Kuridala area. The reverse faults are probably related to the 'Cloncurry Overthrust'.

The two sets of conjugate strike-slip faults in the eastern belt can be used to estimate the crustal shortening that may have resulted from the second compression. With the renewal of compression from the same directions as before (see pp. 52-4), and consequent lateral shortening, any pre-existing fault system would be distorted: the dihedral angle facing the direction of compression would be widened. Some new faults could be expected to develop and some of the old faults would extend further. These new-formed faults would strike in a direction determined by the existing stress field and would therefore differ in strike from the faults of earlier systems (see Fig. 19). The pattern presented by the strike-slip faults in the eastern belt conforms to the postulated development. Several of the major 025-030° faults show sharp deflections at their south-west ends, and the 045-130° directions are close to those in the previously undeformed strata of the western belt.

If the first-formed conjugate fault system had originally the same orientation as the later-formed system crustal shortening within the eastern belt as a result of the second period of compression can be measured. It is about 30% of the original width.

Jointing

Insufficient data have been recorded to give much value to any statistical study of the frequency of occurrence of joint directions. A histogram was constructed to determine the pattern of joint-direction distribution in the Lower Proterozoic rocks in the Cloncurry and Duchess 4-mile Sheet areas. 175 measurements were plotted. For all rock types 70% of measured joint directions fall within the arc 320°-040°; a pronounced maximum occurs at 340°. However, if joints in granite (which show a very strong maximum at 340°) be omitted, the joint directions for other Lower Proterozoic rocks show an even spread throughout the arc 320°-040°. These data are based on field measurements only. The study could be greatly extended by recording joint directions from air photographs.

Locally, there may be a strongly dominant joint direction: for example in the Mary Kathleen mine area, east-north-east and east-striking joints predominate. Joints in the Argylla Formation, Marraba Volcanics, and Mitakoodi Quartzite south-west of Cloncurry (Fig. 11) strike from 030° to 100°.

Cleavage, Schistosity and Foliation

Fissile slates are not very abundant in the area having regard to the degree of deformation. Many of the rocks of low metamorphic grade display only a rude

fracture-cleavage; those of moderate grade are either schistose or gneissose. However, the pelitic rocks, including graphitic slate, in the Corella and contemporaneous formations particularly, are generally well-cleaved.

The cleavage and schistosity are parallel to local fold axes. Gneissose foliation in the strongly metamorphosed or metasomatized rocks, on the other hand, commonly strikes at a large angle to the fold axes; in some places it can be demonstrated to be parallel to bedding, or relict bedding, planes, and seems to be mimetic.

An interesting structure may be seen in the bed of the Corella River, near the Rosebud copper mine, and in other places. Small lenses of dark green amphibole in calc-silicate rocks of the Corella Formation lie oblique to the bedding (Pl. 11, fig. 1). The lenses appear to have filled tension-gash openings, but close examination shows a conjugate pattern akin to that of strike-slip faults. In many cases only one of the two directions is clearly defined, but in adjacent beds the complementary component may be well developed. The lenses have no connexion with cross-bedding, and it is suggested that they were formed in the course of the folding and the subsequent metamorphism or metasomatism of the region. The lenses differ in orientation from the major transcurrent faults of the region and were apparently the product of special local conditions.

Lower Proterozoic Western Belt

Folding

Along, and east of, the Mount Gordon Fault-zone the structure of the western belt is dominated by broad north-pitching north-south anticlines, separated by narrow synclines. Some fold axes in the north-east of the area of outcrop strike north-west to north-north-west, possibly because of basement control. West of the Mount Gordon Fault-zone linear trends are not readily apparent; major folds tend to form complex domes, and such linear fold axes as can be traced strike at all angles.

The Eastern Creek Volcanics and older formations crop out only east of the Mount Gordon Fault-zone. The major trends in the eastern part of the belt are indicated by the distribution of the Surprise Creek Beds and Mount Isa Shale. Beds dip vertically in a few places, but the average dip is estimated to be 55°-65° in the synclines, and only 40°-50° in the intervening anticlines. The strata exposed in the synclines are dominantly shale, siltstone, dolomite, and sandstone, compared with a predominantly sandstone succession and basalt in the anticlines; this difference in lithology may account for the tighter folding in the synclines. Folds pitch north, with only local reversals, throughout the whole of the region east of the Mount Gordon Fault. Pitch readings in excess of 60° are common (see Pl. 26, fig. 2). Probably the eastern portion of the western belt possessed greater mobility than the western portion during sedimentation.

South of the Barkly Highway the Judenan Beds and Mingera Beds appear to be 'wrapped around' the Sybella Granite and metamorphics to give a two-pronged distribution in outcrop. Structure may have been controlled by an underlying rigid

basement. South of the highway the whole structure pitches north, but the pitch changes abruptly to south near the highway. The trace of the pitch-change strikes north-west and is marked by intense dislocation. A few miles farther north the pitch reverts to north.

West of the Mount Gordon Fault-zone two large complex domal structures, which appear to have determined the overall trend of the region, have been recognized. The larger dome is centred north-west of the Mount Oxide mine, about lat. 19°15′S, long. 139°15′E, and the second between Archie Creek and the Gregory River (lat. 18°45′S, long. 138°55′E). The Weberra Granite crops out in the core of the northerly dome and in a minor anticlinal structure on the northern flank of the southern dome. Many small domes and basins can also be recognised. In the Lawn Hill area the fold axes of two pitching anticlines, which form the Caroline Range and Ploughed Mountain, strike north-east, although farther north some fold axes strike east-west.

Faulting

Conjugate strike-slip fault systems are responsible for many of the faults, though not the longest, in the western belt. Both the systems apparent in the eastern belt may be recognized. Most of the 130° faults (see Fig. 18a) occur in the Mount Guide Quartzite and Eastern Creek Volcanics in the Urandangi Sheet area; movement on these is north block west. On the other hand the 050° and 140° faults occur mainly in the sediments north of Mount Isa; most have been displaced horizontally not more than a few hundred feet, and the movement is generally consistent with east-west compression. Vertical movement on some faults is considerable.

The complex Mount Gordon Fault-zone, which is a major structural element in the western belt, is responsible for the 010°-015° peak in Figure 18a, and many of the 025°-striking faults are related to it. It is roughly parallel to the Gorge Creek - Quilalar fault system; the two fault systems possibly have common origins. They appear to have been active discontinuously throughout the whole period of sedimentation of the western geosynclinal basin, and subsequently.

A third system of faults has played a large part in determining the present distribution of the units in the western belt. This is a system of roughly east-west faults which have caused repetition of the Eastern Creek Volcanics. The vertical movement on some of these faults must have been several thousand feet. The radial fault system in the Eastern Creek Volcanics is believed to have originated during the extrusion of the lavas as a normal fault system and to have continued beyond that time. It is best developed in an area north and south of the Mount Isa - Cloncurry road, a few miles north-east and east of Mount Isa. At lat. 20°40′15″S, long. 139°35′55″E, a fault belonging to the radial system has an apparent lateral displacement of at least 12,000 feet, but the fault has been observed to die out in the overlying Eastern Creek Volcanics, about 4,000 feet away. This can only be explained by fault movement contemporaneous with the extrusion

of the basalt. The distribution of stratigraphic units and of sediments also required fault movement, probably on an archetype Gorge Creek-Quilalar fault system, during and after the extrusion of the Eastern Creek Volcanics.

The Mount Isa Fault is a high-angle reverse fault, with considerable oblique movement, which dips west at about 65°. It is a bedding-plane fault, but the Judenan Beds, to the west, are overturned, whereas the Mount Isa Shale, to the east, is not. The amount of movement on the fault is not precisely known, but is thought to be large. The thrust movement, like that of the 'Cloncurry Overthrust', may have been related to the transcurrent fault system and may have occurred along a pre-existing fault line (parallel to the meridional synclinal structures). The disparity in the grade of metamorphism on the two sides of the fault indicates some post-granite movement. The Leichhardt Fault, which lies parallel to, and east of, the Mount Isa Fault, displays little of the complexity of the Mount Isa Fault. However, Knight (1953, p. 359) states that the degree of crumpling and brecciation indicates a large displacement. The Mount Isa and Leichhardt Faults are responsible for the 'peak' at 360° in Figure 18a.

The relative ages of the various fault systems are difficult to determine because of the complexity of fault patterns and the fact that more than one movement may have taken place on some of the faults. The history of faulting is given on p. 45 ff.

Jointing

A very strongly developed north-south joint system can be seen in the Leander and Mount Guide Quartzites. Some of the joints are filled by metadolerite: the joints were therefore formed early in the history of the region. Apart from these joints, and joints in the Sybella and Weberra Granites, jointing on a regional scale is not well developed in the western geosynclinal area.

Cleavage

The older strata in the western belt — Eastern Creek Volcanics and older — display cleavage and schistosity widely. The cleavage in the quartzite and metabasalt is generally a rough irregular fracture-cleavage parallel to the fold axes. The younger strata, however, are not conspicuously cleaved: only the most incompetent argillaceous sediments are fissile, other than in shear zones. The Mount Isa Shale is so weakly cleaved in most places that parting occurs along bedding rather than along cleavage; near the Mount Isa Fault, however, phyllite has developed.

Upper Proterozoic

Folding

In the Constance Range - Westmoreland area dips throughout are moderate — generally not more than 30° except near faults. Dragging on faults has produced local dips up to vertical. In the Constance Range area structure is dominated by two complex, faulted, broadly elliptical basins with major axes roughly east-west; north of the Nicholson River fold axes trend strongly east-west, although dips are generally lower than those of the Constance Range area.

Folding in the Pilpah Sandstone is very irregular. Bedding trends differ greatly from place to place, but the commonest are north-west to west. Dips generally do not exceed 30°. The Quamby Conglomerate lies essentially in narrow down-faulted belts. Folds are open and reflect the direction of the boundary faults. They may be largely fault-induced. Dips up to 70° have been recorded.

The Makbat Sandstone, east of the Wills River, forms two basins, with dips up to 50°, the long axes of which strike north-west to north-north-west.

Faulting

Three fault directions predominate in the Constance Range - Westmoreland area. The east-west faults of the Constance Range area are the most important. Vertical movements of 4,000 feet have been recorded. Most are normal faults in which the south block has been downthrown; but, in the south of the area, thrust-faulting younger than Middle Cambrian has been superimposed on the normal east-west faulting to produce the complex fault zone along the southern boundary of the Constance Range area. The north-west and north-east faults are probably also normal faults, but some lateral movement has been recorded. Vertical movement is, in places, indicated by the high dips of strata adjacent to the faults. Feldspar porphyry dykes and dolerite dykes occupy some of these faults in the Westmoreland area. All faults are steeply dipping; some are silicified but there are no massive quartz veins. Normal high-angle faults with relatively small displacements are fairly common in the Pilpah Sandstone.

Jointing

Very prominent joint patterns are developed in the volcanics of the Westmoreland area, in the Westmoreland Conglomerate (see Pl. 27), and in the basal beds of the Constance Sandstone. The joints are generally open and have weathered out to produce deep, steep-sided gullies. Numerous joints are parallel to the dominant fault directions, but near-meridional joints are also important in the Cliffdale Volcanics.

Post- Precambrian

In the Duchess and Boulia Sheet areas the Lower Palaeozoic sediments have been strongly deformed by tectonic movements. The steepest dips — up to 80° — have been produced by dragging on faults, but the strata have also been folded on north-north-west axes. Near Black Mountain dips up to 55° have been measured (Casey et al., 1960, unpubl.), but generally dips are considerably lower. Most of the Cambrian - Precambrian boundaries are fault contacts.

West of the outcropping Precambrian the Palaeozoic sediments are little disturbed; faulting is fairly common and there are some high slump-produced dips, but folding is gentle to absent. Thrusting along the Cambrian-Upper Proterozoic contact at the southern margin of the Constance Range area has severely crumpled Cambrian strata and has set some fault blocks vertically. In the same area, and in the Boulia area, Mesozoic sediments have been slightly faulted.

PART II: ECONOMIC GEOLOGY

North-western Queensland ranks with Broken Hill as the most important region in Australia for the production of minerals other than coal. In 1958 it produced metallic minerals worth £22,000,000; this figure was exceeded only by the Broken Hill district. Up to the end of 1958 nearly £190,000,000 worth of metallic minerals, including gold, had been won. With expanding production of base metals from Mount Isa, and the start of production of uranium oxide from Mary Kathleen in 1958, the quantity of mineral obtained from the region may be expected to increase for some years. Added to this is the prospect that the Constance Range area may become one of Australia's most important sources of iron ore in the future.

Copper, silver, lead, zinc, and uranium are the only minerals produced in important amounts at present, but a wide range of metallic and non-metallic minerals has been mined in smaller amounts, or recorded. 'Limestone' (crystalline calcite) is the non-metal produced in greatest abundance; it is used as smelter flux.

Although the region has been prospected for many years and hundreds of copper 'showings' have been tested, very few have been worked in the primary zone. The region would probably well repay large-scale and intensive scientific mineral exploration.

MINING HISTORY

Cloncurry and Mount Isa Gold and Mineral Fields*

Since the discovery of mineral deposits in the district in the eighteen sixties, mining activity has been subject to the fluctuations common to the industry in general. However, taken overall, the fields have grown in importance over the years and more minerals have been produced in recent years than ever before. The history of the region may be divided into three periods. In the early period (1867-1900) mining was very largely confined to the gold deposits. During the second period (1901-1930) the copper-gold deposits were developed. The third period (1931 to date) has been dominated by the production of silver, lead, zinc, and copper from the Mount Isa deposit. The commencement of uranium mining at the Mary Kathleen late in 1956 continued the trend of expansion in the mining industry.

* In 1957 the Cloncurry Gold and Mineral Field was amended and the Mount Isa Gold and Mineral Field was created. The two fields together cover the same territory as the original Cloncurry Field (see Fig. 1).

The Early Period (1867-1900). Gold was reported from Sunday Gully in the Bower Bird area in 1867, and later in the year from Top Camp, south of Cloncurry. In the same year Ernest Henry took up a mineral selection over the Great Australia copper deposit. Lees (1907, p. 45) states that Henry had discovered 'extensive copper deposits' in the Cloncurry district as early as 1865. In the late eighteen sixties, gold was discovered in the Pumpkin Gully, Gilded Rose, and Soldiers Cap areas, east and south-east of Cloncurry. Of the early production in the Top Camp area little is known. It is described as the richest alluvial gold area in the Cloncurry Field, but, though some of the ground was extremely rich, it was not very extensive. Some large nuggets were reported, including one of about 330 oz., and another of 210 oz. from Chinaman's Flat in the Top Camp area. In 1872, after a brief period of great activity, most of the miners left to join in the rush to the Palmer Gold Field. In 1886, when the Two Mile diggings near Top Camp were discovered, a nugget weighing 320 oz., and shaped roughly in the form of a frying pan, is reported to have been found in this area. The largest nugget from the Two Mile Diggings mentioned in official reports is one of 88 oz. The gold was very pure and was associated with bismuth minerals.

The Gilded Rose, which started production in 1872, was the largest reef mine to be worked, and though records are incomplete, it is known to have produced 4,713 oz. of gold between 1875 and 1883. Small crushing plants were erected at the various centres to handle the ore, and cyaniding plants operated at the Gilded Rose and Bower Bird centres. The total amount of gold recorded from the original Cloncurry Field, which was obtained from reef and alluvial deposits, is less than 30,000 oz., and though much of the production, particularly from alluvial sources, was undoubtedly not recorded, the field does not rank as a major producer of gold.

To Ernest Henry and his partner Roger Sheaffe are attributed most of the important early discoveries of copper in the district. After the discovery of the Great Australia, the Argylla, Dobbyn, Crusader, and Mount Oxide deposits were found. The Great Australia and Argylla copper deposits and the Dugald River lead-zinc deposit were taken up as freeholds before the Mineral Lands Act of 1882 did away with this form of tenure. The first report on the mineral deposits of the Cloncurry Field was made by Government Geologist R. L. Jack in 1885 (see p. 26). The development of known copper deposits during this early period was greatly retarded by lack of communications, the remoteness of the field, and the lack of local fuel supplies other than wood. Ore had to be carted by packhorse or camel north to Normanton (near the Gulf of Carpentaria) or east to the railhead. (Construction of the Great Northern Railway from Townsville began in 1880, and by 1887 the line had reached Hughenden.) After reaching the coast the ore had to be shipped to southern States or overseas for treatment. The Great Australian mine did not produce appreciable quantities of ore until 1884, when two charcoal-fired water-jacket blast furnaces were erected at the mine; and in 1887, when the price of copper declined, production ceased after only 3,650 tons of copper ore had been treated.

After a period in which little copper was mined, the Hampden deposits were opened up in 1898. Some ore was carted to the railhead at Winton, but only very high-grade ore could return a profit owing to the cost of transport to the treatment works. The important Mount Elliott, Duchess, and Mount Cuthbert deposits were prospected in the eighteen nineties, but they remained undeveloped for many years.

The Second Period (1901-1930). In the first decade of this period the benefit of rail communications, which reached Cloncurry in 1908, was enhanced by an upward trend in the price of copper; and the period of greatest development of the copper-gold deposits of the district followed. The years of highest production were 1911-1920, when the region had the greatest output of copper in Queensland. Production of copper reached a maximum of 11,625 tons in 1918 and gold reached a maximum of 13,039 oz. in 1912; almost all the gold was produced as a by-product from copper ores.

In 1907 several small furnaces (blast and reverberatory) were constructed; and, later, smelters went into production at the principal mining centres of Mount Elliott (1909-1919), Hampden (1911-1920), Rosebud (1915-1917), and Mount Cuthbert (1917-1920). Blast furnaces were employed at these smelters. The only attempt to concentrate copper ores was made at Hampden in 1918. The concentration plant did not get past the experimental stage, and only a few thousand tons of ore were treated.

Hampden-Cloncurry Mines Ltd took over the development of the Hampden copper mines from the original syndicate, which had begun to work the deposit in 1898. Subsequently the company purchased the Duchess and Trekelano mines, and later acquired the properties of MacGregor-Cloncurry Copper Mines Ltd in the Ballara area. The Hampden-Cloncurry Mines Ltd smelter treated 542,466 tons of copper ore for a yield of 50,614 tons of copper, 20,703 oz. of gold, and 379,124 oz. of silver. Flux requirements were largely supplied by the Salmon and Dingo deposits in the Dolomite area. Approximately 150,000 tons of cupriferous limestone were produced from these deposits while the smelter was in operation.

Mount Elliott Ltd was formed in 1905, and, in addition to the Mount Elliott mine, the company acquired control of the Hampden Consols and later the Mount Oxide mine. Through its subsidiary, Dobbyn and Cloncurry Copper Mines Ltd, it also had an interest in the Great Australia, Dobbyn, Crusader, and Argylla properties. The company smelter treated 315,891 tons of ore for a yield of 28,703 tons of copper, 38,439 oz. of gold, and 37,439 oz. of silver.

The Mount Cuthbert N.L. Company, whose interests extended to the Kalkadoon, Mighty Atom, Orphan, and other smaller mines in the Dobbyn-Kajabbi area, smelted 106,411 tons of ore for a yield of 6,786 tons of copper. The capital required to form the companies operating at this time was supplied mainly by English investors.

Of the copper producers during this period the Mount Elliott and Duchess mines were the largest. At Mount Elliott 264,007 tons of ore were mined for a yield of 24,431 tons of copper (9.3%) and 33,893 oz. of gold (4.2 dwt per ton), and at Duchess 203,468 tons of ore were mined for a yield of 24,747 tons of copper (12.2%) and 2,448 oz. of gold (0.2 dwt per ton). With the release of Government control of the copper market at the end of 1918, the price of copper fell. The average price fell from £113 in the 1916-1918 period to £68 in 1921. By 1920 the rich secondary copper ores of the district had been largely worked out, and although very considerable reserves of low-grade ore remained, it was found unprofitable to continue working the deposits when the price of copper fell. The position was aggravated by serious labour troubles after the 1914-1918 war. When the last of the smelters closed down at the end of 1920 it became necessary to send ore to the Chillagoe smelter some 900 miles away by rail; this made production, even on a small scale, very difficult.

During the period 1921-1926 mineral production was at a low ebb. However, it was during this period that the Mount Cobalt mine came into production. The deposit had been discovered in 1919, and between 1921 and 1934 produced 766 tons of cobalt, which was sent overseas as hand-picked ore and concentrates. Elsewhere cobalt is usually obtained as a by-product from base-metal ores, but this mine is notable for the fact that cobalt was the only metal present in quantity in the lode.

In 1927, the Mackay electro-chemical treatment plant was completed at Cloncurry. The plant was erected at this central point to concentrate the large quantities of low-grade copper ores available from the Field; but after it had been erected at great expense it was found to be unsuitable for the successful treatment of the ores and never went into production.

The Third Period (1931 to date). The Mount Isa deposit was discovered in 1923, but it was not until 1931 that large-scale production by Mount Isa Mines Ltd began. With this event a new phase in the mining history of the Cloncurry Mineral Field commenced. The history of the Mount Isa mine is dealt with separately below.

Little alluvial and reef gold had been produced over the years from 1900 to 1930, but the industry was partly revived in 1931. Gold was won mainly from reef deposits in the Gilded Rose and Soldiers Cap localities. The years of maximum production were 1933 to 1937, during which more than 2,300 oz. of gold were obtained. Since 1942 production of gold from all sources has been negligible.

After the severe slump in the early nineteen twenties the production of copper began to increase in 1927 and reached 3,377 tons in 1929. Production continued at the rate of about 2,000 tons per annum, despite the low price of copper (which reached its lowest point in 1934, when the average price was only £33 per ton). The main production came from the Trekelano mine, which produced over 100,000 tons of ore for a yield of approximately 11,800 tons of copper between 1927 and 1943. The ore was sent to the Chillagoe State Smelters for treatment. Altogether

the mine produced 184,811 tons of ore for a yield of 20,141 tons of copper (10.9%) and 13,606 oz. of gold (1.6 dwt per ton). Mount Oxide, which produced nearly 30,000 tons of ore between 1927 and 1944, was the only other copper-gold deposit to produce a considerable amount of ore during this period. It is noteworthy that the Trekelano and Duchess were the only copper-gold deposits to be worked extensively in the primary zone: in other mines production came very largely from enriched secondary ore, and the primary sulphide ore was found to be of very low grade. The discovery of the Paradise Valley copper deposits in 1937 attracted a considerable amount of interest at the time (Denmead, 1938), but very little was produced until the Lady Annie mine was reopened in 1953.

In 1943 the Chillagoe State Smelters closed down, and in the same year Mount Isa Mines Ltd, as a wartime measure, changed from silver-lead-zinc to copper production. Despite the advantages of smelting facilities thus introduced on the field and an improvement in the price of copper, production from the copper-gold deposits did not increase; partly this was because of the shortage of manpower, and partly because no payment was made by Mount Isa Mines Ltd for the gold content of custom copper ore. After Mount Isa Mines Ltd began to produce silver-lead-zinc again in 1946 the production of copper fell to a very low level. From 1947-1952 it was necessary to send ore to Mount Morgan for treatment. Apart from the Mount Isa mine little mining of any sort took place during this period.

When the copper smelter at Mount Isa was completed early in 1953 many small copper mines were reopened. This renewed activity was further assisted by the steep rise in the price of copper, which reached a peak of £A537.5 in April 1956. Production of copper from mines other than Mount Isa exceeded 1,000 tons in the years 1955 to 1957. Much of the production in the 1953-58 period came from Mount Oxide (1,742 tons), the Lady Annie (698 tons), and the Blockade (539 tons). In addition, part of the production since 1953 has come from the reworking of low-grade ore from mine dumps which, under the favourable conditions, became profitable to treat (e.g. at Hampden and Mount Oxide). Up to 1956 Mount Isa Mines Ltd encouraged the production of siliceous copper ore as this is suitable for use as flux in smelting operations, but the Company now has an adequate supply of siliceous fluxing ore in the Mount Isa mine. Subsequently, the production of custom copper ore with a high lime content has been encouraged. On the other hand, the presence of traces of nickel in some copper ores, particularly from deposits in the Argylla-Duchess area, has made them unacceptable for treatment at Mount Isa.

The total production of copper from the Cloncurry and Mount Isa Mineral Fields to the end of 1958 was 333,570 tons; and the region has succeeded Mount Morgan as the premier copper-producing district in Queensland. The Mount Isa mine has been the principal producer of copper in Australia since 1953, and now accounts for more than half of the total Australian mine production (72,568 tons in 1958).

Since 1947 several major companies have shown considerable interest in the development of base-metal deposits in the Field. Broken Hill South Ltd purchased the Trekelano mine and obtained options over several of the main copper-gold deposits where reserves of low-grade ore were known to exist at the time the mines closed down. Diamond drilling was carried out at the Mount Elliott, Hampden, Mount Oxide, and Trekelano deposits, but results have been inconclusive. Enterprise Exploration Co. Pty Ltd carried out extensive prospecting work north and south of the Mount Isa leases without success. This company also obtained the Dugald silver-lead-zinc freehold and in 1952 carried out a programme of diamond drilling on the deposit. The results indicated that development could not be profitably undertaken at that time. Titanium Alloys Manufacturing Co. Ltd prospected a number of lead-zinc gossans in the Cloncurry area, but no substantial mineralization was located. In the 1955-1957 period, diamond drilling of the Mount Cobalt deposit by Mining Corporation (Australia) N.L. failed to prove reserves that would justify further mining. After this the Company carried out diamond drilling in a search for copper immediately south of the Mount Isa leases. Since 1955, Rio Tinto Australian Exploration Pty Ltd has carried out large-scale exploration for uranium and other metalliferous deposits. In addition, Mount Isa Mines Ltd have been active in the exploration of many deposits outside the leases already being developed or worked.

Mount Isa Mines

The discovery of the Mount Isa silver-lead-zinc deposit was made in 1923 by a prospector named Campbell Miles. W. A. Corbould, who had a big hand in the affairs of Mount Elliott Ltd, was also influential in the forming of Mount Isa Mines Ltd, which took over the deposit from the original company late in 1925. The American Smelting and Refining Company has figured prominently in the development of Mount Isa Mines Ltd since 1930, when it purchased a one-third interest in Mining Trust Ltd, which had previously gained a controlling interest in Mount Isa Mines Ltd. The American Smelting and Refining Co. also purchased a considerable share interest in Mount Isa Mines Limited. It became the principal shareholder in 1948 on the liquidation of Mining Trust Ltd. The history of Mount Isa Mines Ltd has been described in some detail by Kruttschnitt (1953) and Gross (1953).

Production of silver-lead began in 1931, when the mill and lead smelter were completed. Large influxes of underground water into the mine, and metallurgical problems, particularly in the sintering process, retarded early production. Despite this, 38,008 tons of silver-lead bullion were produced in the year ended 30th June 1932. Production of zinc concentrates began in 1935. From 1931-1934 the near-surface carbonate ore was extracted by 'glory-holing', and since that time sulphide ore has been milled. A small amount of carbonate ore has been sent direct to the smelter and used as siliceous flux.

During an exploratory drilling campaign of 1927-28 to define the downward extension of the silver-lead-zinc bodies, sulphide copper orebodies were discovered which do not crop out and are of commercial grade only below 800 feet. Major developmental work was not carried out until 1941 on these copper orebodies. In April 1943, at the instigation of the Commonwealth Government's Mineral Production Committee, production of silver-lead-zinc was discontinued in favour of copper production: this was a wartime measure to help reduce the deficiency in Australian supplies of copper. The lead smelter was improvised to handle the copper ore, and the production of blister copper continued for a little over three years. During this time over 800,000 tons of ore were produced for a yield of 34,015 tons of copper, the grade being 4.3%.

The production of silver-lead-zinc was resumed, and that of copper was discontinued, in 1946. The rise in metal prices in subsequent years resulted in a period of prosperity for the company. A copper smelter was constructed and went into production early in 1953. Since that time the mining, milling, and smelting of silver-lead-zinc and copper ore have gone on concurrently. The mine is unique in that silver-lead-zinc ore and copper ore from distinct orebodies are transported to the surface through the same ore shaft. In recent years the Black Rock secondary copper orebody has been mined open-cut on a large scale.

The lead-zinc sulphides are separated and concentrated by flotation, and silver-lead bullion is produced from the blast furnace. The mill recoveries in 1958 were 82.8% for silver, 83.7% for lead, and 33.8% for zinc. The lead bullion and zinc concentrates are shipped from Townsville, 603 miles by rail from Mount Isa. The lead bullion is refined in London by a wholly owned subsidiary, Britannia Lead Company Ltd, and the zinc concentrates are sent mainly to the United Kingdom and Belgium for treatment.

The copper ore is concentrated by flotation, roasted in multiple hearth furnaces, and smelted in a reverberatory furnace to produce copper matte. The copper matte is then treated in converters to produce blister copper. Until 1959 the blister copper was exported to U.S.A. for refining, but a refinery at Townsville to treat Mount Isa blister copper was completed in 1959. Limestone for fluxing has been obtained from quarries at Juenburra and Dolomite and various other smaller quarries at scattered points over the Field. The coke consumed in smelting is obtained from the State Coke Works, Bowen (722 miles by rail from Mount Isa), and the coal used at the power-house is obtained from a company-owned mine 56 miles by rail from Bowen. Mount Isa mine, with a daily production of nearly 8,000 tons of ore (1959), now has the largest output of any single mine in Australia. The production of ore in 1958 was only exceeded by Mount Lyell (1,951,973 tons in 1957) where the ore is open-cut. (For details of production see Appendix II, Table IV.) Published ore reserves exceed the tonnage mined since operations began. In addition, the presence of very large tonnages of low-grade copper and silver-lead-zinc ores has been indicated by exploratory drilling. Plans have been made to expand greatly the rate of production over a period of years to enable these low-grade reserves to be mined along with the higher-grade ore.

In 1948, as a result of a detailed geological survey and prospecting campaign by Mount Isa Mines Ltd, small seams of lead carbonate were found near Tombstone and Handlebar Hills about 12 miles north of Mount Isa. Since that time a programme of drilling and shaft sinking on the Northern Leases has revealed silver-lead-zinc deposits of considerable size. Large reserves of low-grade sulphide ore have since been indicated by underground exploration, but exploration was suspended in 1958.

Uranium Prospects

In March 1954 a new development in the mining history of the Cloncurry and Mount Isa Mineral Fields took place with the discovery of appreciable quantities of uranium at the Skal, about 20 miles north of Mount Isa, by Berger Schildt and party. The discovery led to one of the greatest bursts of prospecting in the history of the Fields, and many more deposits were discovered. In July 1954, the Mary Kathleen deposit was discovered by the Walton prospecting syndicate. This is easily the largest uranium deposit known in north-western Queensland. After being purchased from the discoverers by Australasian Oil Exploration Ltd, it was developed for production by Mary Kathleen Uranium Ltd, in which Rio Tinto Mining Co. of Australia Pty Ltd have a controlling interest. Mining started in October 1956 and the treatment plant was completed in June 1958.

Most of the other uranium deposits discovered are too low-grade to permit economic development at present prices; and many occurrences are associated with pegmatite and are unlikely to produce appreciable quantities of ore. Queensland Mines Ltd are attempting to prove sufficient ore reserves at the Counter and Skal deposits to warrant development.

Following the discovery of uranium by a prospector in Upper Proterozoic rocks in the Northern Territory, near the Queensland border, an airborne scintillation-counter survey by the Bureau of Mineral Resources revealed radioactivity in Queensland, north of the Nicholson River. The most promising anomalies were examined and tested by Mount Isa Mines Ltd, but no economic deposits have been proved.

Lawn Hill (Burketown Mineral Field) and Constance Range Areas

The first lease in the Lawn Hill area was taken up in 1887 on a silver-lead-zinc deposit by F. H. Hann of Lawn Hill Station. Subsequently a large number of silver-lead-zinc deposits were discovered, but all are fairly small, and the remoteness of the field has retarded development. The Burketown Mineral Field, which takes in an area of 317 square miles, was proclaimed in 1899. Several companies have examined the field over the years, including Mining Trust Ltd in 1930, Mount Isa Mines Ltd in 1954, and Broken Hill Proprietary Co. Ltd in 1958. However, owing to the scattered distribution and comparatively small size of the deposits, company interest has never reached the stage of mining.

Silver-lead ore has been produced in a desultory fashion since 1897, but the total recorded production of the field to the end of 1958 is only 4,953 tons of lead, 152,245 oz. of silver, and 87 tons of copper. In the early days ore was carted to Burketown, some 100 miles away, for shipment overseas. At an early stage in the history of the field, it was proposed to erect a concentrating plant at a central point and build a narrow-gauge railway from the concentrating plant to Burketown; but neither was built. The result has been that the small production has been obtained by selective mining and hand-picking; the ore despatched for treatment commonly assays more than 50% Pb.

Considerable quantities of milling-grade ore are known to exist, particularly at the Silver King mine, which has been the largest producer of silver-lead in the area. A small mill with concentrating tables was erected at the Silver King in 1956 and the output of the mine was substantially increased.

The present period of production began in 1948. Ore is smelted at Mount Isa, over 200 miles away by road. Activity was stimulated by the high price of lead in the 1951-52 and 1955-56 periods, but the future outlook is not encouraging unless the price of lead recovers from the depressed levels of 1957-59.

A new chapter, with great possibilities for the region, was begun with the discovery of the vast low to moderate grade sedimentary iron deposits of the Constance Range area. The beds were first recorded in 1950 and 1954 in the course of the regional mapping programme of which this Bulletin is a report, but were regarded as sub-economic. Their existence was brought to the attention of geologists of the Broken Hill Proprietary Co. Ltd in 1954 and the Company's subsequent exploration and drilling has revealed that the deposits are of great potential economic importance.

GENERAL DISCUSSION OF MINERALIZATION

The production of silver-lead-zinc and copper from Mount Isa mines so dominates the production figures for the whole region that, from the regional viewpoint, the figures give a misleading idea of the relative abundance of metallic ores. Copper is the most widely distributed metal in the region, followed by uranium and gold. Silver-lead-zinc ore, in economic or near-economic deposits, is known in only a few localities.

Copper occurs in Precambrian rocks of all ages. Uranium is widespread in the Lower Proterozoic, and has also been found in the Upper Proterozoic in the extreme north-west, but no important deposits are known in the Leichhardt Metamorphics or Argylla Formation, nor in strata of the western belt (see Pl. 1 and Fig. 4) younger than the Eastern Volcanics. Radioactivity has been recorded in the Lower Cambrian Mount Birnie Beds, south of Duchess. Gold occurs mainly in association with copper ores, in the eastern portion of the eastern geosynclinal belt; it does not occur in recoverable quantities in the Mount Isa ores. Reef and alluvial gold deposits have been worked in the south-east of the region, in two places in the western belt, and in the Quamby Conglomerate, which is mapped as Upper

Proterozoic. Deposits of silver-lead-zinc, of ore grade and size, occur only in Lower Proterozoic rocks, in three widely separated localities, but small quantities of galena have been recorded in Upper Proterozoic and Palaeozoic sediments in adjoining areas.

Huge oolitic iron beds occur in the Upper Proterozoic of the Constance and Little's Ranges area and deposits of introduced siliceous ironstone occur in the Lower Proterozoic of both the eastern and western belts.

Cobalt deposits are restricted to the Lower Proterozoic in a belt from Mount Cobalt to west of Kajabbi, with Mount Cobalt the only large producer. Manganese is fairly widely distributed and is known to be associated with Lower Proterozoic, Upper Proterozoic, and Palaeozoic rocks, in supergene concentrations, but the only deposits likely to be of economic importance for some time are those in and south of the belt of Marimo Slate, south of Cloncurry.

Other metallic ores are of little importance and are only known in the metamorphic rocks or associated granites. Minerals with pegmatitic associations, such as mica, beryl and monazite, occur in a small area south-west of Mount Isa.

The only non-metal which has been worked extensively is 'limestone' (crystalline calcite), which is used as smelter flux at Mount Isa. It is found abundantly in the metamorphic rocks of the Corella Formation, and deposits have also been worked in the Charley Creek Formation and the Leichhardt Metamorphics.

The metallic minerals are found in a wide range of geological settings. The diversity of metals and of their mode of occurrence is probably due in part to the several ages or phases, and processes, of ore formation. Distinctions can be made between sources and modes of formation of some of the deposits: for example, the sedimentary iron ores are clearly unrelated to the fissure lead-zinc lodes of the nearby Lawn Hill field. But the bulk of the epigenetic deposits in the Mount Isa and Cloncurry Mineral Fields can rarely be distinguished by genesis because our knowledge of the ages of the various granites — and particularly of individual outcrops of granite — is quite inadequate.

A broad geographical and stratigraphical classification of deposits can be made and each group is found to have certain common features:

Upper Proterozoic

North-west of area: 1. Copper and uranium. Uranium secondary only, some occurrences epigenetic, but not clear whether others epigenetic or syngenetic. Copper not common in Queensland, generally epigenetic.

2. Sedimentary iron; some recrystallization, most of which may be diagenetic.

West of Mount Isa: Devoid of economic mineralization.

Eastern belt: Minor gold - Mount Quamby, not clear whether syngenetic or epigenetic.

Lower Proterozoic, Strata Affected by One Orogeny Only

Western belt: Major copper and silver-lead-zinc; minor gold. Mineralization largely confined to less competent strata. Most deposits fissure-type, but Mount Isa deposits replacement-type, possibly syngenetic with epigenetic concentration. No close spatial association with granite.

Eastern belt: Practically devoid of mineralization.

Lower Proterozoic, Strata Affected by Two Orogenies

Western Belt: Copper, uranium; minor gold. Generally small, uneconomic deposits in small faults, shears or fractures. Uranium deposits partly replacement bodies, some with carbonate gangue.

Eastern Belt: Most of large economic deposits of region, other than Mount Isa. Copper and copper-gold bodies most abundant. Mostly related to faults and shears, may be some local replacement; many in Corella Formation have calcitic gangue. In other formations commonly a close association between amphibolite (metadolerite or metabasalt) and copper. Uranium deposits partly metasomatic (e.g. Mary Kathleen), partly related to pegmatites; others related to structures, probably hydrothermal. Lead-zinc mineralization, mostly weak, associated with carbonaceous slate. Other metals generally related to faults or shears. Metallic deposits, particularly gold, generally have some quartz associated with them. Deposits commonly fairly close to granite.

Very few of the metallic deposits have been worked in the primary zone. Knowledge of factors controlling epigenetic deposits is therefore scanty, particularly as, for most of the time that the field work was being done, very little small-scale mining was in progress and practically all workings were inaccessible. Deposits were for the most part examined only incidentally in the course of regional mapping.

Earlier records of the workings generally report in general terms the distribution of mineralization and, in greater or less detail, the geological setting. It is therefore difficult to reconstruct the layout and associations of the ore with sufficient precision to form opinions about structural and lithological control of ore-shoots, ore genesis, etc., in individual deposits.

Certainly examples could be found of a great many of the various types of epigenetic orebodies recorded in the literature - hypothermal, mesothermal, epithermal, telethermal; fissure, replacement; contact; pegmatitic, greisenous, hydrothermal.

Several authors have discussed, or commented on, aspects of ore genesis. They include Ball (1908), Grondijs & Schouten (1937), Nye & Rayner (1940), Blanchard & Hall (1937 and 1942), Shepherd (1953), Jones (1947 and 1953), Edwards (1956), and Knight (1957). In general, mineralization is related to orogeny and granite emplacement, and views as to the mode of concentration range from metamorphism and metasomatism to hydrothermal solutions. Knight (1957) refers to the possibility of a primary sedimentary origin for the Mount Isa silver-lead-zinc.

Secondary Ore Deposits

Nature of Outcrop

Owing to secondary redistribution of the metallic minerals by supergene processes the grade and mineral assemblages of mineral deposits of the region above the water table are generally markedly different from those of the primary ore. As a result size and grade of surface exposure are seldom a good indication of what is to be found either at the water table or in the primary zone.

As the region has been exposed to weathering over very long periods, during which the water table, and therefore the zone of oxidation and leaching, has

probably fluctuated over a vertical range of several hundred feet, movement of metallic components of deposits has been very great. In particular, in those areas where the present land surface apparently lies close to the pre-Mesozoic land surface (see pp. 34 and 84 and White (in press)) the weathering effects have been profound. Even the usual gossan-type of outcrop may have been destroyed in such areas. This possibility appears to offer a field for detailed study.

Age of Mineralization

All the important mineralization is believed to be Precambrian. There are probably at least two distinct epochs of epigenetic mineralization — that which produced the copper and uranium deposits in the Upper Proterozoic strata in the extreme north-west of the region, and that, or those, which formed the deposits in the Lower Proterozoic. Some of the mineralization in the Lower Proterozoic could be genetically related to Upper Proterozoic igneous activity. The history of ore formation in the Lower Proterozoic strata is undoubtedly complex, as many processes were involved and granite emplacement probably accompanied each of the two orogenic phases of deformation. Some ore may have been concentrated during the first deformation and redistributed during the second.

Lead mineralization, or mineralization associated with lead deposits, has been recorded in strata younger than the folded Upper Proterozoic. Shepherd (1953, p. 388) records manganiferous siderite and quartz in basal Cambrian beds (Thorntonia Limestone). The occurrence overlies the Magazine Hill lead-zinc deposit (see Ball, 1931); but it cannot be taken as evidence for Palaeozoic mineralization because it was formed by superficial redistribution during weathering of gangue material from the underlying lode. It contains no lead minerals. The other three deposits, in Camooweal Dolomite and Ordovician beds (see p. 219) contain crystalline galena. They, too, cannot be regarded as evidence for the Palaeozoic age of any of the main mineral deposits in the Precambrian, as lead appears to be capable of migration under a very small energy gradient and these sub-economic deposits were probably formed by redistribution of either pre-existing accumulations of lead in older strata or of syngenetic lead. In this connexion the scarcity of other base-metal deposits in the Palaeozoic strata is important. The silver-lead-zinc deposits in the Precambrian were most probably formed under the high-energy gradients existing during the Precambrian orogenies.

Some of the mineral deposits in the Lower Proterozoic rocks are related to some phase of the metamorphism and granite-emplacement, though some may have had a sedimentary origin before concentration. Many of the fracture-filling deposits were probably emplaced at a late stage in one or other of the granitic processes related to the two orogenic phases of deformation (including post-orogenic granites).

The first orogenic deformation was most intense in the eastern belt and was probably accompanied, or followed closely, by granite; and as metallic deposits

preponderate in this belt, some deposits were probably related to the first orogeny rather than the second.

Upper Proterozoic vulcanicity continues in the Northern Territory to a higher stratigraphical level than in Queensland, and a copper deposit near Calvert Hills homestead, in the Northern Territory, 44 miles west of the Queensland border, is in folded Upper Proterozoic strata younger than those in Queensland. If the mineralization in the Upper Proterozoic is related to a late-stage differentiate of the magma from which the volcanics were derived, it cannot be older than late Upper Proterozoic.

Briefly, then, if the epigenetic mineralization of the region be related to igneous activity, important deposits were formed at the close of the Lower Proterozoic orogenesis, and earlier deposits may have been formed as a result of the earlier Precambrian orogeny. A third period of mineralization occurred in late Upper Proterozoic times. The formation of a single large mineral deposit is probably a lengthy process and a mineral province may have required repeated episodes, perhaps spread over a long time, for its development.

METALLIC MINERALS

Copper

Although the copper deposits were among the first to attract the attention of prospectors in north-western Queensland, major developments awaited the completion of rail communication to Cloncurry in 1908. In the following decade hundreds of copper deposits distributed over an area of approximately 15,000 square miles were developed; nearly all of them consisted of small concentrations of secondary ore of no great vertical extent. The most extensive mine workings were at the Duchess, which was successfully mined to a depth of 850 feet. The richness of some of the deposits may be illustrated by the Mount Oxide mine, which averaged 21% copper, and up to 1958 produced over 10,000 tons of copper from mine workings to a depth of 300 feet.

The Mount Isa copper deposits have only been thoroughly explored and developed in recent years. In 1958, 971,140 tons of ore, assaying 4.3% copper, were treated. Exploration during 1956 showed that the deposits are much more extensive than previously believed, and enormous reserves of low-grade copper ore have been indicated. A figure of the No. 12 Level of the mine (depth 1810 feet) is reproduced to show the arrangement of the orebodies (see Fig. 20).

The total production of copper from the copper-gold deposits of the Mount Isa and Cloncurry Mineral Fields is nearly 150,000 tons, and reserves amount to roughly 2 million tons of 4% copper, according to estimates by the companies operating the mines at the time of closure (Nye & Rayner, 1940). However, the deposits are scattered over the Mineral Fields and only the Mount Elliott, Hampden Consols, Mount Oxide, Great Australia, and possibly the Mount Cuthbert and Argylla deposits have estimated reserves of more than 100,000 tons

of low-grade ore. These reserves are located within and below old mine workings and the mines would be difficult to reopen. Most deposits are incompletely explored, e.g. the Labour Victory, where a well-defined geophysical anomaly has not been tested to date (Horvath & Tate, 1954, unpubl.). The Trekelano deposit has not been adequately tested below the mine workings, which extend to a depth of 864 feet; the grade of copper (10%) was maintained to this depth. Most deposits of primary ore that have been tested contain 3-4% copper, or less.

Distribution

The copper deposits of the Cloncurry Complex are very widespread: practically no section of the eastern belt is devoid of economic copper deposits. In the western geosyncline, which roughly coincides with the Mount Isa and Burketown Mineral Fields, copper deposits are sparsely distributed; the impressive Mount Isa and the Mount Oxide and Lady Annie mines are the only worthwhile producers. Most of the important deposits and the largest groups of deposits occur in north-south belts in the Cloncurry Mineral Field. One such belt includes the Great Australia, Mount McNamara, Hampden, Mount Elliott, and Answer deposits; another includes the Orphan, Dobbyn, Crusader, Mighty Atom, Kalkadoon, Mount Cuthbert, Rosebud, Wee MacGregor, Duchess, Trekelano, and St Mungo deposits.

In general, mineralization is grouped around roughly defined centres. In the Dobbyn-Kajabbi locality an area 16 miles long and 8 miles wide contains 9 deposits which have each produced more than 100 tons of copper, and a large number of smaller deposits. Other groups of deposits occur in the Dugald River, Ballara-Argylla, Duchess, Kuridala-Selwyn, Cloncurry, and Marraba areas. In some cases this grouping of mines has been influenced by the proximity of communications to these centres, as accessibility has always been an important factor in the development of deposits in north-western Queensland.

Surface Expression

Where the mineralization is associated with resistant strata, or introduced material such as quartz, outcrops are prominent, but a great number of deposits have very little topographic relief. Deposits in carbonaceous slate commonly have rather poor outcrops and appear as malachite veins or coatings on bedding and cleavage planes; those with calcitic gangue (mainly in the Corella Formation) also do not produce perceptible relief and may have sulphide minerals very close to the surface.

Gossans, with boxwork, have been recorded from many deposits, but are generally poorly developed. The sparse boxwork is probably due to the low grade of most primary orebodies. Limonite and quartz are commonly associated with the lode outcrop: in a few the limonite is manganiferous. Few of the numerous hematite and quartz-hematite bodies in the region have much copper associated with them at the surface. An exception is the Mount Oxide copper body, where a large outcropping body of hematite lies next to the lode in the hangingwall; but

this capping may be a supergene product, whereas the other hematite bodies are hypogene. In a few deposits, e.g. the Answer, a light brown, fine-grained, massive, siliceous outcrop, with weak malachite staining, marks the line of lode.

The weathering has been so profound in places, e.g. west of Selwyn (see p. 84 and White, in press), and the alteration of the sediments and metamorphics which crop out so thorough, that the surface expression of some orebodies may be practically obliterated or very different from the usual type of lode outcrop.

Features of the Secondary Zone

Within the zone of oxidation the distribution of ore is commonly very different from the primary distribution. Secondary enrichment has usually taken place at or near the present, or some fossil, water table. These concentrations provide very rich pockets of ore; the richest are of chalcocite. The amount of chalcocite present varies greatly from deposit to deposit; its formation may be dependent on the host rock, on the gangue, and on the proportion of pyrite present. These factors would influence the oxidation potential of the environment.

The overall grade and tonnage per vertical foot of ore in the secondary zone appears, in those deposits whose primary zone has been worked or tested by drilling, to be considerably greater than in the primary zone. This implies that copper has been concentrated from portions of the body which have now been eroded away. Small deposits generally are uneconomic in the primary zone. The depth of oxidation in small deposits generally extends from less than 100 feet to about 300 feet according to geographical, topographical, and geological environment. In the Mount Isa mine secondary copper minerals occur at more than 500 feet.

Controls

Stratigraphical and Lithological Control

Copper mineralization in economic quantities and grade occurs in practically all the Lower Proterozoic units, and in some of the volcanic Upper Proterozoic formations in the north-west of the region. In general, however, the control appears to be lithological rather than stratigraphical. Acid lavas (and their metamorphic derivatives) and quartzite appear to be unfavourable host rocks. The deposits which occur in the Leichhardt Metamorphics and Argylla Formation are generally related to fractures close to, or in, basic igneous rocks or schists. Quartzite is almost everywhere barren, although some deposits have quartzitic footwalls or hangingwalls and some occur in argillaceous or other sediments in a predominantly quartzitic succession. The arenaceous units, such as Leander, Mount Guide, Ballara, Knapdale, Roxmere, and Deighton Quartzites and the Myally Beds, appear to offer poor prospects for economic copper deposits.

Copper mineralization is closely associated with shales and slates (particularly carbonaceous, graphitic, and calcareous shales and slates)—for instance at Mount Isa, Mount Elliott, Hampden, Lady Annie, and Mount Oxide. In some deposits the argillaceous strata appear to have become host rocks because of the ease of deformation under stress, which provided structural traps; other deposits have been formed by replacement and have apparently favoured the argillaceous rocks because of their chemical properties. On these grounds the presence of important deposits in the Kuridala Formation, Mount Isa Shale, and Paradise Creek Formation may be explained. Shales and slates, with copper deposits, also occur in the Soldiers Cap Formation, Answer Slate, Staveley Formation, and Marimo Slate, and as lenses in the Corella Formation.

The calc-silicate rocks of the Corella and contemporaneous Formations appear to have been unfavourable to ore deposition. Mineralization was very probably later than the metamorphism of the region; the metamorphic minerals were sufficiently stable to be unfavourable for replacement, and the rocks sufficiently competent to fracture rather than flow. The calcite lenses and bodies which probably formed during granite emplacement and metamorphism were probably amenable to deformation, replacement, and remobilization. Many of the copper orebodies in the Corella Formation have calcitic gangue, e.g., Rosebud, Great Australia, Dolomite. Most orebodies of this type are low-grade, but the best prospects for large copper orebodies in the Corella Formation probably lie in calcitic bodies.

Throughout the region, basic igneous rocks and copper mineralization are closely associated. Examples include Crusader, Hampden, Mount Elliott, the Marraba mines, Duchess, and the copper mineralization in the Colless Volcanics. Sparse chalcopyrite and pyrite crystals are common in the basic rocks, but mineral deposits appear to be confined to zones of structural deformation, particularly in shears and faults. The significance of these associations is discussed below (p. 209).

The relationships between the acid plutonic rocks of the Precambrian and copper mineralization are not well defined. Granite intrusions are too widespread in the main portion of the mineral belt to permit deductions as to relationships between copper mineralization and granitic intrusions; nor has the distribution of the various granites been adequately defined (see Part I, p. 143). But deposits tend to be more abundant close to intrusions of granite, and deposits are sparsely distributed in the northern part of the Mount Isa and in the Burketown Mineral Fields, particularly where granite intrusions are absent. The Duchess, Referee, and King's Cross deposits occur along shears in the Kalkadoon Granite and are therefore considered to be younger than the granite. The Kalkadoon Granite (or portions of it) is believed, on other grounds, to be older than some, at least, of the other granites of the region.

The copper deposits in the Upper Proterozoic acid lavas (most of the deposits are in the Northern Territory) are younger than any known granite intrusion.

Structural Control

Almost without exception the copper deposits of the region are within, or very close to, fault zones or shears. Some of the low-grade copper bodies with calcitic gangue bear no obvious relationship to fractures, but they have not been closely studied. The Mount Isa copper body is associated with extensive breccia, though the breccia may not be tectonic; however, the close proximity of the major Mount Isa Fault is probably not coincidental. In some places orebodies are reported to be localized at the intersection of faults; in others, e.g., Mount Isa, pitch changes of folds, or flexures in the strike of fault planes, appear to have exercised an additional control. In some faults, particularly strike faults, displacement has probably been slight, and the shearing or faulting is due to adjustment to relieve local stresses built up during deformation of the region because of the different mechanical properties of contiguous rock masses.

Not all faults, or fault systems, appear to be equally favourable to ore localization. Of the 20 copper deposits of which summary descriptions are given below, 16 are associated with faults or shear zones trending north to north-north-west; some are strike faults, many appear to have been normal faults at some stage in their history, e.g., Hampden Fault, along which the Hampden deposits lie. The major strike-slip faults, particularly the north-east component, which forms such prominent features in the eastern belt, are not associated with many important deposits; but off-shoots from some of the north-east faults contain deposits, e.g., Referee and King's Cross. The Mount Oxide mine, also, is on the north-easterly Mount Oxide Fault, which is an offshoot of the north-north-easterly Mount Gordon Fault.

In a region of east-west compression any east-west faults associated with the shear-fault system would be tensional and could be expected to provide suitable loci for ore emplacement. This type of fault is not well developed in the region, but several such faults have orebodies on them, e.g., Mount Olive, Lillimay, Lady Annie, and the Marraba group of mines.

Little is known about the localization of ore-shoots within most copper deposits. At Mount Isa the lodes are localized in north-south zones of brecciated and dolomitized shales and are arranged *en echelon*. Successive lodes occur in the footwall and to the south of the lode above. In the Black Star section, the orebodies pitch north, but farther south the pitch appears to reverse.

The Mount Elliott deposit has a somewhat similar *en echelon* arrangement: the ore-shoots pitch north-east and each is stratigraphically below and slightly south of the one above. At the Trekelano deposit the ore-shoots are controlled by a secondary system of fractures or shear planes at an angle of 30° to the main northerly-trending shear-zone, and the mineralization decreases from hangingwall to footwall; here again the pitch is to the north. The high-grade ore at Mount Oxide is localized between two flexures in a concretionary shale bed. The flexures pitch steeply to the north-east and are about 400 feet apart. Other minor structural controls observed are changes in strike and dip of the mineralized fault and cross-fault features.

Mineralogy

Oxidation of the copper deposits has given rise to a great variety of copper minerals. Malachite is almost ubiquitous, but secondary sulphides and oxides, though less widely distributed, have probably been as important as a source of ore. The secondary minerals in approximate order of importance are malachite, chalcocite, cuprite (with 'tile ore'), chrysocolla, tenorite, azurite, covellite, native copper, chalcanthite (and brochantite), tetrahedrite, atacamite, and dioptase. Secondary sulphide enrichment is well developed in only four deposits, the Mount Oxide, Ivena, Referee, and Megaphone, although chalcocite is an important constituent of the secondary ore of many other deposits, e.g., the Federal, Mount Cuthbert, Kalkadoon, Duchess, Trekelano, Hampden, Dobbyn, and Great Australia. Early mine reports frequently refer to 'black oxide'; but in some cases this may refer to 'sooty' chalcocite. Copper carbonate and oxides were the important constituents of the secondary ore at Mount Elliott, Hampden, Dobbyn, Wee MacGregor, Great Australia, Orphan, Mighty Atom, Lady Annie, Lady Fanny, Crusader, and most of the smaller mines.

Apart from Mount Isa the only deposits to be worked extensively in the primary zone have been Duchess, Trekelano, St Mungo, Federal and Rosebud. Chalcopyrite is the predominant primary sulphide except in the Duchess and Federal deposits, where bornite ore gave place to the lower-grade chalcopyrite ore in the lower levels of the mines. In other mines where the primary ore has been tested, the grade is generally less than 3% copper, and the pyrite/chalcopyrite ratio increases with depth. Pyrrhotite is also common, but normally less so than pyrite. In deposits where significant secondary enrichment took place the pyrite/chalcopyrite ratio of the primary ore is almost invariably high.

The major sulphide orebodies at Mount Isa consist of chalcopyrite with pyrrhotite, pyrite, and small amounts of sphalerite and galena. They carry only trace amounts of gold, whereas most other deposits in the region contain appreciable amounts—up to $1\frac{1}{2}$ dwt per ton in some primary ores.

Quartz and calcite (or dolomite or both) are by far the most abundant gangue minerals in the copper deposits, but siderite, kaolin, chlorite, hematite, sericite, hornblende, talc, biotite, tremolite-actinolite, scapolite, magnetite, diopside, augite, selenite, tourmaline, fluorite, apatite, psilomelane, barytes, epidote, garnet, and sphene also occur. Jasper and limonitic gossan commonly occur in the leached outcrops.

Ore Genesis

The distribution, variety of host rocks, and almost invariable localization in fractures, of copper deposits are clear indications that the deposits are epigenetic. A possible exception is the copper in the Colless Volcanics, but even here malachite occurs in small fissures in adjacent sediments; the copper in vesicles of the flows may therefore be epigenetic.

In general terms the copper in the Lower Proterozoic strata bears a spatial relationship to granite consistent with a genetic association. The presence of garnet, epidote, scapolite, augite, hornblende, and magnetite in the gangues of various deposits indicates that the deposits were formed under fairly high temperatures and pressures and were probably related to the granitic processes of which metamorphism, metasomatism, and hydrothermal solutions were concomitants. Our knowledge of the ages and distribution of the various granites is inadequate to relate copper mineralization to any particular epoch of granite emplacement. It is unlikely that all mineralization is related to one granite, and the introduction of granite would probably cause redistribution of any nearby pre-existing deposit. However, the existence of copper deposits in shears in the Kalkadoon Granite shows that this granite (or portions of it) is older than some copper deposits. Nye & Rayner (1940, p. 13) relate the copper deposits to the 'Newer granites' and associated porphyries, but the present programme of mapping and petrological work has shown that the granite history is more complex than that recognised previously.

Ball (1908, p. 30) states '. . . both iron and copper ores are due primarily to regional metamorphism, perhaps enriched in parts by ascending metalliferous solutions', and (p. 31) 'the Cloncurry deposits may possibly be due, at least in part, to the metamorphism of originally cupriferous igneous rocks . . .'. The widespread association between basic igneous rocks and copper deposits is consistent with this view (though any redistribution could equally well be attributed to metasomatism or to hydrothermal solutions); certainly sparse crystals of chalcopyrite are to be found in basic lavas and intrusives throughout the metamorphic belt (and also in other rocks). Nevertheless, copper deposits occur in shears and fractures in basic igneous rocks, and more commonly at the contact between basic igneous rocks and incompetent sediments such as graphitic shale or slate; and an alternative (and preferred) explanation is that the differing mechanical properties of the two rock types in juxtaposition produced structural traps during regional deformation.

Edwards (1956, p. 111) draws attention to the widespread scapolitization in the Cloncurry district, which he attributes to metasomatism associated with metamorphism. He suggests that the copper mineralization is likewise due to a soaking by mobile copper-bearing hydrothermal solutions which, lacking a favourable stratigraphic unit, emplaced the copper in favourable structures.

The granites of the region have assimilated vast volumes of basic igneous rocks: if these contained the normal percentage of copper they would have provided an ample source of copper, but this process would have taken place below the present surface and not in the immediate vicinity of known copper bodies. Copper from a granitic source would have had to migrate a considerable distance to form the Lady Annie, Mount Oxide, and nearby deposits. The nearest outcrops of granite are many miles away and the country rocks are little metamorphosed.

The evidence, then, is inadequate to arrive at any sound conclusion either as to the origin or the mode of emplacement of the copper in the Lower Proterozoic rocks, but granitic activity and the formation of copper deposits appear to be closely related.

The deposits (mainly in the Northern Territory) in Upper Proterozoic strata undoubtedly belong to a different mineral province and epoch to most, or all, of these in the older rocks. Most are younger than exposed granites in the area, but may be related to the lavas, which commonly form the host rock.

The Principal Copper Mines

Mount Isa

(S. R. Carter, 1953b)

The copper deposits occur in 'silica-dolomite' bodies on the hangingwall or western side of the silver-lead-zinc deposits and the two are separated by a zone of shearing. The 'silica-dolomite' bodies occupy zones of fractured and brecciated shales which have been impregnated and partly replaced by dolomite, calcite, ankerite, siderite, and quartz. The copper ore is localized in numerous fractures induced by shearing.

The ore in the *Black Star section* is mineable only below 800 feet from the surface. It consists of two orebodies (referred to by Mount Isa Mines geologists as the 650* and 750 lodes) 1,000 feet long and of maximum combined width 140 feet. Their centre portions are close enough to allow continuous stoping over the combined width. The orebodies strike northerly and dip west at a steeper angle than that of the surrounding shales. They pitch north at a similar angle to that of the silver-lead-zinc orebodies, and successive orebodies occur stratigraphically lower in the shale succession and to the south of those above. Up to 1956 the production of copper came very largely from this section. The orebodies have been developed to a depth of 1,600 feet.

The '500' orebody occurs stratigraphically below and to the south of the Black Star orebodies. A block of 3.4% copper ore 1,000 feet long, of average width 105 feet and a proved vertical extent of 500 feet, has been delineated by underground workings. The orebody at the bottom of this block of ore shows no sign of decreasing in width or grade. For a further 600 feet north and 1,600 feet south along the strike, the orebody has been delineated by diamond drilling and some underground development work, and retains its width and grade. In a further 2,700 feet south, the orebody has been intersected by four diamond drill holes from the surface, and the intersections indicate that the width is considerably greater than and grade similar to the rest of the orebody. The mineralized 'dolomite' widens to include footwall beds of the '500' orebody horizon. Throughout the total length of 5,900 feet, a considerable width of lower-grade material has been indicated by exploratory drilling. This cannot be profitably extracted at the present scale of mining operations.†

A small copper orebody occurs between the Black Star and Racecourse sections and 1,000 feet below the surface. It is about 350 feet long, of maximum width 40 feet, and extends over a vertical range of at least 150 feet. The grade averages 5% copper.

In hand specimen the sulphide ore from Mount Isa consists of chalcopyrite, pyrrhotite, pyrite, and rarely sphalerite. In addition, arsenopyrite, marcasite, cobaltite, valleriite, chalcostibite, galena, dyscrasite, jamesonite, magnetite, and gold have been detected in polished section. Approximately 0.35 oz of silver per ton is recovered from the ore during refining.

---

* Indicates the stratigraphic distance (in feet) above the basal marker bed.

† The figures quoted in this paragraph were obtained from the Report of the Proceedings at the Twenty-Fourth Ordinary Annual General Meeting of stockholders held on 4th December 1956.

The *Black Rock oxidized orebody,* which did not crop out, is mined by open cut; it consists of copper carbonates, oxides, silicate, and a little native copper, and occurs on the hangingwall of the Black Rock silver-lead-zinc orebodies. The ore has a siliceous gangue and is supplied direct to the copper smelter as fluxing ore.

Total production of blister copper from Mount Isa mines to June 1959 amounts to 207,964 tons from 5,837,969 tons of ore (3.7% Cu). In addition, 38,685 tons of copper concentrates (assaying 25.3% Cu) were sent to Japan for smelting in 1958-59. To the end of 1958, 10,678 tons of copper had been derived from copper-lead dross produced at the lead smelter. Published ore reserves amount to 19,150,000 tons of sulphide ore of grade 3.7% copper and 950,000 tons of oxidized ore of grade 5.3% copper.

Mount Elliott
(Sullivan, 1953a)

Mount Elliott mine lies one mile south of the railway terminus at Selwyn, in a north-north-west shear zone in slate, adjacent to which is an amphibolite—a sill-like basic intrusive with minor dykes along the margins. The orebody dips at 65°-75° east-north-east, and pitches steeply to the north-north-west. The ore consisted of malachite, cuprite, and lesser amounts of tenorite, azurite, chrysocolla, and native copper, in the oxidized zone, and chalcopyrite with pyrite, magnetite, and pyrrhotite, in the primary zone. The gangue consisted of calcite, diopside, scapolite, gypsum, apatite, sphene, and prehnite. The country rocks around the orebody are hornfelsed slates. Searl (1952b unpubl.) postulated that mineralization was closely related to the intrusion of the metadolerite, dyke-like apophyses of which extend into the zone of shearing, where ore was deposited.

The ore averaged 12% copper and 4 to 5 dwt gold per ton to the base of oxidation, at the 285-ft level. The orebody was developed to the 550-ft level, but the grade of the sulphide ore decreased from 6% copper on the 400-ft level to 2% copper on the 550-ft and 650-ft levels because the ratio of pyrite to chalcopyrite increased. The orebody consisted of three main ore-shoots arranged *en echelon* in section (Searl, 1952b unpubl.). The outcropping ore-shoot was 110 feet long and 50 feet wide. The lowest ore-shoot developed was 320 feet long and 300 feet wide on the 550-ft level.

The mine produced 264,027 tons of ore for a yield of 24,431 tons of copper (9.3%) and 33,893 oz of gold. Estimates of reserves, when the mine closed in 1920, ranged from 360,000 to 600,000 tons of 3% copper ore (Nye & Rayner, 1940). The closure was caused by the fall in the price of copper coupled with the exhaustion of the reserves of higher-grade oxidized ore. Broken Hill South Ltd and Mount Isa Mines Ltd have undertaken exploratory drilling in recent years in an attempt to prove ore reserves beyond the mine workings.

Duchess
(Broadhurst, 1953)

The Duchess deposit is situated near the railway junction of Duchess on the Mount Isa line. It occurs in a north-trending shear-zone in granite, near the intersection of the Juenburra-Duchess shear (which strikes north-north-east) and the Railway Fault (which strikes north-east). The mineralized shear dips west at 80° near the surface, but flattens to 60° west below a depth of 400 feet. The orebody pitches steeply to the north. The country rocks are mica schist, amphibolite, and scapolite granulite, in addition to granite.

Down to the 260-ft level some chalcocite, malachite, and cuprite ore was won, but the main ore mineral was bornite. Chalcopyrite became the dominant sulphide in the lower levels. Calcite was the commonest gangue mineral in the upper levels, but quartz was abundant below the 500-ft level. The deposit was successfully worked over a strike length of 400 feet, an average width of 7 feet, and to a depth of 850 feet. The main shaft reached a depth of 1,070 feet, but below the 850-ft level the ore deteriorated in grade rather abruptly, although the shear zone was still well defined. Broadhurst attributes

the sharp fall-off in grade to an unrecognised structural control, a change in the host rock, or possibly thermal control of deposition. The low-grade mineralization consists of pyrite and chalcopyrite in quartz.

From 201,468 tons of ore 24,747 tons of copper and 2,448 oz of gold were produced (12.3% Cu). When the mine closed in 1920 the ore reserves were practically exhausted.

Trekelano
(Shepherd, 1953b)

Trekelano was discovered in 1907, but the main period of production was from 1928-1943, after most of the other copper-gold mines had closed. It lies 9 miles south-east of Duchess, in a north-trending shear-zone in hornblende schist and scapolite-pyroxene granulite. Aplitic granite crops out a few hundred feet from the mine. The orebody has a westerly dip of 65° and a steep northerly pitch. The zone of shearing is 110 feet wide and well defined hangingwall and footwall shears occur. The ore-shoots are associated with subsidiary zones of shearing which traverse the main shear zone diagonally at 020°; at least three of these zones of shearing occur, each approximately 25 feet wide. Ore deposition was more pronounced on the hangingwall side of the shear zone than on the footwall side. Some chalcocite, malachite, chrysocolla, and tenorite ore was mined to a depth of 200 feet, but the main production was derived from chalcopyrite-pyrite (marcasite) ore, which had a gangue of calcite.

The deposit was worked over a length of 350 feet and to a depth of 864 feet, and although the size of the ore-shoots decreased in the lower levels the grade of ore was maintained. 184,811 tons of ore were produced for a yield of 20,141 tons of copper (10.9%) and 13,606 oz of gold. The mine was closed in 1943, mainly because of labour difficulties. The operating syndicate had made little attempt to develop ore reserves ahead of mining operations. Diamond drilling by the Queensland Department of Mines in 1938, to test geophysical anomalies, showed the presence of disseminated chalcopyrite in schist, but no deposits of economic grade (A.G.G.S.N.A., 1939a, pp. 73, 74.). Further diamond drilling has been carried out in recent years by Broken Hill South Ltd in an attempt to prove sufficient ore reserves to warrant re-opening the mine. The results have not been conclusive.

Hampden
(Sullivan, 1953b)

The Hampden mines are near Kuridala siding on the Selwyn branch railway. The mineralization occurs in a major north-trending bedding-strike shear along the eastern limb of a south-pitching syncline, in slates which have been crushed against a competent amphibolite. The shear zone dips to the east at 75°; the overall pitch of the lode cannot be determined from the available data. The main deposit was worked over a length of 3,200 feet from the Hampden and Hampden Consols mines. The shear zone is up to 250 feet wide, and the orebody consists of several ore-shoots of 40 feet maximum width in the oxidized zone but averaging no more than 3 feet in the primary zone. The oxidized ore consisted of malachite, chrysocolla, tenorite, and chalcocite, and the primary ore consisted of chalcopyrite, marcasite, and pyrite; the principal gangue minerals were quartz and kaolin. Oxidized ore extended to a depth of 350 feet, and the primary ore was worked to a depth of 600 feet in the Hampden section and 480 feet in the Hampden Consols section. The deepest shaft, Hampden No. 3, extended to 700 feet (Broadhurst, 1936). 205,640 tons of ore were produced for a yield of 14,576 tons of copper (6.8%), and 12,092 oz of gold. The mine was closed in 1920 and the only production since that time has been obtained by the reworking of dumps, from smelter flue-dust, and from shallow mine workings. The grade of ore in the lower mine levels was 3.5-4% and the operating companies estimated reserves at 450,000 tons in the Hampden Consols section and 50,000 tons in the Hampden section. Diamond drilling by Mount Isa Mines Ltd and Broken Hill South Ltd failed to locate any extension of ore beyond the mine workings (Sullivan & Matheson, 1950 unpubl.).

Mount Oxide

(Edwards, 1953b)

The Mount Oxide deposit is rather remote from the other important copper deposits: it is 88 miles north-north-west of Mount Isa. The mineralization occurs in a north-east-trending crush-zone in a bed of concretionary sandy shale on the western limb of a major syncline. The orebody dips to the south-east at 60° and the pitch is steeply to the north-east. The crush zone in which the orebody occurs dips at a slightly higher angle than the shale bed. All production has come from the zone of oxidation and secondary enrichment, and the deposit provides the best example of secondary sulphide enrichment in the Cloncurry and Mount Isa Mineral Fields. The oxidized ore consisted of malachite, azurite, atacamite, brochantite, tenorite, and cuprite, but below the 114-ft level the ore mineral was almost exclusively chalcocite. Low-grade pyrite-chalcopyrite ore occurs below the 300-ft level, but not much is known of the primary mineralization.

No granite or other intrusions crop out in the area, and the deposit lies in moderately strongly folded, slightly metamorphosed sediments of the Gunpowder Creek Formation.

The high-grade ore-shoot has been worked over a maximum length of 300 feet and an average width of 8 to 10 feet. The grade of ore generally diminishes from the hangingwall towards the footwall. Lower-grade mineralization extends into the graphitic shales on the footwall side and along the strike beyond the limits of high-grade ore, but this has only been explored on the 208-ft level. Quartz is the only important gangue mineral, but a large body of hematite occurs on the hangingwall of the copper lode and forms a prominent outcrop. The production to 1958 amounted to 50,450 tons of ore of which 48,249 tons contained 10,140 tons copper (21%); 28,723 oz. of silver were recovered from 19,759 tons of the ore. Much of the remaining high-grade ore was extracted by tribute parties in the 1955-58 period. Indicated reserves of low-grade ore (2-4% copper) are estimated to be between 150,000 and 200,000 tons (Shepherd, 1946b). The drilling of three holes by Broken Hill South Ltd in 1953 gave negative results; but the holes did not adequately test the primary mineralization.

Mount Cuthbert and Kalkadoon

The Mount Cuthbert and Kalkadoon deposits lie 9 miles north-west of Kajabbi, which is on the Cloncurry-Dobbyn railway line. They occur in a northerly-trending shear-zone in schist and slate near the contact with altered acid volcanics and metadolerites. The dip is to the east and the pitch is almost vertical. The shear-zone is up to 300 feet wide, but the mineralization is mainly confined to ore-shoots over a 100-foot section on the hangingwall and to a lesser extent near the footwall of the shear zone. The ore consisted of chalcocite, malachite, 'tile ore', cuprite, and azurite in a gangue of quartz, siderite, and calcite. Chalcopyrite ore was reached in the lower levels but little was mined.

The Mount Cuthbert mine was worked over a length ranging from 300 feet at the surface to 650 feet on the 350-ft level; the main shaft reached a depth of 484 feet. The ore-shoots had a maximum width of 30 feet. The Kalkadoon, which is half a mile north of Mount Cuthbert, was mined over a maximum length of 650 feet and to a depth of 350 feet; the main shaft reached a depth of 401 feet. The ore-shoots ranged in width from 4 to 12 feet. Mount Cuthbert produced 60,680 tons of ore for a yield of 4,324 tons of copper (7.1%), and the Kalkadoon produced 45,887 tons of ore for a yield of 3,495 tons of copper (7.6%). The mines were closed in 1920, but some ore was subsequently produced from shallow workings by tribute parties. Shepherd (1939, unpubl.) estimated that at least 200,000 tons of 5% oxidized ore remained in the Mount Cuthbert mine, and additional low-grade reserves probably remain in the Kalkadoon. Mine plans are held at the office of the Inspector of Mines, Mount Isa.

Dobbyn

The Dobbyn deposit lies near the terminus of the Cloncurry-Dobbyn branch railway. Mineralization is localized in a north-trending shear in schists on the contact with altered rhyolite. The shear dips east at 75°. The orebody was worked only in the oxidized zone, where the ore consisted of copper carbonates and oxides with some chalcocite, in a gangue of quartz. The primary ore mineral was chalcopyrite. The deposit was developed over a maximum length of 440 feet, a width of 3 to 12 feet, and a depth of 330 feet. The main shaft reached a depth of 350 feet. The mine produced 16,581 tons of ore for a yield of 2,820 tons of copper (17.0%). Production took place mainly from 1909 to 1919 and 1927 to 1933. At the time of closure the operating company reported that 41,000 tons of 5.0% sulphide ore remained (Nye & Rayner, 1940). Mine plans are held at the office of the Inspector of Mines, Mount Isa.

Orphan

(Shepherd, 1946c)

The Orphan mine lies 1½ miles east-north-east of Dobbyn, in a fault which bifurcates to the north-west of the mine. The fault dips to the south-west at 70° and the orebody pitches steeply south-east. The country rocks are hornblende schist and altered porphyritic rhyolite. The ore consisted of malachite, cuprite, chalcocite, and azurite in the oxidized zone and chalcopyrite and pyrite in the primary zone. The gangue consists of quartz and siderite. The deposit was mined over a length of 300 feet, a width of 5 to 9 feet, and a depth of 175 feet. The main shaft reached 275 feet. The orebody widens to 15 feet at the junction of the fault branches. Production was 23,746 tons of ore for a yield of 2,740 tons of copper (11.6%). Most of the production took place between 1927 and 1937; the ore reserves were not exhausted at the time of closure, but have not been estimated. Favourable geophysical indications were obtained by the Aerial, Geological and Geophysical Survey of Northern Australia (Nye & Rayner, 1936).

Wee MacGregor

(Honman, 1938, unpubl.)

The Wee MacGregor is the largest of the Ballara group of copper mines, which used to be connected by railway with the Cloncurry-Duchess line at Devoncourt siding. The deposit occurs in a north-north-west fault in micaceous schist and altered rhyolite. It consists of two ore-shoots with a rather flat westerly dip and a northerly pitch of 30°. The western or hangingwall shoot is the larger. Ore was produced from the oxidized and semi-oxidized zones and consisted of tenorite and malachite in the upper levels, and chalcopyrite, pyrite, and tenorite in the lower levels. The gangue mineral consisted largely of quartz, with some calcite, garnet, and biotite. The deposit was worked over a length of 550 feet, a width of 5 to 18 feet, and a depth of 320 feet. The main shaft reached 490 feet and preliminary development was carried out on the 480-ft level. Production amounted to 44,411 tons of ore for 2,731 tons of copper (6.2%). The lode decreased in size and grade in depth and probably little ore of economic grade remains in the mine.

Great Australia

(Sullivan & Dutton, 1952, unpubl.)

The Great Australia was the first copper deposit developed in north-western Queensland; it resulted in the establishment of the township of Cloncurry one mile to the north. It is associated with an intersecting fault system, the members of which strike north and north-east. The faults dip west and north-west at 45° to 60° and the pitch of the lodes is to the south-west at 35°. The country rocks consist of metadolerite and altered tuffs. High-grade ore was obtained from the 'jasper' lode to a depth of 100 feet, but below this level the grade deteriorated. The lode was worked over a length of 250 feet and a width of 2 to 15

feet. The ore consisted of copper oxides and native copper, with the addition of chalcocite towards the base of the oxidized zone (below the 200-ft level). A body of dolomite carrying chalcopyrite and pyrite and averaging 2.5% copper had its apex at about the 200-ft level. It was partly developed on the 300-ft level, where its dimensions were 500 feet by 50 feet. Reserves of dolomitic ore to a depth of 350 feet were estimated by the operating company at the time of closure (1919) to be 110,000 tons of 2.5% copper. Reserves of oxidized ore were estimated to be 13,000 tons of 4% copper. Only a little ore has been produced, by tribute parties, since 1919. The recorded production amounts to 33,965 tons of ore for a yield of 2,693 tons of copper (7.9%), and in addition 58,000 tons of cupriferous dolomite flux were mined for the Mount Elliott copper smelter.

St Mungo

The St Mungo is a comparatively small but high-grade deposit 18 miles south of Duchess, in a fissure along the contact of amphibolite and granite. High-grade ore-shoots of massive chalcopyrite occur at the intersection of vertical and flat-lying fault or fracture planes. The deposit was developed over a maximum length of 350 feet and the width ranged from a few inches to 8 feet. In the lower workings an ore-shoot at right angles to the northerly trend of the main deposit was developed. The width of ore decreased considerably on and below the 380-ft level. Repetitions of ore may occur below existing workings, but no reserves were developed ahead of mining operations. The main shaft reached a depth of 448 feet and levels were developed to a depth of 380 feet. Total production was 7,017 tons of ore, of which 6,596 tons was estimated to contain 1,537 tons of copper (23%). The main production took place between 1910 and 1918.

Mighty Atom

The Mighty Atom lies near the Cloncurry-Dobbyn railway north of Oona siding. It consists of eastern and western lodes in a northerly-trending shear zone which dips east at 70°. The country rocks are biotite and chlorite schist, which occur in schistose dacite and basic volcanics. The oxidized ore consisted of carbonates and chalcocite in a calcite-quartz gangue. Chalcopyrite in calcite is reported from the lower levels of the mine. The deposit was worked over a length of 600 feet, a width of 1 to 5 feet, and a depth of 250 feet. The deposit was developed to the 350-ft level, but the ore is reported to have pinched out below the 250-ft level. Production was 9,503 tons of ore for a yield of 1,163 tons of copper (12.2%). The mine closed in 1920 and it is considered unlikely that important reserves of ore remain. Mine plans are held at the office of the Inspector of Mines, Mount Isa.

Federal

The Federal deposit, near the Cloncurry/Mount Isa road, 20 miles west-north-west of Cloncurry, lies in a northerly-trending strike shear in mica schist and carbonaceous slate and dips to the west at a steep angle. High-grade chalcocite ore with some copper carbonates and oxide is present to a depth of 120 feet. Below this depth high-grade bornite ore occurs. On the 200-ft level an appreciable amount of chalcopyrite appears; this becomes the most abundant primary ore mineral in the lower levels, where it is associated with pyrite (cf. Duchess ore). The gangue consists of quartz, kaolin, and calcite. Descriptions of underground workings are not explicit, but it appears that the deposit was worked over a length of 210 feet and a width of up to 5½ feet. The main shaft reached a depth of 412 feet and levels were developed to 400 feet. The high-grade ore has largely been stoped to this depth. Recorded production amounts to 4,156 tons of ore, which yielded 977 tons of copper (24%), but the total production was probably considerably greater. Mining took place principally from 1913 to 1920 and 1927 to 1930. Mine plans are held at the office of the Inspector of Mines, Mount Isa.

Rosebud

(Honman, 1938, unpubl.)

The Rosebud deposit is on the north bank of the Corella River, 5 miles south of Mary Kathleen township. It occurs in a north-north-west-trending fault in amphibolite and calc-silicate granulite; granite crops out a few hundred yards to the east. The ore consists of narrow veins of chalcopyrite associated in part with pyrite and magnetite; the gangue is calcite and quartz. Very little secondary enrichment appears to have taken place.

Mine workings extend to a depth of 300 feet and a length of 350 feet. Average ore widths of 25 and 30 feet are given for the north and south drives on the 200-ft level. The grade over these widths ranged from 2 to 7% and probably did not average much more than 3%; some higher-grade ore was reported to a depth of 135 feet. Heavy influxes of water from the nearby Corella River hampered mining operations on the 200-ft and 300-ft levels. Total recorded production of ore is 21,020 tons of 5 to 6% copper. Production took place mainly between 1915 and 1917, when a small copper smelter was in operation at the mine. Probably considerable quantities of low-grade calcitic ore remain in and below the present mine workings.

Mount Mascotte

The Mount Mascotte deposit, 13 miles north-north-west of Duchess, is of the narrow, high-grade, fissure vein type. Recorded production is 4,824 tons of ore which yielded 866 tons of copper (18%) and 248 oz of gold (1.1 dwt per ton). The lode trends east-north-east and occurs in micaceous schist. Secondary ore consists of chalcocite and some 'tile' ore in a gangue of quartz and calcite; the primary sulphides are bornite and chalcopyrite, and ore-shoots of massive sulphide are one to three feet wide. The main periods of mining were 1914 to 1920 and 1927 to 1928. Mining extended over a length of 200 feet and to a depth of 300 feet, but there is no record of ore reserves at the time of closure. Mine plans are held at the office of the Inspector of Mines, Mount Isa.

Answer

(Honman, 1938)

Thirteen miles south-west of Selwyn the Answer copper deposit occurs in a northerly-trending shear. The shear conforms to the strike of the black micaceous slate which forms the country rock, and dips steeply to the east. A considerable body of jasper and ferruginous gossan is present in the outcrop of the lode. Mineralization persists over a length of at least 1,200 feet, but stoping was restricted to a length of 300 feet and a width of 15 feet. The main shaft reached a depth of 211 feet and the mine was developed to the 200-ft level; but almost all the ore was obtained above a depth of 150 feet in the zone of oxidation and secondary enrichment. The secondary ore consists largely of chalcocite. In the northern section of the workings on and below the 100-ft level, bornite is the principal sulphide mineral, but elsewhere and throughout the 200-ft level, pyrite, with subordinate chalcopyrite, occurs. The main ore-shoot near the northern shaft is 60 feet long and 2 to 12 feet wide, but at a depth of 150 feet this ore-shoot pinches out. On the 200-ft level the better sections of pyrite-chalcopyrite ore average only 5½% copper, and in the poorer sections, the lode consists almost entirely of pyrite or white glassy quartz. The mine produced 8,488 tons of ore, of which 8,133 tons yielded 828.5 tons of copper (10%), and 356 oz gold (0.8 dwt per ton). When the mine closed in 1920, ore reserves were estimated at 7,000 tons of 8.5% copper (Nye & Rayner, 1940).

Magnet

The Magnet has been the most productive of the Dugald River group of copper deposits. It is 8 miles north-west of Quamby, which is on the Cloncurry-Dobbyn railway. Mineralization occurs in a shear zone which strikes 080° and dips 70°-80° to the north. The country rocks are mica schist and biotitite, which form a small roof pendant near the margin of the Naraku Granite. Copper carbonates and chalcocite are present in the secondary zone in a quartz gangue. Primary ore was reached in the lower mine workings, which extended to 230 feet; the ore consisted of pyrite and chalcopyrite with a little molybdenite. The lode is 500 feet long and up to 15 feet wide, but high-grade ore is restricted to small lenticular ore-shoots with a maximum width of 5 feet. The mine has a recorded production of 6,784 tons of ore, of which 5,937 tons yielded 728 tons of copper (12%), and 231 oz of gold (1.3 dwt per ton). No estimate of ore reserves at the time of closure is available, but probably little higher-grade secondary ore remains. Only small parcels of ore have been produced, from shallow mine workings, since the mine closed during the general decline of copper mining in 1920. Mine plans are held at the office of the Inspector of Mines, Mount Isa.

Lady Annie

(Denmead, 1937b)

The Paradise Valley group of deposits, of which the Lady Annie is the most important, remained undiscovered until 1937, and it is one of the few discoveries of outcropping copper deposits since the 1900-1920 period. Paradise Valley is 70 miles north-north-west of Mount Isa. The Lady Annie is a disseminated replacement deposit in shale on the hangingwall of a prominent easterly-trending fault plane. The ore minerals are cuprite, malachite, and tenorite, in a gangue of quartz and kaolin. The deposit has been worked over a length of 115 feet and a maximum width of 65 feet (see Pl. 29. fig. 2). The ore has been open-cut to a depth of 42 feet and has been partly developed by underground mining to a depth of 180 feet below the open cut. Oxidized ore is present to the base of the existing workings, at a vertical depth of 200 feet. Low-grade oxidized ore extends beyond the limits of the higher-grade body, and could possibly be profitably mined if larger-scale operations were undertaken. Production to 1958 was 7,588 tons of ore containing 737.1 tons of copper (9.7%), but indicated and inferred ore reserves were estimated in 1955 at 48,000 tons of 9% copper (Brooks, 1956a). Most of the production has taken place since 1953, and is still in progress on a small scale. A small concentrating plant is being erected at the mine by Copper Corporation of Australia Pty Ltd with the object of up-grading copper oxide ore.

Small Copper Deposits

In addition to the deposits described above, numerous small ('gouger') copper deposits have been mined. Table IIA (Appendix 2) lists 515 mines that have produced more than one ton of copper. Many of these are narrow fissure-vein or shear-zone deposits in which small secondary ore-shoots have been mined to a depth of less than 100 feet. Their potential production is small. However, there are mines which have produced only small quantities of ore but which have potential importance as large low-grade deposits. For example, at the Argylla (Blockade) deposit the total recorded production of 584 tons of copper has come from several secondary ore-shoots within a massive siliceous lode, half a mile long and an average of 60 feet wide. Part of this lode may contain sufficient copper to allow development by large-scale open-cut mining. For a description of some of the small copper mines in the Cloncurry Field reference may be made to Ball (1908), Shepherd (1946d), and Brooks (1956a).

Silver-Lead-Zinc*

Although the Dugald River and Lawn Hill deposits were discovered very early in the history of the region, silver-lead-zinc ore was not mined on a large scale until 1931, when the Mount Isa mine commenced production. The output and value of metals from the Mount Isa mine since then far exceed those from all other sources in north-western Queensland. It ranks second in importance to Broken Hill among the Australian silver-lead-zinc deposits. Up to June 1959, 15,320,017 tons of silver-lead-zinc ore had been mined for a yield of 969,746 tons of lead, 459,019 tons of zinc, and 75,773,391 oz of silver. Present published reserves are 25.2 million tons of grade 5.6 oz silver per ton, 7.8% lead and 6.0% zinc (at 30th June 1959). In addition, large quantities of lower-grade ore are known to exist. If the present expansion programme is implemented these low-grade ore reserves will be mined and the final yield of metals will be greatly increased. Exploration of the Northern Leases has continued since the discovery of the deposits in 1948, but there are no immediate plans for production. The development of the large low-grade ore reserves on these leases is included in the later stages of the expansion programme at present under consideration. Silver-lead has also been produced from several other small deposits in the Mount Isa Shale; the Bernborough, 2½ miles south of Mount Isa, was the largest producer. The Dugald River prospect is a low-grade deposit which is potentially a large producer of silver-lead-zinc, but it is not of a size comparable with the Mount Isa deposits. The Lawn Hill deposits form a distinct geographical and geological group; production is quite small, and relative to the Mount Isa deposit their production potential appears slight. However, the deposits have not been adequately tested at depth.

Distribution

In contrast to the copper deposits of the Cloncurry and Mount Isa Mineral Fields, silver-lead-zinc deposits are few and are confined to small areas. The main deposits occur in two narrow north-south belts in the Mount Isa and Dugald River areas. In both areas the deposits occur in shale, which is dolomitic, siliceous, and carbonaceous in the Mount Isa area (Mount Isa Shale), and graphitic and calcareous (Corella Formation) in the Dugald River area. Very low-grade lead-zinc mineralization is widespread in shale and slate horizons in the Marimo Slate and Corella Formation between the Dugald River area and the Top Camp area, south of Cloncurry.

Fissure vein deposits occur in the Lawn Hill area, Burketown Mineral Field; near Gorge Creek, south-west of Westmoreland; on upper Elizabeth Creek, Constance Range area; near the Seymour River, on the old Thorntonia-Riversleigh track; at Doughboy Creek, south-west of Kajabbi; at Snake Creek, near Cloncurry; in the Toolebuc-McKinlay area; and between Kuridala and Florence sidings, on the Selwyn branch railway. Lead has also been found in drill cores, and at the surface, on the Milo uranium lease. Of these, only the Lawn Hill deposits are economically important.

* See pp. 236-7 for additional information on silver deposits.

Small quantities of lead are associated with gold and arsenic at the Silver Ridge lodes near Kajabbi (see p. 243) and samples from a gossan in the western Lochness ironstone belt gave 0.46 and 0.62% Pb, and a trace of gold (Jensen, 1941b). Galena has been recorded from the Mary Kathleen deposit, but is rare (Matheson & Searl, 1956). Elsewhere in the region, other than in the Mount Isa orebodies, where very small quantities of copper (0.15%) occur in the silver-lead-zinc ore, silver-lead-zinc above trace quantities is not known to occur in association with other economic minerals. Throughout the region the silver-lead-zinc orebodies differ from the copper orebodies as regards structural and lithological controls and paragenesis.

Minor deposits of galena are reported from Little Tott's Creek, 25 miles north-north-east of Camooweal (Blanchard & Hall, 1942, p. 59), in Upper Proterozoic or Cambrian Camooweal Dolomite; from 6 miles south-south-west of the Ibis bore on Chatsworth Station at lat. 22°00′S, long. 140°03′E (Shepherd, 1945b) in dolomitized Ordovician Ninmaroo Limestone; and from 70 miles south-west of Boulia. These occurrences are of no economic significance, but they are of importance in indicating the presence of lead mineralization in the younger rocks.

Surface Expression

The lode outcrops of the Mount Isa deposits were generally of thin bands of cerussite, with some anglesite and pyromorphite, commonly with a coating of blue manganiferous iron oxides. The dark blue coloration enabled the lodes to be readily recognised once the association was realized. Some of the lead carbonate was white, earthy and amorphous. There was a little green malachite staining in places. Much of the lead ore at the surface assayed more than 50% Pb and hundreds of ounces of silver to the ton. The lead outcrops generally lay on the flank of a prominent jaspery ridge, commonly superficially brecciated, which may be traced for many miles through the district. This siliceous ridge appears to have been formed by weathering of pyritic material, and not to be directly related to lead mineralization. In places the lead lodes formed slight to pronounced ridges with gossanous cappings. Vegetation was sparse to absent on the lode outcrops.

On Mount Isa Mines Ltd's Northern Leases the lode outcrops are most inconspicuous. The mineralization was first recognised by the density of a glassy specimen which cropped out in a watercourse and which was found by assay to be rich in lead.

The Dugald River deposits are marked in places by ferruginous gossan, with showings of red and yellow iron oxide, cerussite, and some yellow lead oxide (massicot), and possibly the red lead oxide (minium); some malachite is present. The lode outcrop forms a low ridge over more than a mile. It is completely barren of trees and shrubs.

In the Lawn Hill area metallic minerals have been completely leached from surface outcrops. Some manganiferous gossans occur; other 'gossans' form prominent siliceous ridges. Some deposits, however, did not crop out conspicuously:

they were located by the presence of galena in the black soil plain along Louie Creek. The siliceous outcrops range from large 'gossany' blows and quartz gossan reefs to cellular quartz reefs, perhaps formed by the leaching of siderite crystals; some are jaspery. The gossans are considered to be largely derived from the weathering of siderite and manganiferous siderite (see Jensen, 1941a).

The weak lead-zinc mineralization in the shales, slates and schists of the Corella Formation and the Marimo Slate does not show conspicuously at the surface. Small patches of boxwork gossan and the presence of yellow and red ?iron oxide mark some of the occurrences.

Features of the Secondary Zone

Blanchard & Hall (1942, pp. 48-51) divide the zone of oxidation of the Mount Isa deposits into a zone of complete oxidation and a 'transition' zone where alteration is incomplete and secondary enrichment has taken place. Thorough oxidation extends 175 to 200 feet below the surface, and in places, e.g. along some faults, reaches a depth of 600 feet. The transition zone is 50 feet thick. Galena persisted in small residuals to the surface. A wide variety of secondary minerals has been formed (see under 'Mineralogy'). For the most part the lead content was not much affected by oxidation, but mechanical concentration during erosion did result in considerable enrichment within 10 feet of the surface.

Zinc has been completely leached from the uppermost 100 feet of the Mount Isa deposits, except for isolated 'perched' patches of smithsonite; down to 150 feet leaching is general. In the 'transition' zone supergene zinc sulphide enrichment has increased the zinc content of the ore by 15-20% above that of the primary ore (Blanchard & Hall, 1942, p. 49).

Silver has been generally leached from the uppermost 80 feet of the Mount Isa deposits; most of it has been redeposited, with consequent enrichment, in the 75 feet immediately above the primary zone. Above the transition zone, leaching, with resultant impoverishment, was progressively greater towards the surface. Native silver was the most abundant secondary mineral.

The Dugald River deposit is completely devoid of zinc in the upper levels of the secondary zone, although zinc is five to ten times as abundant as lead in the primary zone. Lead and silver, with some gold, occur at the surface. The ratio of silver to lead in the main ore-shoot is about 0.7 dwt silver per 1% lead, both at the surface and in the primary zone, but the grade of both metals is higher at the surface than at depth. Information is inadequate to decide whether the differences in grade are due to supergene enrichment or to variations in the grade of the pre-existing primary ore.

In the Lawn Hill area the first few feet from the surface have been almost completely leached of metallic minerals. Analysis of gossans from ten deposits revealed traces of lead and low silver values (Jensen, 1941a, p. 13). Cerussite and galena occur within a few feet of the surface. The base of the oxidized zone in the Silver King mine is 100 feet below the surface. In the lower part of the

oxidized zone there appears to have been considerable secondary enrichment in zinc and a smaller measure of enrichment in lead and silver, as the zinc has been almost completely leached from the overlying portions of the lode, but the silver and lead, particularly the former, have tended to stay in place. Except near the outcrop, anglesite is more common than cerussite.

Controls

Stratigraphical and Lithological Control

No stratigraphical control, in the regional sense, can be recognised, but all lead-zinc mineralization in the Mount Isa Shale appears to be confined to a belt of siliceous thin-bedded shale and soft argillites 5,000 feet thick (Knight, 1953, p. 354). The host rocks for the Mount Isa deposits were named the Black Star Group, the Black Rock Group, and the Rio Grande Group by Shepherd (1933c—see Table II, this Bulletin).

The lithology of the host rock is closely related to lead-zinc mineralization, however. In addition to the Mount Isa and the Dugald River deposits very low-grade lead-zinc mineralization was recorded in the course of regional mapping in the pelitic and carbonaceous lenses in the Corella Formation and in the beds of similar lithology in the Marimo Slate. Tests in twelve other localities indicated lead or zinc in geochemically anomalous quantities. At lat. 20°48′30″S, long. 140°27′30″E, gossanous material assayed up to 22% Zn and a trace of Pb. Detailed examination of several of these localities by company interests failed to locate any economic deposits. The close association between rock type and lead-zinc mineralization raises the question of their relationship. The matter is discussed below (p. 233).

Structural Control

Regardless of whether or not the lead and zinc of the Mount Isa deposits and the Dugald River and related deposits are considered to be syngenetic (see p. 233), concentration, controlled by structure, has clearly taken place. Presumably the structure recognisable in and near the orebodies has had some influence on their present distribution. S. R. Carter (1953, p. 363) states, of the Mount Isa deposits, 'the governing ore-localizing rock-structure, to which other localizing agencies are related and complementary, is the folding'. Probably the Mount Isa Fault has also exercised some control over the formation of the deposits.

The Black Star group of orebodies occurs on the west limb of a north-pitching fold, about 1,500 feet south of the nose of the fold. It dips parallel to the axial plane of the fold, and parallel to a weakly-developed fracture cleavage. It occurs in a zone of strike-shearing, and individual orebodies occur where the zone intersects groups of thinly-bedded and extensively crenulated strata between more competent, thick-bedded, claystone. In this way successive orebodies occur *en echelon* and on the footwall of the body above. The controls in the Black Rock and Rio Grande groups of orebodies are similar; the mineralization extends into the noses of the folds with which they are associated.

The Dugald River mineralization is confined to a zone of shearing between two strike-faults. Honman (1937a) suggests that the richest part of the lode was formed at a point where the strike of the lode changes slightly. However, there appear to be more pronounced changes in the strike of the lode elsewhere, without a corresponding increase in the grade of ore.

The Lawn Hill deposits are all fissure lodes, related to the regional fault pattern. Locally stockworks occur and breccia has been replaced.

Most of the minor deposits are related to fractures or other small structures. The control of the occurrence in the Camooweal Dolomite is not known as exposures are poor. The deposit on Chatsworth Station, in Ordovician strata, occurs on a faulted anticline in association with a zone of dolomitization. The galena about 70 miles south-west of Boulia is concentrated in cross-cutting quartz veins in the Lower Cambrian Sun Hill Arkose (J. N. Casey, personal communication). Malachite is also present.

MINERALOGY

The Mount Isa ore is the only one on which comprehensive mineragraphic studies have been carried out. The sulphide ore minerals are galena, sphalerite, and lesser amounts of tetrahedrite; the sphalerite is somewhat marmatitic and also carries a small amount of cadmium. In general the minerals are fine-grained and intimately associated with each other. Gangue minerals are pyrite, pyrrhotite, quartz, graphite, and carbonate minerals. After an early generation of fine-grained pyrite, the order of paragenesis was pyrite, quartz, carbonate, sphalerite, pyrrhotite, and galena (O'Malley & MacGhie, 1939; Blanchard & Hall, 1942). Small quantities of arsenopyrite, marcasite, chalcopyrite, valleriite, proustite, and polybasite are also present. The supergene lead and zinc minerals are cerussite, smithsonite, anglesite, pyromorphite, phosgenite, leadhillite, hydrocerussite, mimetite, and massicot. The pyrite has been altered to goethite, and, where massive, has given rise to ferruginous jasper, which generally crops out prominently.

The mineralization at the Northern Leases is in many ways similar to that at Mount Isa; but the primary silver-lead and lead-zinc ratios are considerably lower. Specimens of drill core examined by Edwards (1955b) consisted of primary ore containing pyrite, sphalerite, and galena, with minor amounts of native silver, arsenopyrite, pyrrhotite, chalcopyrite, and tetrahedrite, in a dolomitic gangue. A considerable body of cerussite ore occurs to a depth of 200 feet.

At the Dugald River prospect the primary sulphides are pyrrhotite, sphalerite, galena, pyrite, arsenopyrite, tetrahedrite, and pyrargyrite. The sphalerite is marmatitic. In the oxidized zone, which is less than 125 feet deep, cerussite, massicot, and a little minium occur.

The chief secondary mineral in the Lawn Hill deposits is anglesite; some cerussite, massicot, goslarite, and malachite have been recorded. The dearth of cerussite, smithsonite, and hemimorphite is notable. Primary ores are galena and sphalerite. Some probable greenockite has been recorded from the Silver King mine, and rare chalcopyrite and pyrite from other mines. Silver is apparently contained in the galena and sphalerite, which are low in iron but contain cadmium.

Ore Genesis

Past workers have attributed each of the three main groups of silver-lead-zinc deposits to nearby granitic bodies. Blanchard & Hall (1942, p. 58) relate the Mount Isa orebodies to the Mica Creek pegmatite, some 5 miles to the south-west. Honman (1937a) suggests that the Dugald River deposit is genetically related to the granite boss 2½ miles to the east. Jensen (1941a) postulates a concealed deep-seated granitic or tourmalinic body as the source of the Lawn Hill fissure lodes.

However, the constant association with shales or slates, with carbonaceous and dolomitic components, throughout the region (including Lawn Hill fissure lodes) could be interpreted to indicate common sources for the base metals and the sediments, the sediments having accumulated in an environment favourable for the accumulation of unusually high percentages of silver, lead, and zinc. It can hardly be argued that epigenetic concentration has not taken place. S. R. Carter (1953, p. 373) has recorded that certain sequences of shale containing ore at Mount Isa are up to 20 feet thicker where mineralized than elsewhere and that the thickening bears a close relationship to the grade of the ore. Further, in many places sulphides occur in veins and stringers which cut the bedding. Edwards & Carlos (1954) have studied the selenium:sulphur ratio of Australian ores and have shown that the ratio for Mount Isa lead-zinc ore is comparable with that of epigenetic rather than syngenetic ores.

Walpole (1958, p. 891) has drawn attention to the fine banding of some of the Mount Isa lead-zinc orebodies. The bands clearly correspond with bedding and in places 'faithfully follow the outlines of primary sedimentary structures such as small slump nappes'. He suggests that the precise agreement in configuration between ore layers and bedding in such complex structures can be more readily explained by syngenesis than epigenesis, but recognises that later reconcentration has taken place.

On the evidence available no conclusive answer can be given to the problem; but the ore has at least been concentrated epigenetically, though source and concentrating agent are not necessarily the same. Granite is probably the main agent responsible for concentration into orebodies; but the presence of veins of galena in Upper Proterozoic to Ordovician sediments, which are younger than any known granite, shows that lead, at least, may move under a thermal gradient or other directional energy gradient unrelated to granitic activity.

Principal Silver-Lead-Zinc Mines and Prospects

Mount Isa

(S. R. Carter, 1953b).

The Mount Isa deposits occur in the Mount Isa Shale, which extends in a north-south belt over a width of three miles. The deposits are 2,000 feet from the western margin of the shales, which is formed by the major Mount Isa Fault. A large concordant granitic body, the Sybella Granite, crops out in a north-south belt whose eastern margin is 5 miles west of Mount Isa. The granite has four phases, with one of which the Mount Isa mineraliza-

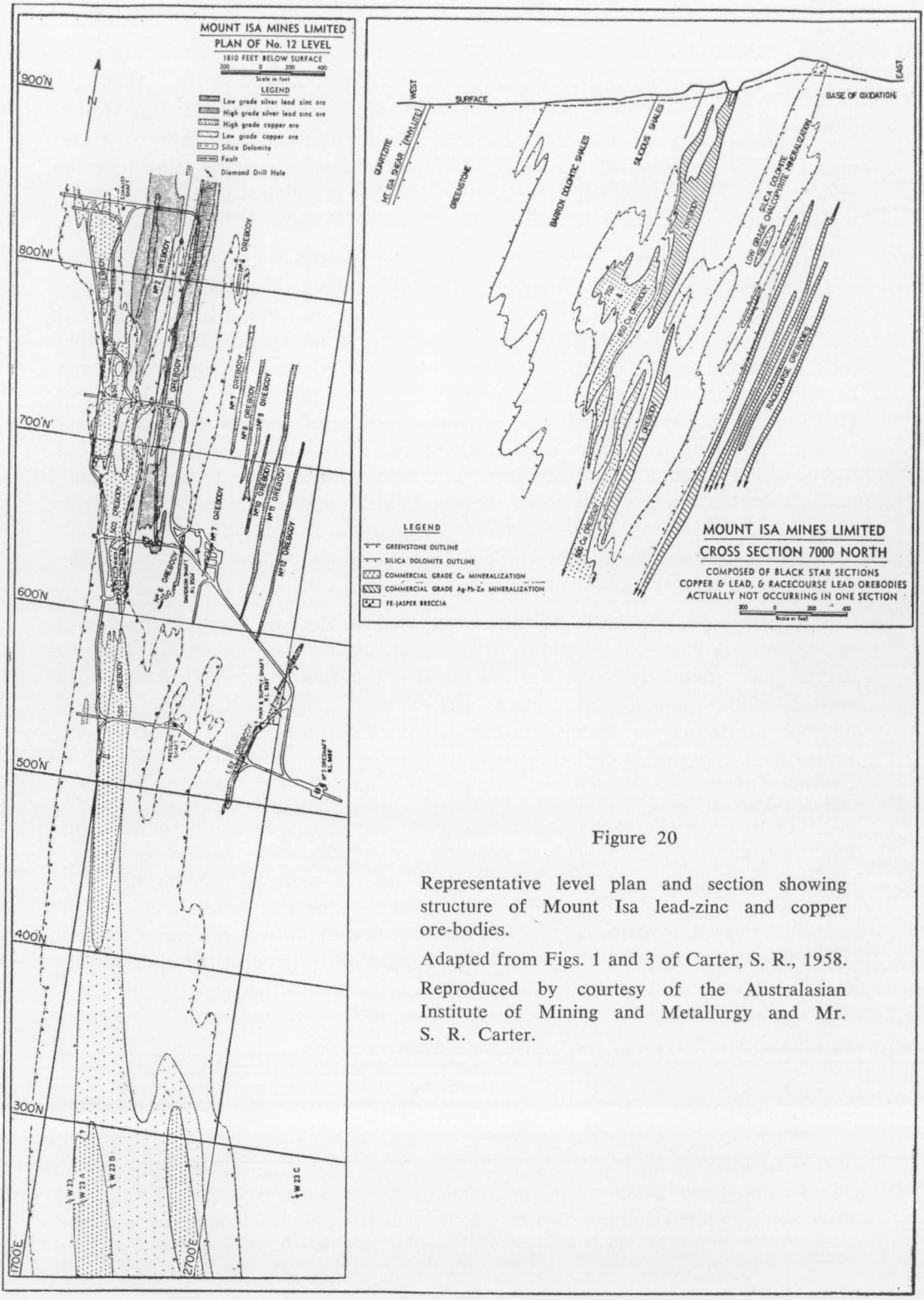


Figure 20

Representative level plan and section showing structure of Mount Isa lead-zinc and copper ore-bodies.

Adapted from Figs. 1 and 3 of Carter, S. R., 1958.

Reproduced by courtesy of the Australasian Institute of Mining and Metallurgy and Mr. S. R. Carter.

tion may be genetically related (cf. Blanchard & Hall, 1942, p. 5; Walpole, 1958). The base-metal mineralization occurs discontinuously over a length of 2¼ miles and a maximum width of 2,000 feet. The general structure is described on p. 221.

Black Star Section. Of the several Mount Isa orebodies those in the Black Star section occupy the highest stratigraphical position in the shale succession and are by far the largest of the silver-lead-zinc orebodies, although they are of lower grade than the others. The outcropping orebodies, No. 1 and No. 2, are more than 2,000 feet long, and were worked over a combined width of 180 feet in the oxidized zone. In the primary zone they were stoped separately over widths of 30 feet and 80 feet respectively. Successive orebodies occur below in the footwall shales and are arranged *en echelon* in plan and section (see Fig. 20). They dip at 60° west and pitch to the north at 30° or less. The orebodies, which conform to the folding of the shales, terminate against the hangingwall 'dolomite' body, which dips west at a steeper angle than the lodes. At least 12 orebodies have been located, but some are not of economic size and grade and others have been worked only in the higher-grade sections. Development has extended well below 2,000 feet from the surface and the mineralization has persisted to the base of the workings. Exploratory drilling has shown that lower-grade ore extends north from the Black Star orebodies (in places as an envelope to the higher-grade ore) for 1700 feet. Farther along the strike the silver-lead-zinc ore horizon is represented by pyritic and dolomitic shales.

Black Rock Section. This section lies south and slightly east of the Black Star and is stratigraphically lower in the shale succession. It consists of two high-grade orebodies 4 to 14 feet thick, separated by 12 to 50 feet of barren shale. Its length is 1,200 feet and the orebodies have been worked to a depth of 500 feet. The beds containing the Black Rock orebodies are also mineralized farther north, where they are known as the Racecourse and Mount Isa sections. This mineralization is of minor importance near the surface, but below 1,000 feet the mineralized zone increases in size and grade and is of probable economic importance over a length of 2,000 feet and a vertical range of 400 feet. The orebodies contain over a million tons of prospective ore but have not been developed.

Rio Grande Section. The five parallel orebodies of this section occur south-south-east of the Black Rock Section. They are 600 feet long and of similar width to the Black Rock orebodies. They have been stoped to a depth of more than 700 feet. The pitch of the Rio Grande orebodies is rather steep to the south, so that in longitudinal projection the Mount Isa orebodies appear to be broadly arched.

Bernborough Orebodies. These are the southernmost and least important of the silver-lead-zinc orebodies in the Mount Isa area. There are seven small orebodies which are in general not more than one foot wide; they have been worked over a length of 600 feet and to a depth of 200 feet (Healy, 1951b, unpubl.). Production from this section ceased in 1951, when the mine was purchased by Mount Isa Mines Ltd.

Production from the Mount Isa orebodies to 30/6/51 (S. R. Carter, 1953b).

Sulphide Ore	Dry Tons	Ag oz	Pb %	Zn %
Black Star No. 1 and No. 2 orebodies	6,492,217	5.4	7.6	9.3
Black Star No. 5 orebody	534,365	6.7	7.8	8.4
Black Rock orebodies	361,046	8.4	11.5	5.1
Rio Grande orebodies	769,362	16.4	15.7	5.9
Bernborough orebodies	6,531*	5.9	26.3	-

*Compiled from Ann. Rep. Dep. Min., Qld.

Northern Leases

(S. R. Carter, 1953a)

Between 10 and 13 miles north of Mount Isa a belt of pyritic strata gives rise to prominent brown jaspery outcrop. Silver-lead-zinc mineralization has been found adjacent to it in several places, but surface evidence is slight. The belt of mineralization strikes north-north-west. The geological environment is very similar to that at Mount Isa, although folding is less well developed. The Sybella Granite crops out less than 2 miles to the west. A section 4,000 feet long and 200 to 400 feet wide is mineralized to economic or near economic grade. In the Handlebar Hill section, where the lodes at the surface are largest, two lodes of cerussite ore have been exposed over a length of 500 feet. They are 8 feet wide and 10 feet apart, and carry an average of 14% Pb at the surface. Underground exploration to 1951 had indicated an orebody of 277,000 tons of carbonate ore of 10% Pb. Large tonnages of sulphide ore have since been proved in the Handlebar and Tombstone Hill areas by exploration, but no estimate of tonnage and grade has been published. The deepest shaft has reached a depth of 500 feet and several prospecting shafts have tested the oxidized zone, whose base is at 200 feet. No work is in progress at present.

Dugald River

(Knight, 1953, unpubl.)

The Dugald River silver-lead-zinc prospect is 36 miles north-west of Cloncurry. The mineralized zone occurs in a north-trending shear in contorted graphitic slates. Mineralization can be traced along the strike for over a mile, but the main ore-shoot is 700 feet long and 40 feet wide at the surface. The grade of the main shoot at the surface averages 4.9% Pb and 3.6 oz per ton Ag. The dip of the lode is vertical to steep west and the lode pitches flatly to the north. Diamond drilling has shown that the oxidized zone extends less than 125 feet below the surface. In the primary zone the lead and silver values deteriorate and the lead-zinc ratio is low. The drilling has indicated 1,280,000 tons of ore containing 1.6% Pb, 11.6% Zn, and 1.2 oz per ton Ag to a depth of 500 feet in the main ore-shoot. A further 2,000 tons per vertical foot has been indicated in three other ore-shoots of lower-grade lead but similar grade zinc. The deepest drill hole intersected the main ore-shoot at a depth of 800 feet. The drilling was done by Enterprise Exploration Co. Pty Ltd.

Lawn Hill Area

The Lawn Hill silver-lead-zinc deposits form a distinct group in a north-north-westerly belt 16 miles long and 6 miles wide in the small Burketown Mineral Field, 150 miles north-north-west of Mount Isa. The only deposits known to occur in the field are of silver-lead-zinc. Isolated small deposits of copper occur in the same general area (Waanyee north-east of Lawn Hill homestead, Blue Bell near Riversleigh homestead, and Ridgepole west of Lawn Hill), but these are beyond the boundaries of the Mineral Field. The remoteness of treatment plants and the smallness and scattered nature of the deposits have prevented any large-scale continuous production. Mining has been profitable only in periods when the price of lead was high. The most recent period of production began in 1948 and fluctuating production has continued to the present time (see Appendix II, Table VA). The bulk of the production has come from the Silver King, Star of the East, Mended Hill, Western King, Axis, Lucky Dollar, Anglo American, and Lilydale mines.

The deposits occur in the Lawn Hill Formation of sandstone, shale, and thin acid lavas and tuff. A few small scattered outcrops of granite, which have been grouped with the Weberra Granite, are exposed about 16 miles east of the mineralized area; these are the only known igneous intrusions within many miles of the silver-lead-zinc deposits. Folding in the Lawn Hill Formation is moderately strong, but open; normal faults and fractures are widespread. Fault directions are diverse and are commonly related to the axes of folding. The deposits are of complex fissure vein type with parallel, anastomosing, and crosscutting veins.

The principal sulphide minerals are galena and sphalerite, with small amounts of pyrite and chalcopyrite. Ore from the Silver King has assayed up to 0.1% cadmium. The galena is very finely granular, and has a steely appearance near the surface. In the primary zone it is for the most part coarsely crystalline. The galena ore produced by selective mining and reworking of dumps in recent years has averaged more than 50% Pb and 14.5 oz per ton Ag. (From 1888-1954 the average silver content has been 29.4 oz per ton of lead.) This ore, however, has come mainly from the Silver King and Mended Hill mines, which contain a higher proportion of silver than most deposits in the Field (see Appendix II, Table VA). In general the Field is reported to contain 1-3 dwt Ag per 1% Pb and about 1 dwt Ag per 1% Zn. Sphalerite is in general more abundant than galena in the primary zone but is not recovered for treatment. It contains a small amount of silver and little iron. The gangue minerals consist of quartz and siderite with minor psilomelane and iron oxides in the secondary zone.

Silver King

The Silver King has the largest production in the Burketown Mineral Field and also has the largest reserves. It is the only mine to have been worked below 100 feet. The mineralized veins strike north-north-east and dip steeply to the west. At the surface there are two main veins which branch and rejoin along the strike. At the 130-ft and 200-ft mine levels, three roughly parallel veins occur. The outcrop of the deposit was not impressive, but at a shallow depth enriched silver-lead ore occurred in ore-shoots averaging 3 to 4 feet in width. At a depth of nearly 100 feet the lower-grade primary ore was reached. In the main underground workings on the 200-ft level, from Carson's Shaft, mineralization is exposed over a length of 150 feet, and the ore zone is 60 feet wide. The main mineralization within this zone is restricted to three parallel ore-shoots which assayed as follows (Ball, 1911):—

	Average Width	Silver oz/ton	Lead %	Zinc %
Eastern ore-shoot	2.5 ft	8.5	20.0	26.0
Western ore-shoot	3.5 ft	2.0	12.5	16.0
Central ore-shoot	1.75 ft	1.5	8.5	9.6

Diamond drilling to below the 200-ft level indicated the persistence of mineralization in depth but demonstrated the erratic nature of the ore-shoots. In all, the workings extend over a length of 650 feet and most of the high-grade ore has been extracted to a depth of 100 feet. Recorded production to 1958 is 2,599 tons of ore for a yield of 1,356 tons of lead (52%) and 47,152 oz of silver (18 oz per ton). The most recent period of production began in 1949. In 1958, 513 tons of ore were produced for a yield of 277.6 tons of lead and 6,486 ounces of silver. Ore reserves to a depth of 240 feet and including surface dumps were estimated at 45,000 tons, assaying 5.0 oz per ton Ag, 16.0% Pb and 14.2% Zn (Mount Isa Mines Ltd, 1954).

Uranium

(E. K. Carter, 1955; Brooks, 1956b)

The output of the Mary Kathleen mine now makes the Cloncurry Mineral Field the largest producer of uranium oxide in Australia. No data on Mary Kathleen ore reserves have been published, but a contract for the sale of £A40,000,000 worth of uranium oxide to the United Kingdom Atomic Energy Commission was arranged in 1956 and this indicates that the reserves already proved were large. Exploration for uranium has only been in progress since 1954, when the initial discovery was made, and other deposits of importance may yet be found. More than 500 leases, most with some higher-than-background radioactivity on them, were effective in the latter part of 1954.

In addition to the Mary Kathleen, several uranium deposits are potential producers, but their economic value is uncertain because of marginal grades and metallurgical problems; with the advance of uranium metallurgical practice it may be expected that many of these problems will be overcome. Most deposits, however, are too small or too low-grade to be of economic interest.

With a few exceptions the uranium deposits are unrelated to copper or other metals. The Monakoff, north-east of Cloncurry, and the Mount Doré are the only deposits previously worked for copper which have been found to be significantly radioactive; and these are very low-grade. Chalcopyrite occurs together with pyrrhotite and pyrite in a section of the Mary Kathleen deposit, and small amounts of torbernite are associated with cobalt minerals at the Mount Cobalt deposit.

Distribution

Uranium, generally in small uneconomic deposits, occurs widely throughout the Cloncurry Complex. Sub-economic concentrations have also been located in the Lower Cambrian Mount Birnie Beds, Middle Cambrian strata south-east of Ardmore Homestead, and the Lower Cretaceous Toolebuc Member of the Wilgunya Formation (Casey et al., 1960, unpubl.); these deposits are probably supergene.

Within the Precambrian area of outcrop uranium is not as widely distributed as copper, as it is confined, apart from the Upper Proterozoic occurrences north of the Nicholson River, to the eastern belt and the Eastern Creek Volcanics in the western belt. Within this area fewer occurrences have been found in the north and south than between the latitudes 20°S and 21°S.

Surface Expression

Secondary uranium minerals are generally not readily discernible at the surface of known deposits, most of which were located by radiation counters. In some deposits secondary minerals can be seen in pits and costeans only a few inches below the surface; in the Westmoreland Conglomerate a pale yellow non-radioactive mineral coats rocks in radioactive areas, particularly on the underside of boulders. Yellow autunite or carnotite, and torbernite, occur just below the surface in many places where the yellow coating is found.

Most of the Lower Proterozoic deposits show very little sign of mineralization at the surface. In the east of the area, however, ferruginous caps mark some of the deposits. The weak mineralization in the Lower Cambrian Mount Birnie Beds is also confined to highly ferruginous outcrops. Many of the deposits in the Eastern Creek Volcanics are associated with concentrations of hematitic carbonate gangue, which may be recognised at the surface by the pink coloration.

In the central part of the region, between Mount Isa and Cloncurry, davidite crystals are clearly visible, mainly in pegmatites. The davidite crystals are dark-brown to black, subhedral, and up to 3 inches long, and many specimens show little apparent alteration. On some leases davidite weathered out of the host rock forms sub-economic detrital deposits, e.g. Six Kangaroos (see p. 234). The Mary Kathleen deposit appears at the surface to be little altered; the main mass of the outcrop consists of a hard black fine-grained bouldery rock. Along joints and on the surface of some outcrops, however, there are secondary alteration products, including yellow gummite, uranophane, and beta-uranotil. The main Milo deposit appeared at the surface as a light-coloured clay, which contains flakes and veins of torbernite from a few inches to 30 feet below the surface.

Features Of The Secondary Zone

Very little is known of the subsurface characteristics of deposits because very few deposits have been tested more than a few feet below the surface.

The Mary Kathleen deposit is extensively altered to a depth of 50 feet (Matheson & Searl, 1956, p. 537), and secondary uranium minerals have formed in place, and migrated to fill fractures. Oxidation is less thorough at greater depths, but extends to about 120 feet. Between 50 and 120 feet uraninite crystals have haloes of secondary minerals, but uranium does not appear to have migrated, and primary sulphides are present. The effect of weathering on the distribution of radioactivity is probably slight.

Shafts up to 50 feet deep and cross-cuts on the Mothers Day and Flat Tyre leases, 5 and 7 miles north-west of Mount Isa, have revealed sporadic radioactivity, but there is very little sign of secondary minerals. Drilling on the Skal and Counter leases has shown radioactivity continuously below the surface for 200 and 800 feet respectively. In general surface and sub-surface assay results indicate that uranium has been redistributed only slightly during weathering, so that near-surface grade is a reasonable indication of grade at depth (subject to original variations in grade). The same conclusion applies to most of the apparently-leached deposits in the east of the region, in deposits of the type found on the Tinboll and Embla Ridge leases, 13 miles north-east and 14 miles south-south-west of Cloncurry respectively. Secondary minerals appear to have been concentrated a few feet below the surface in the Milo deposit, and in the Redtree (Livingstone's) deposits in the Upper Proterozoic Westmoreland Conglomerate, but the behaviour of the uranium at greater depths is not known. The deposits with ferruginous outcrops are probably richer at the surface than at depth.

Controls

Stratigraphical and Lithological Control

No deposits are known to occur in Lower Proterozoic acid lavas and quartzite. Otherwise mineralization in the eastern belt occurs in several rock types and formations, but most deposits, including the Mary Kathleen, are in the Corella Formation. In the western belt nearly all deposits are confined to the Eastern Creek Volcanics and are mainly in the metasediments; some occur in metabasalt. At the Counter deposit, a magnetite-bearing greywacke is mineralized and adjacent quartzite and basic volcanics are unmineralized. Elsewhere the uranium is commonly associated with ferruginous and calcareous sandstone and quartzite.

Uranium in the Upper Proterozoic strata is known only north of the Nicholson River, where it occurs in coarse impure sandstone of the Westmoreland Conglomerate, and in lavas of the Peters Creek Volcanics (and also in the Cliffdale Volcanics).

Structural Control

Some type of structure, generally a fault, could be recognised in almost all deposits in Lower Proterozoic strata that have been examined in the field. In many the control is weak and mineralization diffuse, but it seems clear that all such deposits are epigenetic. (The control in the davidite-bearing deposits is generally not apparent as they occur in, or near, feldspar pegmatites.) Some deposits occur in deformed strata near faults, rather than along the faults themselves. Some appear very diffuse; others have clearly defined lode boundaries. Matheson & Searl (1956) attribute the localization of the Mary Kathleen deposit to a combination of fault, lithology, and joint control.

Mineralogy

The only known concentrations, of more than mineralogical interest, of secondary uranium minerals are on the Milo lease, 21 miles west-south-west of Cloncurry, where torbernite is disseminated through, and along fracture planes in, a clay rock (possibly a weathered and hydrothermally altered igneous rock); and in the Redtree area of Mount Isa Mines Ltd's Westmoreland Authority-to-Prospect, where torbernite and carnotite occur in coarse sandstone. Gummite, uranophane, and beta-uranotil occur in the uppermost 120 feet of the Mary Kathleen deposit and are recovered in the course of treatment. The relative scarcity of secondary uranium is probably due to the Tertiary warping of the region and the chemical stability and impermeability of the host rock in many deposits. Small amounts of uranophane, carnotite, gummite, beta-uranotil, autunite, saleeite, and other, unidentified, yellow ochreous minerals occur as films and stains near the surface of several deposits, but do not persist at depth. Torbernite is found in the Lower Proterozoic strata mainly in the eastern part of the metamorphic belt, in association with ferruginous or jaspery outcrops. It has also been found on the Valhalla lease, near the Barkly Highway, 27 miles from Mount Isa.

Uraninite (or pitchblende) is the most important primary uranium mineral. It generally occurs as fine disseminated grains which are not visible in hand-specimen, and is commonly preserved near the surface of deposits. No pitchblende vein-type of deposit has yet been found in north-western Queensland, but some occur in Upper Proterozoic strata a few miles west of the Northern Territory border, north of the Nicholson River.

At Mary Kathleen about 96% of the uraninite occurs as discrete grains from 0.001 to 0.5 mm. in diameter, together with allanite, stillwellite (a borosilicate of the lanthanons), caryocerite (a borosilicate of the cerium group) and rinkite (a silicate of calcium, sodium, iron, titanium, and cerium). A little uraninite is associated with pyrrhotite, pyrite, and chalcopyrite.

The radioactive mineral in the Counter lease has not been identified. It is fine-grained and disseminated, and occurs in association with biotite, sphene, and rutile.

The refractory minerals davidite, brannerite, and absite (all of the magnetite-ilmenite group) commonly occur in association with pegmatite, or as detrital minerals, by weathering of pegmatite. 'Davidite-type' minerals have been found in at least twenty localities, many of which are in the Cameron River, Ballara, and Mica Creek areas, and the area east of Kuridala. Laboratory studies have shown that the mineral referred to in the field as davidite generally consists of a mixture of davidite and ilmenite, with associated hematite in some specimens (Lawrence, 1957). The uranium content of specimens analysed ranged from 2.17% to 20.16% U_3O_8. The uranium is thought to be present in both davidite and ilmenite in some deposits. Uraniferous magnetite, hematite, and columbite have also been found, but may not represent distinct mineral species.

Ore Genesis

The concentrations of radioactive materials in the post-Precambrian deposits appear to be due to the action of special 'concentrators', organic matter in the Wilgunya Formation and iron in the Mount Birnie Beds (see p. 228). The uranium was probably obtained by erosion of the nearby Precambrian terrain.

The source of the uranium in the Upper Proterozoic Westmoreland Conglomerate has not been established; there is no known granitic source (though there are acid and intermediate lavas younger than the Westmoreland Conglomerate), and the deposits, of secondary minerals only, tend to be confined to certain beds. Some of the deposits, however, lie along a joint on which movement has probably taken place. As deposits in lavas in the Northern Territory are related to fissures, the uranium deposits in the Westmoreland Conglomerate may be epigenetic and related to igneous activity, but one of us (Brooks) considers them to be supergene.

In the Mary Kathleen area the uranium is associated with zones of intense garnetization in calc-granulites between two granite masses. The uranium may be related to the end-phase of granitic intrusion. In places these granites and others in the region give readings up to 5 times background, but in general no direct relationship between granitic intrusion and uranium mineralization is evident, except for the davidite-brannerite-bearing pegmatites.

The deposits in the Eastern Creek Volcanics cannot be related directly to granite, but they are probably epigenetic; the presence of exsolution intergrowths of magnetite and hematite in a specimen from the Skal lease, 20 miles north of Mount Isa, indicates that they formed at temperatures above 1000°C.

Principal Uranium Mines and Prospects

Mary Kathleen

(Matheson & Searl, 1956)

The Mary Kathleen uranium deposit is 30 miles west of Cloncurry. It has been tested to a depth of 400 feet by diamond drilling on a grid with 50-foot centres, and by deeper drilling.

The deposit is of the pyrometasomatic replacement type and is probably genetically related to nearby granite. It lies near the axis of a large overturned syncline in the Corella Formation. The rocks in the area are highly metamorphosed and metasomatized. A garnet rock is closely associated with the uranium mineralization; the garnetite, which consists of almandite, some andradite, allanite, and diopside, together with other minor constituents, is thought to have formed partly by metamorphism and partly by the introduction along fractures of late stage differentiates from granite. Subsequent fracturing provided channels for the ore solutions, which partially replaced the wall rocks.

The orebody is roughly mushroom-shaped. Mineralization is very irregular; it is thought to have been controlled by a complex joint or fracture system. The overall control of the garnetization and mineralization was by favourable host rocks—diopside granulite and breccia-conglomerate—and faults, shears, and joints—the deposit lies between two north-westerly faults. Flat-lying joints were important. Although the garnetization preceded the mineralization the two processes are considered to have been closely related.

The main uranium-bearing minerals are listed on p. 231. They replace garnetite and garnet-diopside granulite. Diopside, albite, microcline, apatite, calcite, and rarely molybdenite and galena also occur in the orebody. Andradite is preferentially replaced by allanite-uraninite. A little thorium is present in the weakly radioactive allanite; the uranium to thorium ratio is approximately 3 to 1 and the uranium is in equilibrium. Irregular localized bodies of massive sulphide (pyrrhotite, pyrite, and chalcopyrite) carry disseminated uraninite. The allanite contains 21.5% and the stillwellite 58.4% of rare earth oxides (see 'Rare Earth Minerals').

In the 1956-1958 period 384,173 tons of ore were produced from the open cut and 657,400 tons of waste rock and marginal ore were removed. In the six months from June 1958 to the end of the year the mill treated 201,342 tons of ore for a yield of 250.8 tons of uranium oxide (U_3O_8). The present rate of mining is just over 1,000 tons of ore per day.

Counter

The Counter deposit lies 9 miles north-east of Mount Isa, in a succession of interbedded metabasalt and arenaceous metasediments which have been intruded by basic dykes. Uranium mineralization is confined to a greywacke which has undergone low-grade metamorphism and carbonatization. The main constituent minerals are quartz, chlorite, biotite, and plagioclase, with minor magnetite, apatite, sphene, zircon and rutile. Some of the metagreywacke has been mylonitized. The host rock is a magnetite-chlorite-biotite-quartz-epidote 'hornfels'. It strikes easterly, dips 70° to the north, and is intersected near the eastern end by a metadolerite dyke which trends northerly. Strike faults on either side of the greywacke, and the north-south fracture along which the dolerite was intruded, probably provided openings for the introduction of the uranium-bearing solutions.

The main section of the deposit is 150 feet long and 55 feet wide (650 tons per vertical foot at the surface). The average grade of ore is 0.19% U_3O_8; it includes many chloritic, low-grade to barren, masses of rock within the lode. Extensive diamond drilling in 1953, by Queensland Mines Ltd, indicated over 500,000 tons of ore; possibly reserves to 1,000 feet depth total 1,000,000 tons. Extensive faulting, possibly in part later than the mineralization, has affected the deposit.

Skal

The Skal deposit is 20 miles north of Mount Isa and was the first discovery of uranium reported in north-western Queensland. Uranium has been localized in a zone of strike shearing. The country rocks are sandy slate, calcareous quartzite, chloritic schist, and metabasalt. They strike northerly and are strongly to intensely fractured. Quartz has been introduced along the line of shearing. Owing to poor stratification and strong fracturing, structure could not be elucidated without detailed mapping, but extensive drag-folds have probably been associated with the shear.

A little secondary carnotite occurs on fracture-planes at the surface. Where visible, primary uranium mineralization consists of blebs of brannerite, with crystals of chalcopyrite and galena, in a gangue of calcite, magnetite, and hematite. Generally, however, the primary uranium is disseminated in grains too small to be seen with the unaided eye.

The deposit consists of two main ore-shoots. The southern ore-shoot is 370 feet long and 60 feet wide (1,700 tons per vertical foot) and averages 0.06% U_3O_8 at the surface. Drill holes put down by Mount Isa Mines Ltd revealed that values were higher at 100 feet than either above or below that depth: at 100 feet the average grade is 0.16% U_3O_8 and at 200 feet the average grade is 0.03% U_3O_8. The northern ore-shoot is 300 feet long and 76 feet wide (1,750 tons per vertical foot) and averages 0.04% U_3O_8 at the surface. The 100-ft intersections averaged 0.17% U_3O_8 and the 200-ft intersections averaged 0.06% U_3O_8. In view of the refractory nature of the ore and the rather low grade, it is doubtful whether it could be profitably developed under existing conditions, but further exploratory diamond drilling has been carried out by Queensland Mines Ltd.

Milo

The Milo deposit, 21 miles south-west of Cloncurry, lies within a belt of slates, some carbonaceous, which are interbedded with recrystallized impure limestone and calc-granulite of the Corella Formation. Visible secondary meta-torbernite forms coarse flakes along joint planes and finer flakes irregularly disseminated in a kaolinitic rock. It is thought that the torbernite has formed by supergene concentration in a favourable lithological and structural environment, and that it was derived from a disseminated source of uranium in the adjacent limonitic jasper and silicified slates.

The main deposit of torbernite ore is 120 feet long and 15 feet wide and the average grade is 0.11% U_3O_8. It strikes northerly and dips east at 50-60°. A trial parcel of 9.3

tons of handpicked ore was treated at Rum Jungle, Northern Territory, and assayed 0.76% U_3O_8. Diamond drilling to test the primary zone intersected weak copper-lead-zinc mineralization but no uranium.

Six Kangaroos

The Six Kangaroos deposit lies near the Mount Isa road, 27 miles west-north-west of Cloncurry. It is unimportant as a possible source of uranium, but is representative of numerous 'davidite-type' deposits which occur in the Corella Formation and most of which are closely associated with outcropping pegmatites or granite.

At the Six Kangaroos the davidite occurs as medium to coarse subhedral grains (some of which are more than 3 inches long) in a lens of calcite. Some magnetite, ilmenite, and hematite are associated with the davidite. The davidite has a uranium content of 2.6% U_3O_8 (Whittle, 1954, unpubl.). A considerable amount of detrital davidite occurs in the scree, but the davidite *in situ* is sparsely and irregularly distributed through the calcite. Graphic granite and pegmatite crop out within a few hundred feet of the deposit and a little davidite is associated with them.

Gold

Gold was the first metal to be exploited in north-western Queensland and was responsible for the early movement of population to the area in the latter part of the nineteenth century. Since 1943 very little has been produced. The region does not rank as a major gold field as the total recorded production is only 102,043 oz, of which 74,593 oz was derived from auriferous copper ores.

Most of the productive gold deposits lie south and east of Cloncurry. The chief mining centres were Top Camp (alluvial), Gilded Rose (reef), Pumpkin Gully (reef and alluvial), and Soldiers Cap (reef). The close relationship between copper and gold mineralization is demonstrated by the fact that the gold-copper ratios of the auriferous copper deposits in this south-eastern section are, in general, much higher than elsewhere in the mineral province. Isolated gold deposits occur in the Bower Bird - Doughboy Creek area (reef and alluvial), south-west of Kajabbi; in the May Downs area (reef), north-west of Mount Isa; in the Agate Downs area (reef), south of Kuridala; at Mount Quamby (in conglomerate), north-west of Quamby; and 9 miles west-south-west of Cloncurry. They are all of minor importance.

Honman (1939) stated that the more important gold deposits in the Soldiers Cap Formation occur at, or close to, a particular stratigraphical horizon where it is cut by cross-faults or intersecting faults. This horizon is near the base of the middle section of the Soldiers Cap Formation (see p. 69), below the succession of metabasalts (amphibolites) and arenaceous metasediments.

At Mount Quamby the gold is disseminated through part of the Quamby Conglomerate. It occurs in the matrix of the conglomerate in association with hematite. Whether the gold is of sedimentary or epigenetic origin has not been definitely established, but the presence of gold at all levels in the succession and its constant association with hematite are consistent with a hydrothermal origin. The overall grade is very low, although some superficial enrichment has taken place. Some alluvial concentrations have been derived from the conglomerate.

Copper-Gold Deposits

Nearly all the copper deposits of the mineral province, with the notable exception of Mount Isa, contain significant amounts of gold. Among the larger deposits the amount of gold recovered ranged from 4.2 dwt per ton from the Mount Elliott mine to 0.24 dwt per ton from the Duchess mine. The subject of the copper-gold ratios has been treated in detail by Nye & Rayner (1940). The main gold producers were Mount Elliott (33,894 oz), Trekelano (13,606 oz), and Hampden (12,075 oz). Much of the copper-gold ore was obtained from the oxidized zone, where the gold was concentrated. Little is known of the gold contents of the primary ores, though at the Trekelano deposit the 10% chalcopyrite ore yielded an average of 1.5 dwt per ton. Gold is reported in mineragraphic descriptions of Mount Isa copper ore, but is not present in recoverable amounts.

The small Brilliant, King Edward, and Flying Dutchman mines in the Pumpkin Gully/Soldiers Cap area have produced both gold and copper-gold ore. Small amounts of scheelite are associated with gold at the Falcon and Brilliant Extended mines in the Soldiers Cap area.

Alluvial Deposits

Only 12,729 oz of alluvial gold is recorded from the Mount Isa and Cloncurry Fields, but this probably represents only a small percentage of the actual production, as much of the alluvial gold was won between 1867 and 1878, before official records were commenced, and even since 1878 the figures cannot be regarded as complete. The main alluvial deposits were in the Top Camp area, 21 miles south of Cloncurry. Here the gold was associated with bismuthinite and native bismuth and occurred in small rich areas of alluvial wash (Shepherd, 1933c and d, unpubl.) The gold was traced to auriferous 'leads' in the adjacent hills, but reefs were not successfully mined. A small gold-copper-bismuth deposit, the Lone Hand, has been mined in the nearby Marraba area (Shepherd, 1932b). The Pumpkin Gully deposits are in the headwaters of Fishers Creek, 10 miles east of Cloncurry. They were not as rich or productive as the Top Camp deposits.

Reef Deposits

Only 14,423 oz of reef gold is recorded from the Mount Isa and Cloncurry Fields; more than half of this total was obtained from the Gilded Rose group of reefs, which is described below. Auriferous quartz reefs in the Soldiers Cap area (25 miles south-east of Cloncurry) occur in fault or fracture planes, or in shear-zones. The only deposits of any importance are the Mount Freda, Comstock, and Falcon (Honman, 1939). In the Bower Bird/Doughboy Creek area both reef and alluvial gold was mined (Honman, 1937a). The reef deposits include quartz reefs on the contact between quartzite and basic volcanics (Victoria) and fissure veins in slate and quartzite (Gertrude). The absence of copper deposits in the Bower Bird area may be contrasted with the close association of gold and copper in the south-eastern portion of the mineral province. The small May Downs deposits occur as quartz reefs in phyllite, not associated with other metals.

Gilded Rose
(Honman, 1936)

The Gilded Rose group of auriferous reefs is situated 10 miles east-south-east of Cloncurry, in schist and quartzite close to a band of amphibolite. The schist which forms the reef walls is commonly garnetiferous or sericitic. The reefs strike east-south-easterly in conformity with the surrounding schist, and dip south at 75°. Auriferous quartz occurs as fissure veins at numerous places over a length of nearly half a mile. The fissure veins are associated with strike faults and transverse faults which strike east-north-easterly, and are generally narrow, with an average width of about one foot. The most extensive workings are at the Gilded Rose mine, where the ore-shoot was mined over a length of 440 feet and to a depth of 150 feet. The main shaft was sunk 100 feet vertically and a further 90 feet on the incline of the vein. The ore is highly pyritic in the sulphide zone, which was encountered on the 150-ft level. Practically all the production was derived from the oxidised zone; the ore yielded an average of more than 1.5 oz per ton. Total production for the Gilded Rose group of reefs was more than 8,000 oz.

Silver

The region ranks as a major producer of silver. Total production up to 1958 was 76,518,154 oz, nearly all of which has been derived from Mount Isa silver-lead-zinc ore. The silver is recovered overseas from the lead bullion and to a minor extent from the zinc concentrates. The potential production from Mount Isa is very large; published reserves exceed the total tonnage of ore extracted to 1958, and large reserves of low-grade silver-lead-zinc ore are also known. Other potential sources of production are the Northern Leases, 12 miles north of Mount Isa, and the Dugald River silver-lead-zinc deposit. Minor sources of silver have been the Lawn Hill silver-lead deposits (152,245 oz), the copper deposits of the Cloncurry Field (765,997 oz) and two isolated occurrences of silver ores (139,262 oz).

Silver in lead-zinc ores

The geology of the Mount Isa deposits has been described in the section on silver-lead-zinc ores. The silver content at Mount Isa ranges from 5.4 oz per ton in the ore mined from the Black Star No. 1 and No. 2 orebodies to 16.4 oz per ton from the Rio Grande orebodies. Overall, the silver-lead ore has averaged 76 oz of silver per ton of lead (to 30th June 1956). By comparison, Broken Hill ore has averaged 61 oz and Lawn Hill 29 oz per ton of lead. Supergene silver minerals have been precipitated in a zone of secondary enrichment which extends from about 125 feet to a maximum depth of 250 feet. The secondary minerals include native silver, cerargyrite, pyrargyrite, proustite, and polybasite. Tetrahedrite is the only hypogene silver mineral known in the Black Star orebodies, but minor amounts of proustite and polybasite are present in the other lodes. The tetrahedrite usually occurs at the contact of galena and sphalerite grains. In 1951, 81.2% of the silver was recovered in lead concentrates and 3.7% in the zinc concentrates, and the remainder was lost in mill tailings (Cunningham, 1953).

Drilling in the primary zone of the Dugald River silver-lead-zinc deposit showed low-grade ore containing only 1.2 oz silver per ton of ore (see p. 226).

Silver in Copper Ores

The silver content of the copper ores is, with few exceptions, quite low. Most of the deposits with appreciable contained silver have very little gold. The Mount Isa copper ore averages 0.35 oz of silver per ton, and in the periods 1943 to 1946 and 1953 to 1957, 1,022,808 oz of silver were recovered from the blister copper. The Hampden smelter, which treated ore from the Hampden, Duchess, Trekelano, and other mines (1911-20), produced 379,124 oz of silver (0.69 oz per ton of ore). Ore from the Hampden mine contained 1.06 oz to the ton, and other mines with ores containing more than one ounce of silver per ton were: Mount Oxide, 1.45 oz; Duchess, 1.14 oz; Federal, 2.37 oz; Ivena, 1.49 oz; Mount Norna (Mountain Home) 2.71 oz; Southern Cross, 1.66 oz; St. George, 2.71 oz; Success, 1.14 oz; and Apple Pie, 1.25 oz. These figures were derived from Chillagoe smelter returns.

Occurrences of Silver Ore

Two unusual occurrences of high-grade silver ore have been found in the southern part of the mineral belt. In 1918 a deposit of naumannite (silver selenide) was found 1¼ miles from O'Briens Soak, which is 26 miles from Duchess, on the Urandangi road (McGillivray, 1919). From 8.7 tons of ore 10,124 oz of silver were obtained. The naumannite is reported to have been associated with native silver, cerargyrite, and calcite in a narrow fissure in amphibolite. In 1953 the Silver Phantom deposit was found, 9 miles south-west of Kuridala. The ore consists of cerargyrite and native silver in a gangue of barytes and limonitic jasper (Connah, 1954b). It occurs in a fissure near the margin of the Wimberu Granite. From 85 tons of ore 129,138 oz of silver have been obtained. At present only ore expected to yield more than 1,000 oz to the ton is being despatched for treatment, as it is necessary to send it to Port Kembla, New South Wales.

Cobalt

The Cloncurry Mineral Field has been responsible for the greater part of the production of cobalt in Australia, and Mount Cobalt is the only large deposit in Australia to have been mined primarily for its cobalt. However, the total production of 775 tons of cobalt metal is small by comparison with the principal overseas producers.

Distribution

Seventeen cobalt deposits have been recorded, mainly from the Cloncurry Mineral Field. Occurrences in the Mount Isa Mineral Field are confined to small quantities in the Mount Isa copper orebodies, the Black Star silver-lead orebodies, and the Trekelano copper deposit. The most important deposits are in a narrow belt from Kajabbi in the north to Mount Cobalt (south of Selwyn) in the south. Apart from the Mount Cobalt deposit, the only productive deposits have been the Success (Marraba) and the Queen Sally (Kajabbi), and these produced only a

few tons of metal. There are groups of minor deposits in the Quamby-Dugald River area, the Kajabbi area, and the Soldiers Cap area. Cobaltite was found in 1954 at the surface near the Federal copper mine (Brooks, 1957).

Cobalt deposits have been found in the Kuridala Formation, the Marraba Volcanics, the Soldiers Cap Formation, the Corella Formation, and the Leichhardt Metamorphics. No stratigraphical or lithological control of cobalt mineralization has been recognised. However, it may be noted that basic igneous rocks (amphibolite) are included in the country rocks at the Mount Cobalt, Success, Queen Sally, and Centipede deposits, and the deposit near the Comstock mine, Soldiers Cap. In general the deposits occur in strike faults and shears at the contact of rock types of contrasting competence; the mode of occurrence is similar to that of copper.

Mineralogy

Nearly all the deposits are associated with copper or other metallic minerals, but the Success is the only deposit to be worked for both cobalt and copper. The Mount Cobalt deposit consists of cobaltite, with appreciable amounts of erythrite near the surface, and a little asbolite. The cobaltite occurs in veins in a siliceous matrix and as disseminations in hornblende-biotite schist. The gangue consists of quartz, calcite, biotite, and hornblende. Other minerals present in the same line of lode are malachite, scheelite, and torbernite in the secondary zone, and chalcopyrite and pyrite in the sulphide zone. No nickel has been determined in assay. At the Success mine cobaltite is associated with chalcocite, bornite, chalcopyrite, pyrite, and small quantities of nickel (0.5% Ni) (Rayner, 1938) In several other deposits, e.g. Queen Sally, the cobalt is associated with manganese oxides in the form of asbolite.

Principal Occurrence

Mount Cobalt

Mount Cobalt is 18 miles by road south of Selwyn, the railway terminus. Cobalt mineralization occurs in a zone of shearing along a contact between a metadolerite sill (footwall) and quartzite and quartz-mica schist (hangingwall) in the Kuridala Formation. The shear trends northerly and dips east at 70° to 80°. Honman (1938) considered the deposit to be of the metasomatic replacement type. It has been stoped over a length of 720 feet, an average width of 2 to 3 feet, and a depth of 112 feet. A little ore was stoped immediately above the 212-ft level, which was the lowest level developed. Recent exploration has confirmed that the orebody pitches flatly to the north and extends beyond the old workings, but the overall grade has not been determined. The ore, in general, is rather low-grade, but several high-grade ore-shoots occur through the orebody. Much of the high-grade material was hand-picked to a grade of 16-18% Co for direct shipment. It has been estimated that 1,500 to 2,000 tons of high-grade ore were shipped direct (Rayner, 1938). The bulk of the ore averaged less than 3% and was treated at the mill, but recoveries were low and milling operations were hampered by a succession of drought years during the period of operation. The mill treated about 20,000 tons of ore.

Iron

Several iron deposits have been worked on a small scale for ironstone flux for copper smelting, but none has been exploited as a source of metallic iron (Brooks, 1956c). The low grade, small size, and remote location of the deposits have made production impracticable. Very large low-grade bedded deposits of oolitic iron ore are at present being investigated in the Constance Range area, west of Lawn Hill. These deposits will eventually add very greatly to Australia's reserves of available iron ore, but it may not be practicable to work them in the immediate future.

Distribution

Iron deposits are sparsely scattered throughout the mineral belt. They occur in the Staveley Formation, Corella Formation, Gunpowder Creek Formation (at Mount Oxide), Surprise Creek Beds (at Lochness) and Mullera Formation. Most of the deposits are of the hydrothermal replacement type associated with limestone, calc-silicate rocks, shale, and slate. The deposit west of Lawn Hill is of sedimentary origin and occurs in the Upper Proterozoic Mullera Formation. The hematite bodies south-west of Selwyn appear to be replacement deposits, of magmatic affinities, along strike faults. The Mount Philp deposit is considered to have a similar origin.

Ferruginous laterite is widespread but is not of sufficient grade to form iron ore.

Mineralogy

Most of the deposits consist largely of hematite; some, e.g. Mount Philp and Mount Leviathan, contain subordinate amounts of magnetite. The hematite deposits south-west of Selwyn become magnetitic at depth; the Mount Philp, Lochness, and Mount Leviathan deposits are probably similar. A deposit consisting essentially of magnetite is reported to occur 6 miles south-east of the Dugald River lead-zinc deposit (Sturmfels, 1952, unpubl.). The deposit west of Lawn Hill, in the Constance Range area, consists of hematite, limonite, and goethite at the surface. Drilling has revealed siderite, chamosite and hematite in the unweathered zone. The Mount Oxide deposit consists of limonite associated with hematite. Small limonitic gossans are a common feature throughout the mineral belt, but these generally represent the outcrop of pyrite and copper sulphide bodies and are of little value as sources of iron ore.

Principal Occurrences

Mount Philp

(Carter & Brooks, 1955)

The Mount Philp deposit is 48 miles south-west of Cloncurry and 27 miles by vehicle track from the nearest railhead, at Devoncourt siding. The ironstone forms a prominent ridge, 2.1 miles long and of average width 85 feet. The ore consists of granular hematite and a small, variable amount of magnetite. Quartz is the principal impurity and increases

in amount towards the southern end of the deposit, where the ironstone deteriorates to a hematite quartzite. The deposit is associated with a major fault, and the ironstone replaces altered calcareous and arenaceous sediments of the Corella Formation. Total exposed ironstone amounts to 4.1 million tons averaging 36.6% Fe, including 2.75 million tons averaging 46.9% Fe. At the base of the outcrop the deposit contains 105,000 tons per vertical foot averaging 41.8% Fe, including 71,000 tons per vertical foot averaging 48.5% Fe. Percentages of titanium, phosphorus, sulphur, and manganese present are within acceptable limits for metallic iron production.

Constance and Little's Ranges

These deposits are near the Northern Territory border, 85-115 miles south-west of Burketown. They are of sedimentary origin and consist of up to ten beds (but generally four or less) of which only one or two at any place are likely to be of economic interest (Pl. 7, fig. 1). The beds form a zone up to 300 feet thick from 900-1700 feet above the base of the Upper Proterozoic Mullera Formation of siltstone, shale, and fine-grained sandstone. The distribution of the ferruginous beds, only a small proportion of which are likely to be of ore grade, is shown on the Lawn Hill Sheet (Atlas, Pl. 3). The beds crop out, in two distinct structural basins, through an area of about 250 square miles, and the total length of outcrop, along the strike, is about 50 miles.

The beds are up to 40 feet thick and are separated by 10 to 200 feet, but generally 50-80 feet, of siltstone and sandstone; they vary considerably in grade and thickness, and are gently to moderately folded. The maximum dip of the ore beds is greater than 50° but generally the beds dip at 30° or less. There has been considerable small-scale faulting. The southern limit of outcrop of the Constance Sandstone and Mullera Formation, along the southern scarp of Little's Range, is due to faulting, with a movement of several hundred feet. The iron beds presumably lie beneath younger sediments south of the fault.

The outcrops of highest grade are oolitic and are deep red-brown because of the abundance of hematite. Their grade at the surface is 50-55% Fe. Superficial redistribution of iron, presumably in joints, has produced polygonal structures, composed of limonite and goethite. The lower-grade beds probably do not contain more than 20 or 25% Fe, and are very siliceous.

Drilling by Broken Hill Proprietary Company Ltd has shown that below the weathered zone the ore consists of oolitic siderite, chamosite, and hematite, set in a sideritic or hematitic matrix, and that the interstitial micro-crystalline silica which occurs at the surface is absent. In places the ore is coarsely crystalline, so that, although the iron is certainly of sedimentary origin, it may have been recrystallized during diagenesis or later.

Hematite Siding

The Hematite Siding deposit, situated near the Selwyn branch railway, supplied about 30,000 tons of ironstone flux to the Mount Elliott copper smelter, but is not a potential source of iron ore.

Lochness

Jensen (1941a) records two replacement deposits of iron, the larger of which is known as Hematite Range. They occur in limestone (dolomite?) and form north-trending ridges nearly a mile long.

Some of the ironstone is gossanous. A chip of massive ironstone from the eastern outcrop assayed 44.82% Fe and 0.21%P. Two samples of gossanous material from the western outcrop gave an average assay of 0.54% Pb and a trace of gold. Jensen estimates that between 10,000,000 and 20,000,000 tons of ironstone crop out above the level of the surrounding plain, but the deposits have not been surveyed and the estimate is probably excessive.

Cadmium

Recoverable amounts of cadmium occur in the Mount Isa and some of the Lawn Hill silver-lead-zinc deposits. At Mount Isa the cadmium is intimately associated with the sphalerite and no cadmium mineral has been identified. The amount present varies greatly, but the sphalerite is estimated to contain 0.18% Cd. Greenockite(?) is associated with sphalerite in several of the Lawn Hill deposits, and ore from the Silver King has assayed as much as 0.1% Cd (Ball, 1911).

Cadmium carbonate was first produced from baghouse dust at the Mount Isa lead smelter in 1948. Between 1948 and 1956, 84.1 tons of cadmium carbonate was produced, but cadmium is not now recovered from this source. The baghouse product was shipped to the United Kingdom for the recovery of the metallic cadmium content. The greater part of the cadmium is shipped with the zinc concentrates. The annual output of zinc concentrates is estimated to contain 60-70 tons of cadmium (Sullivan, 1947), but precise figures of recovery are not available.

Tungsten

The small recorded production of tungsten has come from the mining of scheelite (see Appendix II, Table IIF); the most recent production was in 1953. Scattered occurrences are distributed through the Cloncurry Mineral Field. Wolfram has also been reported (Nye & Rayner, 1940), but the occurrences are of mineralogical interest only.

The deposit known as The General is 17 miles by road south of Kajabbi. Scheelite occurs together with some copper minerals as pockets and fine disseminations in quartz veins which are associated with a large lens of calcite in hornblende schist (Shepherd, 1946d). The lode strikes north-west and dips steeply to the north-east. Part of the production has come from eluvial material and the remainder from two shallow open cuts on the quartz-calcite contact. A production of 6 tons of scheelite is recorded.

Small quantities of scheelite are associated with cobalt mineralization at Mount Cobalt. Parcels of ore totalling 5¾ tons were extracted from a small deposit on the Mount Cobalt shear, about half a mile north of the main workings. The scheelite had a gangue of limonitic jasper associated with a lens of calcite.

Scheelite also occurs in auriferous quartz and quartz-calcite reefs in the Soldiers Cap area. The Shamrock, Falcon, Brilliant Extended, Mount Scheelite, and Comstock lodes are reported to contain scheelite (Honman, 1939). Further occurrences are reported from near the Trekelano mine, Duchess; at the West Hampden copper deposit, in the Kuridala area; and at the Lone Hand mine, Marraba. In none of these deposits is there sufficient scheelite for exploitation.

Bismuth

Bismuth is found in a few places in the south-central section of the Cloncurry Mineral Field. It is closely associated with gold, and to a lesser extent with copper mineralization.

The only mine from which production of bismuth has been recorded is the Lone Hand, 2 miles west of Marraba railway siding. In the period 1931-1936 this mine produced 0.51 tons of bismuth, 2.8 tons of copper and 32 oz of gold from 58 tons of ore. Copper carbonates

U

and secondary sulphides were found in the gossan, and the primary ore consisted of chalcopyrite, pyrite, and bismuthinite and a little scheelite in a gangue of siderite, quartz and hematite. The country rock is metabasalt and the deposit occurs in a shear-zone which strikes 023° and dips easterly at 46°. The deposit was worked to a depth of about 100 feet and over a width of 1 to 3 feet (Shepherd, 1932b).

Bismutite has been recorded from the Brilliant Extended reef, Soldiers Cap area, associated with scheelite and gold (Honman, 1939); from the Slaty Creek area, near Marraba, and, with alluvial gold and native bismuth, at the Top Camp diggings. Native bismuth has also been reported from Mary Douglas hill (in an auriferous quartz reef); in alluvial deposits at Pumpkin Gully (Jack, 1885); and in a quartz leader, associated with gold, at the Two Mile diggings, Cloncurry (Rands, 1895).

Manganese

Deposits of manganese oxides have been recorded from a large number of localities, but little interest has been shown in this metal because of the distance from markets. However, some of the larger deposits were examined, and a few samples taken, in 1953 in the course of the regional geological survey. Further investigations by Rio Tinto Australian Exploration Pty Ltd were made to obtain a source of supply of manganese oxide for the uranium treatment plant at the Mary Kathleen mine. This led to the development of the Overhang deposit, from which 941 tons of manganese ore were produced in 1958.

Most of the known deposits are in a north-south belt between Cloncurry and Mount Cobalt, the more important being in the Marimo Slate. Deposits are widespread in the Marimo Slate, but the more important concentrations are confined to a narrow north-south belt between the Top Camp gold diggings and Slaty Creek, near the contact of the Marimo Slate and Mitakoodi Quartzite. The manganese occurs as residual concentrations along strike-faults and shear-zones. Some pyrolusite ore is present, but generally the ore is in the form of hard, massive psilomelane. The deposits are considered to be superficial, and the grade is to be expected to deteriorate at a shallow depth. Iron oxides and quartz are commonly associated with the manganese, and assays have shown the presence of very small amounts of cobalt, nickel, lead, and zinc.

The Overhang deposit is 6 miles east of Marraba railway siding. It has an estimated length of 250 feet and an average width of 45 feet. The deposit is considered to represent a superficial concentration of manganese, probably by meteoric waters. A representative high-grade surface sample assayed 43.6% Mn, 19.3% SiO_2, 0.04% Co, and 0.02% Ni. A similar deposit has been recorded 2 miles north-east of Florence siding on the Selwyn branch railway. It is on the southern continuation of the Slaty Creek-Top Camp belt. Dunstan (1920) reports that the manganese can be traced over a quarter of a mile and is 25 feet wide. Selected samples assayed 46% Mn. Other representative samples from manganese bodies in the Marimo Slate have all assayed less than 40% Mn, the lowest being 11.8% Mn.

Manganese occurs 2 miles west of Bungalien railway siding on the Cloncurry-Duchess line in a shear-zone trending north-north-west. The deposit is 500 feet long and up to 20 feet wide. There are some high-grade patches, but the bulk of the ore is of inferior grade. Other small deposits of siliceous manganese ore occur on the Mangaminny lease, 30 miles south-east of Dajarra, and in the Quita Creek area, 3 miles south-west of Dajarra.

The occurrences in the Staveley Formation and Answer Slate extend from south of the Cloncurry River at Agate Downs Homestead to west of Mount Cobalt. The manganese occurs as superficial stains and impregnations and is not considered to be of economic interest.

Manganese is commonly associated with cobalt deposits and more rarely with copper deposits. Asbolite is reported from the Centipede lode, Kajabbi; Coocerina lode, Dugald River and the Mountain Home copper deposit, Soldiers Cap. Manganese oxides are associated with cobalt at the Godkin lode, Dugald River; the Centipede lode; a lode 1 mile west of the Comstock mine, Soldiers Cap; and on Boomarra station, 90 miles north of Cloncurry (Rayner, 1938). Manganese oxides are abundant in the gangue at the Mount McNamara copper deposit and also occur in the Mount Cuthbert copper deposit.

Small concentrations of manganese oxides have been observed in the Colless Creek area, west of the Lawn Hill mineral field. They occur in residual flat-topped hills of ?Middle Cambrian cherty breccia overlying the Colless Volcanics about 3 miles east of the Ridgepole copper mine, for example at lat. 18°38′55″S, long. 138°18′35″E. No samples have been analysed, but the deposits are small and are probably of very low grade.

Other Metallic Minerals

Antimony

Antimony is rare in the Cloncurry and Mount Isa Mineral Fields. Minor amounts of tetrahedrite occur at the Great Australia, Duchess, and a few other copper mines (Dunstan, 1913). Chalcostibite, dyscrasite, and jamesonite have been detected in Mount Isa copper ore by mineralogical studies; the antimony content of the ore is 0.002% (Carter, 1953b). Tetrahedrite carries the silver of the Mount Isa silver-lead-zinc sulphide ore, and pyrargyrite and polybasite occur in the oxidized zone. Chalcostibite also occurs in a copper lode at Pumpkin Gully (Jack, 1885).

Arsenic

Arsenic has only been recorded from cobalt ores, the Mount Isa deposits, and the Silver Ridge auriferous lodes. Cobaltite and erythrite occur at the Mount Cobalt, Success, Queen Sally, and several non-productive deposits of cobalt (see section on Cobalt). At Mount Isa a little cobaltite and arsenopyrite are associated with pyrite in the sulphide copper ore. The arsenic content of the ore is about 0.024% (Carter, 1953b). Minor amounts of arsenopyrite also occur in the lead-zinc sulphide ore, and mimetite, proustite, and polybasite are found in small quantities in the oxidized ore. Arsenopyrite is associated with pyrite, galena, and gold and silver in the Silver Ridge lodes. The oxidized ore consists of scorodite, oxides of iron and cerussite. Geological and geophysical surveys have shown that the deposits occur as a number of small isolated lenses (Rayner, E.O., 1936; Rayner, J. M. & Nye, 1936a). The presence of arsenic and lead in the ore creates extractive metallurgical problems which have discouraged development of the deposit.

Molybdenum

The known occurrences of molybdenite are only of mineralogical significance. At the Magnet and Trekelano copper deposits minor amounts of molybdenite are associated with the copper. It occurs in calcite, together with quartz and actinolite, on Boomarra Station near Mount Dromedary, 76 miles north of Cloncurry (Ball, 1915). At the Juenburra limestone quarry, 4 miles south of Duchess, molybdenite occurs as small flakes or small bunches of crystals in calcite (Shepherd, 1932b). It is also present in small siliceous veins in aplitic granite near the Native Companion copper mine south-west of Quamby. Matheson & Searl (1956) report sparse molybdenite in part of the Mary Kathleen orebody.

Nickel

Some small cobalt and copper deposits contain appreciable amounts of nickel. Ore from the Success cobalt-copper mine contained 0.5% Ni, and a sample of high-grade ore from the Queen Sally cobalt mine assayed 0.8% Ni. Parcels of ore from 28 copper mines (indicated in Appendix II, Table IIA) have been found to contain nickel in quantities ranging from 0.01% to 0.8%. Sixteen of these deposits are located in the Argylla-Duchess area (Mount Isa Mines Ltd data) — custom copper ore containing more than 0.01% Ni is unacceptable to Mount Isa Mines Ltd. Valleriite and pentlandite have been detected in Mount Isa copper and silver-lead-zinc ore, but no more than trace amounts of nickel occur (by assay).

Rare Earth Minerals

Attention has been drawn to the occurrence of rare earth minerals as a result of the search for uranium, because the two are closely associated in several places. The potential production of these minerals is probably quite large, although no precise data are known.

The uraninite at the Mary Kathleen deposit is intimately associated with allanite and to a lesser extent stillwellite, caryocerite (a borosilicate of the cerium group), and rinkite (a silicate of calcium, sodium, iron, titanium, and cerium). Allanite samples were found to contain 21.6% rare earth oxides, made up of 19.7% cerium and lanthanum oxides and 1.9% yttrium and erbium oxides. The stillwellite samples contained 58.4% rare earth oxides made up of 51% cerium oxide and less than 5% heavy lanthanon oxides (McAndrew & Edwards, 1954c, 1955b; Whittle, 1955, unpubl.). Stillwellite is a new mineral species which has been recognised only from the Mary Kathleen deposit; it is a borosilicate of the lanthanons. It is not known whether these minerals can be successfully recovered during the extraction of the uranium or whether a market can be established for them. However, as the properties and uses of the rare earth oxides become more fully known the deposit may become a valuable source. Other occurrences of allanite are known from the Spear Creek area, north-west of Mount Isa; the Elaine Dorothy lease, 4 miles south of the Mary Kathleen; and the small Hidden Valley deposit, 6½ miles north-east of the Mary Kathleen. Allanite is probably a common accessory mineral in the metasomatized parts of the Corella Formation. It has been recorded by Edwards & Baker (1954).

Tantalum

Tantalite occurs at Mica Creek in a pegmatite parallel with, and about 23 chains east of, the cassiterite-bearing pegmatite described under 'Tin'. A shaft revealed that the pegmatite lenses out at a depth of 19 feet. An analysis of the mineral gave the following result (Denmead, 1937d):

Tantalum oxide	55.75%
Niobium oxide	18.70%
Titanium oxide	1.52%
Tin oxide	0.03%

Manganocolumbite occurs with quartz and mica, 3 miles west of the mica workings at Mica Creek (Connah, 1938). Uraniferous columbite has also been found in the Mica Creek area. One specimen of columbite assayed 0.7% U_3O_8 (Government Analyst, Brisbane).

Thorium

Monazite had previously been known from Mica Creek (Connah, 1938), but during the search for uranium in recent years several other occurrences of thorium have been located. At Mica Creek the monazite is closely associated with muscovite and biotite pegmatites; it occurs in coarse tabular crystals. The thoria content ranges from 5.73% to 6.22%.

A small amount of thorium occurs in the Mary Kathleen deposit in the rare earth minerals allanite and stillwellite. The allanite contains less than 0.2% ThO_2 (McAndrews & Edwards, 1954c). However, a specimen of allanite-bearing rock from the site of a radioactive anomaly half a mile north-east of the Mary Kathleen orebody assayed 6.2% ThO_2, 2.45% U_3O_8 and 7.7% rare earths. An allanite-bearing rock from the Spear Creek area, north-west of Mount Isa, assayed 0.80% ThO_2 and 1.38% U_3O_8. Absite (?) is recorded from the Lady Rachel, Ballara, Three Inkspots, Why Not, and Gumbardo radioactive occurrences.

Tin

The only known occurrence of tin is at Mica Creek, where isolated crystals and small segregations of cassiterite occur in a coarse-grained pegmatite. The pegmatite intrudes gneissic granite and mica-hornblende schist at or near their contact. The dyke trends north-north-west and persists for more than 1½ miles over a width ranging from a few feet to 150 feet. Cassiterite occurs sporadically in the dyke for more than 500 feet, but prospecting has failed to locate a workable deposit (Shepherd, 1938). Books of muscovite of commercial size also occur in the pegmatite, and other associated minerals are fluorite, tourmaline, and monazite.

Titanium

Occurrences of davidite, ilmenite, rutile, brannerite, and absite, of mineralogical interest only, are known. Most of these have been recognised in recent years during the search for uranium. Numerous occurrences of davidite and davidite-like minerals are located in the Cameron River/Ballara area (the Six Kangaroos davidite deposit has been described in the section on uranium).

Other known occurrences in this area are at Three Brunettes, Ballara No. 1 and No. 2, Hobby No. 2, Verpat, Dodge-Loan, Amy and Diane, and Three Inkspots leases, and the Robert Heg lease north-east of Kuridala. All the deposits occur in the Corella Formation and are associated with pegmatite or granite dykes. Brannerite occurs at the Skal lease (see p. 233) and at the Comfort lease near the Six Kangaroos. Absite occurs at the Why Not and Gumbardo and Three Inkspots leases, 15 miles west of Cloncurry, and the Lady Rachel, Ballara. Crystals of rutile occur in association with quartz and mica schist at Mica Creek. Ilmenite and ilmenite-hematite intergrowths are associated with pegmatite within granite to the east of the Trekelano mine, Duchess, and titan-hematite was found near Quamby (Edwards, 1938). Ilmenite also occurs together with hematite in the Blackeye Creek area, south-west of McKinlay.

Non-Metallic Minerals

Limestone and Carbonate Rocks

650,000 tons of 'limestone' (crystalline calcite) have been produced for use as a flux in the smelting of base metals. Between 1911 and 1920, 181,717 tons were used by the copper smelters at the Hampden, Mount Elliott and Mount Cuthbert mines. Since 1931, 463,558 tons have been used in the Mount Isa lead and copper smelters; in 1958 they consumed 49,617 tons (including 10,860 tons of cupriferous 'limestone' flux). There are no major deposits of limestone, and production has come from a large number of small quarries: proximity to rail transport has been a determining factor in the development of the known deposits. For some time after 1954 the flux requirements of Mount Isa Mines Ltd. were supplied by the Wilgar quarry, 11 miles west of Cloncurry, but other deposits near Cloncurry and Kajabbi have since been worked.

The limestone deposits are nearly all in the Corella Formation, in a belt stretching from Dobbyn in the north to Juenburra siding, near Duchess, in the south. None of the sedimentary limestone in unmetamorphosed units (including Cambrian formations) is of the degree of purity required for carbonate flux, and production has been from lenses of coarsely crystalline calcite. The calcite appears to have been derived from adjacent calcareous sediments and redeposited in favourable structures. Lenses of calcite, conformable with the bedding, are abundant in the more highly altered parts of the Corella Formation. They may be due in part at least to the crystallization *in situ* of calcareous sediments. Such bodies are generally too small to be a useful source of 'limestone' flux.

The value of several deposits—Salmon, Dingo, Dolomite, Marimo, Copper Blonde and Juenburra—has been enhanced by the presence of appreciable amounts of copper, which is present mainly as chalcopyrite. The chalcopyrite occurs in narrow irregular veins and as disseminated grains in the calcite. On the other hand, the presence of tremolite-actinolite and diopside in some deposits has made it difficult to obtain high-grade flux; at the Quamby Queen large crystals of diopside contaminate the calcite in certain sections, and the presence of amphiboles and pyroxenes has also rendered selective mining necessary at the Dolomite and Marimo deposits.

The quarries in the Dolomite railway siding area have been the major producers: the Salmon, Dingo, Dolomite, Marimo, and Wilgar (New Year's Gift) quarries have produced over 300,000 tons of flux, but with the exception of the Wilgar are now largely inactive. 1,576 tons of copper ore have been selectively mined from the Dolomite deposits, of which 934 tons yielded 130.1 tons of copper (14% Cu). A future source of 'limestone' flux will be the Valley deposit, 19 miles east of Mount Isa, in which substantial reserves have been proved.

The largest lens quarried in the Duchess area is the McConachie at Juenburra, which is also cupriferous and contains small quantities of molybdenite (Shepherd, 1932b). It occurs in the Duchess-Juenburra shear. Over 122,000 tons of flux have been produced, but the quarries were closed between 1953 and 1957.

A group of small deposits occurs in the Kajabbi-Dobbyn area. Flux for the Mount Cuthbert smelter was supplied from deposits near the Mighty Atom copper mine, at the Digby Denham copper mine, and elsewhere in the Kajabbi area.

The calcite requirements of the Mary Kathleen 'acid-leach' uranium treatment process are being supplied from the Cameron lease, 10 miles north of the Mary Kathleen mine. Other sources of supply are available on the Robin lease, south of the Cloncurry-Mount Isa road and 21 miles from Mount Isa, and the Kuta lease, 13 miles by road east of Mary Kathleen. The larger of these, the Robin, has reserves of the order of 2,000 tons per vertical foot of high-grade calcite (Searl & Fraser, 1956a, unpubl.). In 1958, 225 tons of 'limestone' was produced from the Cameron deposit. The Mount Isa sulphide copper ore occurs in a gangue which consists mainly of dolomite and other basic carbonates. Up to 1955 a sufficient quantity of crude ore was added to the furnace charge to eliminate most of the need for extra lime rock for the desired reverberatory slag. In 1954, 16,788 tons of sulphide copper ore were sent direct to the copper smelter. Since 1955 oxidised copper ore from the Black Rock orebody has been added to the furnace charge and cupriferous 'limestone' flux has been purchased to supply the lime requirements of the slag. It has been found that ore containing more than 30% calcium oxide and up to 3% copper is suitable for addition to the copper smelter charge. 2,195 tons of ore of this tenor have been supplied from the King Solomon mine, 22 miles east of Mount Isa. The Copper Blonde deposit, 14 miles north-north-east of Mary Kathleen, has produced 7,531 tons of cupriferous 'limestone' flux for the Mount Isa copper smelter (Brooks, 1957).

Other deposits of cupriferous carbonate rock are known to be associated with copper deposits. At the Great Australia mine a dolomite body with reserves estimated at 110,000 tons of 2.5% copper was partly developed during early mining operations. This cupriferous dolomite body is similar to the Mount Isa Black Star copper orebodies in that the apex of the dolomite is well below the surface (see p. 215). At the Sunset deposit, narrow irregular veins of chalcopyrite, in a large lens of calcite and calcite-amphibole rock, have been mined to a shallow depth. Overall reserves of cupriferous carbonate rock are not known. Calcite and dolomite are fairly common gangue minerals in the copper deposits throughout the Precambrian of the region: the Duchess, Trekelano, Mount Elliott, Kalkadoon, Mighty Atom, and Rosebud also had a dominantly carbonate gangue.

Siderite is uncommon but is reported from the Mount Isa, Mount Cuthbert, Kalkadoon, Orphan, and Lone Hand copper deposits and some of the Lawn Hill silver-lead-zinc deposits.

QUARTZ (SILICA)

Deposits of quartz are abundant throughout the Precambrian mineral belt, mainly as fault-fillings. Quartz is the most important gangue mineral in the copper deposits, particularly in the smaller fissure-vein type of deposit. Large quantities

of low-grade siliceous copper ore (less than 4% Cu) occur at such mines as the Argylla (Blockade), Mount Hope, 15 miles north-north-west of Duchess, and Edna May, 22 miles east-south-east of Mount Isa (Brooks, 1956a). Many of the major north-easterly faults contain massive infillings of quartz which have resisted the processes of weathering and form prominent ridges. Examples of these are the Mount Remarkable, Wonga, and Fountain Range Faults (Pl. 25). The quartz varies in purity greatly from place to place.

A little quartz was used as flux at the Hampden smelter, but silica flux was not in general use during early copper-smelting operations. A considerable amount of silica flux is required for copper-smelting at Mount Isa. Until May 1956 the Company paid for silica in custom copper ore which contained at least 30% more silica than iron. Copper ores purchased to 1958 amounted to some 74,000 tons, and some 6,000 tons of cupriferous silica flux were purchased from the Edna May mine, and the Chinaman mine, Marraba siding. Over 22,000 tons of cupriferous silica flux have been produced from the Hidden Valley mine west of Mount Isa. Since 1954 siliceous copper ore has been produced in quantity from the Black Rock orebody at the Mount Isa mine and the requirements of silica flux from outside sources have been reduced. In 1958, 44,591 tons of siliceous copper ore were mined. In addition, silica sand and gravel are used in the copper converter; over 4,000 tons of silica were used in the period 1943-46.

CONSTRUCTION MATERIALS

Little use has been made of local materials for construction purposes in the past, but the continued development of north-western Queensland will probably bring them into more prominence.

Road Metal

With a few exceptions, roads have been constructed by the forming and grading of soil and rock material in place. In most areas the soil cover is thin or absent and rock rubble has been utilized. For the construction of the sealed surface of the Barkly Highway, ferruginous residual soil material, of lateritic origin, which covers considerable areas alongside the highway and elsewhere in the west of the Mount Isa - Camooweal region, was found to be very suitable road metal. This material was obtained from a number of shallow quarries close to the highway. In some places, copper-mine dump material has been used. Basic igneous rocks (blue metal) are widespread in the Precambrian and could be used if required.

Dam Construction Materials

Rock-fill dams on the Leichhardt River near Mount Isa and on the Corella River near Mary Kathleen were constructed in 1956 and 1957. At the Corella River dam, siliceous calc-silicate rocks and quartzite of the Corella Formation were quarried from a site near the dam. At the Leichhardt River dam, quartzite was obtained from near-by in the Eastern Creek Volcanics. Sand and gravel

for concrete are available from almost any of the main watercourses which traverse the Precambrian, though many of the sands and gravels contain feldspar and mica.

Building Materials

No demand has yet arisen for building stone, but the large areas of massive granite provide an abundant potential source of supply. Basic igneous rocks, and probably some of the sedimentary and metamorphic rocks, may also be found suitable for this purpose. The emphasis in building has been on timber, iron, and concrete construction, and the materials have been brought in by railway. The recrystallized calcite deposits of the Corella Formation would probably be too small to provide an adequate source of lime for the manufacture of cement, but it may be possible to utilize some of the Cambrian limestones to the west and south of the Precambrian. Some of the Mount Isa Shale would probably be suitable for the manufacture of bricks and tiles, although at present there appears little likelihood of the establishment of a local industry. The absence of coal, oil, or water-power resources is at present a serious deterrent to the development of such secondary industries.

BERYL

Deposits of beryl occur in the Mica Creek pegmatite, south-west of Mount Isa. Beryl-bearing pegmatite is largely confined to a narrow north-north-westerly belt 6 miles long; it intrudes hornblende schist and amphibolite of the Eastern Creek Volcanics. The pegmatite belt extends from the eastern margin of the Sybella Granite, to which the pegmatite is genetically related. Beryl occurs in zoned pegmatite and is generally concentrated along the margin of the quartz core and in the adjoining segregations of albite or albite-muscovite. Pale yellowish-green, green, blue, and amber crystals up to 12 inches across and 4 feet long have been found. Cassiterite, monazite, and tantalite occur in the same pegmatite belt, but are not closely associated with beryl (Shepherd, 1946d).

Nearly all the 79 tons of beryl produced from the area has come from the Big Beryl deposit, 6 miles south-west of Mount Isa. This deposit is near the north-eastern extremity of a large mass of tourmaline pegmatite more than 1½ miles long and up to ¾ mile wide. Beryl crystals are sporadically distributed in albite-muscovite and quartz-muscovite segregations at the southern end of a large quartz core. Open-cut mining has reached a depth of 41 feet. The beryllium oxide content of the ore has ranged from 10.8% to 12.6%.

In 1958 an initial parcel of 7.7 tons of beryl was produced from the Hexagon group of mineral claims, 1.7 miles south of the Big Beryl. The potential production of the deposits is small, but while the strong demand for beryl is maintained, production on a very small scale may be expected to continue.

MICA

Pegmatite containing books of mica is commonly associated with the granite intrusions in the Precambrian mineral belt, but the Mica Creek deposits are the only ones that have produced commercial mica. The sale of 12.5 cwt of muscovite in the 1922-27 period is recorded; other small parcels may have been sold later through the Commonwealth Mica Buyer at Alice Springs.

The Mica Creek deposits are 8 miles south-south-west of Mount Isa. The pegmatites occur in hornblende schist and appear to be genetically related to the Sybella Granite, which crops out to the west. Muscovite and biotite form imperfect sheets up to 150 square inches in area, over a width of 4 feet. Workings are restricted to shallow pits, at which level the mica is generally weather-stained. The 'books' of mica exposed are cracked, bent, or faulted. It is doubtful whether the grade of the mica is sufficiently high, or the quantity adequate, to repay development (Shepherd, 1934a, unpubl.).

A second locality is 35 miles south-west of McKinlay, just north of the McKinlay River at lat. 21°45'S, long. 140°55'E. The deposits have been superficially explored. These may be the mica deposits mentioned in the Cloncurry Mining Warden's report for 1922 as occurring in the Toolebuc area. The pegmatites are near the south-eastern margin of the Precambrian. Muscovite-tourmaline pegmatites contain books of mica 16-20 square inches in area, but the exposed material was mineral-stained. Many muscovite-tourmaline pegmatites occur in a belt stretching from this locality north to the Soldiers Cap area, east of the Williams Granite.

In a locality north of Naraku siding on the Cloncurry-Dobbyn line, mica occurs in small pegmatite dykes in hornblende schist. The largest books of mica are only 8 or 9 square inches in area. South-east of Urandangi, south of Split Creek, pegmatites contain books of mica up to 36 square inches in area.

OTHER NON-METALLIC MINERALS

Andalusite, Sillimanite, Kyanite, Cordierite

Andalusite-bearing schists occur east of the Williams Granite, south-east and south of Cloncurry; in the Upper Snake Creek area, Soldiers Cap; and one mile east of Duchess. Crystals up to two inches long are common in the Snake Creek area.

Schists in the Dugald River area contain sillimanite (Joplin, 1955). Dunstan (1913) records kyanite from 45 miles north-west of McKinlay and specimens 'containing less than 50% kyanite' have been examined from the Kajabbi district, probably near the Referee copper mine.

Cordierite has been recorded in cordierite-anthophyllite rock from the upper Snake Creek area, from north of the Rosebud copper mine, and from north of the Little Sunset copper mine. In the last-mentioned locality large tonnages of rock probably contain at least 30% cordierite.

A concentrate of cordierite from north of the Little Sunset mine was found to contain:

SiO_2	64.80%
Al_2O_3	17.67%
FeO	4.97%
CaO	0.08%
MgO	7.95%
Na_2O	0.87%
K_2O	1.05%
Loss at 100°C	0.00%
Loss at 1000°C	2.92%
Total	100.22%

All iron was calculated as ferrous oxide. Analyst: A. McClure. The concentrate was prepared by (a) handpicking crystals of cordierite; (b) crushing to pass 150 mesh; (c) removing magnetite with a hand magnet; (d) concentrating cordierite by three flotations with bromoform, and centrifuging. Impurities are estimated to be less than 1%. The specimen contains too much iron for use as a refractory.

On account of the remoteness of the region these minerals are not likely to be economic in the immediate future.

Staurolite is abundant in pelitic schist west of the Wee MacGregor copper mine, Ballara area.

Barytes

Barytes is known from several localities, all of minor importance. Silver minerals at the Silver Phantom deposit, Kuridala, occur in a large lens of barytes which fills a joint plane near the margin of the Wimberu Granite. Other occurrences have been reported from Florence Creek, 33 miles south of Cloncurry; from Chatsworth Station, 9 miles west of Selwyn; from Paradise Valley; from near Quamby; and in the Riversleigh-Thorntonia area, north-west of Mount Isa.

Feldspar

Deposits of feldspar occur as segregations from large pegmatite dykes in the Mica Creek area. Half a mile north of the Big Beryl mine, a feldspar pegmatite, with very little quartz, crops out (Shepherd, 1946d). From this outcrop a large tonnage of feldspar could be quarried. Both microcline and albite pegmatites are common in the vicinity. Small intrusions, very largely of albite, are associated with granite in the Dugald River and Soldiers Cap area and west of Mount Isa (Joplin, 1955). Under present economic conditions there is little likelihood that any of the deposits will be developed.

Fluorite

Fluorite is comparatively rare in the Precambrian mineral belt, but occurs as a gangue mineral in several metalliferous deposits. At the Monakoff mine, east-north-east of Cloncurry, purple fluorite is associated with copper and uranium, and at the Milo uranium prospect fluorite occurs with pyrite and chalcopyrite. At the Apple Pie mine, north of Mary Kathleen, green fluorite is reported to be associated with copper mineralization. Mineragraphic studies have revealed the presence of small quantities of fluorite in such deposits as the Dugald silver-lead-zinc prospect and the Mary Kathleen uranium deposit. Small quantities of fluorite occur in the Mica Creek pegmatites.

Graphite

Samples of graphite, some of which were of good quality, have been submitted from the Kuridala (Hampden) area, but the exact location is not known (Dunstan, 1906). Another occurrence is at the Mount Oxide mine, where a bed of graphitic slate up to 100 feet wide lies on the footwall of the copper deposit. Graphitic slate and schist are common; the Corella Formation, Marimo Slate, and Kuridala Formation contain the most extensive exposures, but none is of economic interest as a source of graphite.

Gypsum

Gypsum (selenite) occurs as one of a variety of gangue minerals at the Mount Elliott copper mine, Selwyn. Large clear crystals some feet in length and inches thick were found, in association with native copper and chalcopyrite, on the walls of vugs. Selenite also occurs with gold and copper at Mount Wheeler, Soldiers Cap, but the mineral is not widespread or abundant.

Selenium (Edwards & Carlos, 1954)

In the course of a study of selenium:sulphur ratios of Australian sulphide ores Edwards & Carlos found that specimens from the Duchess mine contained an unusually high proportion of selenium. However, as this mine is abandoned and known reserves of copper ore are small it is unlikely that it could become an economic source of selenium. Edwards & Carlos also pointed out that the copper ore from Mount Isa could be a source of selenium.

The mineral naumannite, silver selenide, was found in a rich pocket of ore near O'Briens Soak, on the Duchess-Urandangi road, in 1918 (McGillivray, 1919). It is described under 'Silver'.

Sulphur (Pyrite)

Pyrite is abundant in the region. Some pyrite is associated with most of the metallic sulphide deposits, and the pyrite content of many of the larger copper deposits is reported to increase at depth. A readily available source is the Mount Isa mine: mill tailing dumps contain very large quantities. Massive pyrite was intersected in drill holes in the Sybella Creek area, south of Mount Isa, and many of the large limonitic gossans in the Mount Isa Shale are the surface expression of massive pyrite bodies.

Water Supply

The naturally-occurring surface water resources and the town water supplies are described on p. 20.

Surface Water

The region abounds in suitable gorges and valleys for large water-storage projects, but in general the low rainfall, small catchment areas, high rate of evaporation, and insufficient demand for water render such projects impracticable for the present. Apart from water supplies for any centres of population which may develop as a result of mineral exploitation there appears to be very little scope for large-scale water utilization. In the future some of the 'black soil' plains to the north and north-east of the Precambrian may be used for improved pasture or intensive cultivation. The Gregory and O'Shanassy Rivers and Lawn Hill and Widdallion Creeks could be fairly readily impounded, the first two within the outcrop area of the Ploughed Mountain Beds and the last two along the Constance Range Scarp. These four streams would be capable of irrigating moderate areas:

the flow of the Gregory River in June, below its junction with the O'Shanassy River, is reported by Whitehouse (1940) to be over 100 cusecs. The unreliability and seasonable nature of run-off into streams would require very large storage volumes on the non-perennial watercourses and would probably only be warranted in the foreseeable future for town or mine water supply. Because of the better soils in the north and the more deeply incised water courses the streams of the Gulf drainage would provide much greater opportunity for water storage than those of the inland drainage system.

Small reservoirs, for domestic or stock purposes, can be built in the soils from some formations. Soils derived from the Corella Formation, the Marimo Slate, and contemporaneous strata farther south; from the basaltic successions; and from most of the sedimentary strata in the western belt; would probably form sufficiently impermeable earth barriers to enable earth tanks or dams to be used. Granitic soils and soils from acid lavas and some arenaceous formations might not contain sufficient clay to retain water, though earth tanks and dams have been constructed by pastoralists in soil derived largely from granite and acid lavas in some areas, for example north of Duchess.

Subsurface Water

There are no large continuous aquifers in the Precambrian strata, and igneous and metamorphic rocks, being generally crystalline, have a low porosity. Subsurface water will therefore be found largely at the soil-rock interface, and in joints, fractures, faults, bedding planes, and cleavage planes. Many faults are silicified, so that the best storage in rocks will be found in strata with many open joints and bedding or cleavage planes.

The most copious and shallowest water supply is to be found along the major watercourses, where permanent water may readily be obtained from sands in the stream bed or from wells or bores in the adjoining alluvial flats. This water accumulates at the base of the unconsolidated material and the depth at which it may be found is rarely more than 100 feet. Along the smaller watercourses and drainage channels greater attention must be paid to local traps, such as 'bars' of impervious rock cutting across the valley of the watercourse. The amount of water available depends on the size and configuration of the sub-surface basin in which the water has collected and on the size of the catchment area.

Water is readily procurable from the rocks of the Corella Formation and the basaltic successions because of strong jointing and some open bedding planes. The silty and shaly strata vary considerably in yield, because of variations both in porosity and permeability and in the prevalence of open joints and bedding planes. Until recently the Mount Isa water supply has been substantially augmented by water from numerous bores in the Mount Isa Shale. Yield varies considerably from hole to hole and tends to be greater near the Leichhardt River than elsewhere.

Many of the arenaceous units, because of their resistance to erosion, form good barriers across watercourses, and also, because of strong jointing, contain good to moderate supplies of water. Springs are numerous in the outcrop areas of the Upper Proterozoic Constance Sandstone and Westmoreland Conglomerate. The location of adequate supplies in the Leichhardt Metamorphics and other acid lava successions, except where strongly fractured or jointed, has proved difficult; but water has been obtained in weathered granite.

Most underground water obtained from the Precambrian has proved to be sufficiently free from salts to be fit for both stock and domestic purposes. Some bores in weathered granite, or soil overlying weathered granite, have yielded water too saline for domestic purposes but suitable for stock. Water from the Mount Isa Shale (other than in mineralized areas) contains up to 140, but generally less than 60, grains of solids per gallon, and its hardness is usually less than 30 (Clark hardness scale); contained solids are mostly carbonates, but sulphates and chlorides occur in appreciable amounts in some bores.

Artesian to sub-artesian water may be obtained from most of the Palaeozoic and Mesozoic strata surrounding the Precambrian outcrops, at depths down to 2,000 feet. Depth and output tend to increase with distance from the outcropping Precambrian.

CONCLUSIONS

The area of outcrop of the folded Precambrian strata of north-western Queensland is one of the most highly mineralized regions in Australia: past production and known reserves mark it as perhaps pre-eminent. The diversity and abundance of known deposits, together with the scope for intensive exploration by modern techniques and the shallowness of most workings, encourage the belief that the region may richly reward painstaking search by both the independent prospector and the major exploration company.

Owing to the distance from manufacturing and other supply centres and the inadequacy of local fuels, power, foodstuffs and water, exploration and mining costs are high. Only relatively high-grade ores have therefore been worked in the past, but the emphasis in exploration will inevitably shift gradually to the search for large low-grade deposits.

GUIDES TO PROSPECTORS

1. Exploration for base metals should be confined to the Precambrian rocks: economic deposits are not likely to occur in younger rocks.

2. Many of the known deposits, particularly copper, have been inadequately tested; some are known to have appreciable reserves of high-grade ore; new ore-shoots in others undoubtedly remain to be found. The primary zone of most deposits is untested. Most will prove to be fairly low-grade and to contain a smaller tonnage per vertical foot than the overlying secondary zone; these will probably be uneconomic to work for some time, except under special circumstances, such as the presence of valuable by-products.

3. The eastern part of the region, i.e. east of the longitude of Mount Isa, contains the most abundant surface indications of mineralization. It has also been most thoroughly tested by prospectors and exploration companies. It probably contains few exposed, unworked deposits of importance. To the north and north-west of Mount Isa, where access is more difficult, outcropping deposits are not common, but some economic deposits, mainly of copper, may be exposed. The Surprise Creek and Ploughed Mountain Beds and the Paradise Creek and Gunpowder Creek Formations appear to offer better prospects than the Myally and Judenan Beds.

4. In general metallic orebodies tend to occur near granite, but not in it; but some deposits do occur in fractures in granite, and within the areas shown as granite on the maps there are numerous small bodies of other rocks, which may contain mineral deposits.

5. Most mineral deposits are associated with faults and shears, but they tend to lie on fairly small structures rather than the major faults which can be traced for tens of miles. They may be found in minor structures near, and related to, the larger faults. Very many of the known mineral deposits occur in faults striking north to north-west, many of which are bedding-strike faults. Easterly faults are comparatively few, but many of them are mineralized; north-east faults, on the other hand, are generally barren. These remarks apply particularly to the eastern portion of the region.

6. The region has not been a large producer of gold and there do not appear to be good prospects for gold mining.

7. Silver-lead-zinc has been found in shales and slates in several localities. In addition to the formations in which silver-lead-zinc has already been mined or tested, lead has been recorded from the Ploughed Mountain Beds, north of Thorntonia Homestead, and the Mullera Formation. The dolomitic strata of the Ploughed Mountain Beds, Paradise Creek Formation, and Surprise Creek Beds may be favourable hosts for such mineralization.

8. Uranium occurrences are widespread, but as the treatment of uranium ore requires a heavy capital outlay a large deposit is needed to permit exploitation. Deposits of a type similar to the Mary Kathleen, within the Corella Formation, could probably be treated in the existing plant, but the 'davidite-type' deposits in pegmatite, also in the Corella Formation, offer little prospect for development. Some of the known deposits in the Eastern Creek Volcanics could probably be worked if the Counter lease, for example, were exploited and a treatment plant erected. Many of the deposits in the Eastern Creek Volcanics can be recognised by the associated pink carbonate gangue.

9. Other metals have been profitably mined, but they do not appear to be sufficiently abundant to encourage prospecting specifically for them. Their modes of occurrence are described earlier in the bulletin. Known deposits of manganese may be profitable to mine in the future. Some of these occur in post-Precambrian strata.

10. The growth in the use of minor metallic and non-metallic elements in industry is creating a demand for minerals not previously searched for. Little is known about the presence in the region of such minerals and some may be found to occur. Rare earth minerals have been found in the Mary Kathleen uranium deposit; allanite, which contains cerium and other rare earths, has been recorded in several localities. The Corella Formation may prove to contain many significant concentrations of such minerals. Beryl and thorium, two elements now acquiring importance in certain industries, do not appear abundant, but new deposits may be found.

11. With the exception of limestone flux, none of the known non-metallic minerals appears to have any value at present. Feldspar, andalusite, and staurolite occur in abundance in places but are not of economic interest in remote north-western Queensland. Pyrite is also common but cannot be economically used. There is no known bauxite in the area.

12. No gemstones or semi-precious stones of requisite quality are known.

LARGE-SCALE EXPLORATION

As the region has been, for the most part, thoroughly examined for outcropping orebodies by prospectors, any large new orebodies are likely to be concealed. Three exceptions to this generalization are:—

Major orebodies may occur near the surface with slight surface indication.

Large more-or-less uniformly low-grade deposits may be exposed at the surface whose grade did not attract prospectors in the past, but which would be profitable if worked on a large scale or under more favourable conditions. (In many parts copper of less than 10% grade has been uneconomic for prospectors in the past).

Demands for elements previously of no economic value may render previously useless mineral deposits valuable.

Geophysical prospecting presents considerable difficulties in the region for various reasons; these are discussed below. Geochemical prospecting techniques, however, appear to be particularly well-suited for testing some of the areas most favoured as ore prospects.

Parts of the region, particularly the Kuridala-Mount Cobalt and Duchess-Buckingham Downs areas, are so profoundly weathered and leached that orebodies may not show gossans and secondary minerals at the surface. Intensive prospecting in favourable areas, bearing this possibility in mind, may be fruitful.

A general statement on the distribution of mineralization appears on pp. 199-203; mineralization is described in greater detail under the various metals and non-metals found in the region; and in 'Guides to Prospectors', above, recommendations are made to assist in the direct search for individual mineral deposits. From these, general conclusions about the best areas for intensive prospecting programmes are drawn:

The Kuridala-Mount Cobalt area, including the Kuridala and Staveley Formations and, perhaps less favourably, the Answer Slate, is considered a promising area for copper.

In the Corella Formation the lenses of slate and schist appear to have formed the most favourable hosts for large metallic deposits, because the bulk of the formation was apparently crystalline before mineralization took place. Large calcitic bodies with low-grade disseminated copper may be found in the more highly metamorphosed strata of the formation. The parts of the formation which have undergone soda metasomatism may contain metasomatic orebodies similar to the Mary Kathleen, but not necessarily of the same minerals. It is thought unlikely that large deposits of base or precious metals would be found in this environment, except in shears and fractures.

The Marimo Slate is generally less favourable to the formation of mineral deposits than strata farther south because it is more sandy. Some deposits may be found in it, however, particularly in association with the numerous manganese-bearing shears and faults.

Large areas of the Mount Isa Shale have not been adequately tested, but appear to be favourable to ore emplacement, particularly along the largely concealed Leichhardt Fault.

Although the Lawn Hill silver-lead-zinc deposits do not appear at the surface to be sufficiently large for large-scale development, they have not been adequately tested at depth. The possibility of other minerals at depth should also be considered. Geological and geophysical work, followed by drilling, appears to be justified.

The Lochness iron deposit has not been tested at depth, but surface samples contain lead and gold (Jensen, 1941a). Possibly these or other metals may occur in economic quantities below the surface.

Other small areas which appear worth examining occur throughout the region, but in particular it should be emphasized, as in the previous section, that most of the previously worked copper deposits have only been worked to the top of the primary zone, and very few have been tested geophysically; mining of some deposits ceased when the price of copper fell disastrously and not because of depletion of ore.

USEFULNESS OF VARIOUS GEOPHYSICAL TECHNIQUES

A discussion of geophysical prospecting is out of place here, but some observations on the effect of the geological setting of deposits may be useful.

Regional prospecting by airborne magnetometer or electro-magnetic methods is difficult because of the abundance of basic igneous rocks, ironstone, and other magnetic or electrically-conducting bodies. Experience would possibly enable a distinction to be made between such rocks and mineral deposits, but a large prospecting company, as a result of wide use of these techniques in the region,

has concluded that they are ineffective. This difficulty does not apply to large parts of the western area, but rough terrain would cause difficulties in maintaining a uniform height above ground level.

Over wide areas rock outcrop is sufficiently good to make airborne radiometric surveys effective but subject to terrain difficulties. Extensive work of this kind has been done in the region.

Vehicle-borne radiometric surveys can be carried out over wide areas of promising country, but greater areas are not suitable for such methods.

The carbonaceous strata are considered to be favourable host rocks for mineralization, but experience has shown that, owing to the high conductivity of carbon, resistivity methods of prospecting are not effective.

Over the deeply weathered areas, such as the Kuridala-Mount Cobalt areas, self-potential methods should be effective.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the great assistance and many kindnesses received from landholders, too numerous to name, in the course of field work. Their help took many forms, including provision of camp sites and water supplies; advice and guidance on tracks, terrain, rock exposures, and old mine workings; food and hospitality. Many prospectors and workers of small mines similarly helped us.

A great debt is also owed to the various mining companies in the region, particularly their geological staffs. Mount Isa Mines Ltd, largely through the kindness of the Company's Chief Geologist, Mr. S. R. Carter, freely made available their knowledge, facilities, and organization to further the regional mapping from the start of operations in 1950. Other Companies whose staff helped us include Enterprise Exploration Pty Ltd, Rio Tinto Australian Exploration Pty Ltd, Broken Hill Proprietary Co. Ltd, and many other mining and prospecting companies. These, and other, companies also made possible the compilation of the bibliography of unpublished references by supplying the necessary information.

Officers of the Land Research and Regional Survey Division of the Commonwealth Scientific and Industrial Research Organization made available unpublished information, and Mr. R. Perry, of the Division, supplied the botanical names of the flora listed.

Assays were done for various field parties by Mr. J. Tregenza, Assayer, Queensland Department of Mines, and from time to time the Cloncurry and Mount Isa Inspectors of Mines helped in many ways.

To those people, and any others not referred to, who contributed so much to the work of the Survey and the preparation of this report on it, we are happy to acknowledge our great debt and to thank them for their assistance.

BIBLIOGRAPHY

PUBLISHED REFERENCES

A.G.G.S.N.A., 1935.—Report for period ended 30th June 1935. *Aer. Surv. N. Aust.*
A.G.G.S.N.A., 1936a.—Report for period ended 31st December, 1935. *Ibid.*
A.G.G.S.N.A., 1936b.—Report for period ended 30th June 1936. *Ibid.*
A.G.G.S.N.A., 1937.—Report for period ended 31st December 1936. *Ibid.*
A.G.G.S.N.A., 1938.—Report for period ended 30th June, 1938. *Ibid.*
A.G.G.S.N.A., 1939a.—Report for period ended 31st December 1938. *Ibid.*
A.G.G.S.N.A., 1939b.—Report for period ended 30th June 1939. *Ibid.*
A.G.G.S.N.A., 1940a.—Report for period ended 31st December 1939. *Ibid.*
A.G.G.S.N.A., 1940b.—Report for period ended 30th June 1940. *Ibid.*

BAKER, G., 1959.—Copper ore from the Argylla Range, Queensland. *Sci. ind. Res. Org. Aust., mineragr. Inv. Rep.* 777.
BALL, L. C., 1908.—Cloncurry copper mining district, parts 1 and 2. *Publ. geol. Surv. Qld,* 215.
BALL, L. C., 1911.—The Burketown Mineral Field (silver lead and zinc mines). *Ibid.,* 232.
BALL, L. C., 1915.—Find of molybdenite at Boomarra, Cloncurry district. *Qld Govt Min. J.,* 16, 300.
BALL, L. C., 1921.—Gold at Mt. Quamby, N.Q. *Ibid.,* 22, 8-12.
BALL, L. C., 1923.—Ore provinces in Queensland. *Proc. Pacif. Sci. Congr.* 1,1790.
BALL, L. C., 1931.—The Lawn Hill Mineral Field. *Qld Govt Min. J.,* 32, 263.
BAUER, F. H., 1959—Historical geographic survey of North Australia, Pt. I. *Sci. ind. Res. Org. Aust., Land. Res. Reg. Surv. Div. Rep.* 59/2.
BERESFORD, R. F., 1953.—Faulting in the Black Star Mine. *Proc. Aust. Inst. Min. Metall.,* n.s. 171, 67-76.
BLANCHARD, R., 1938.—Paragenesis of pyrrhotite (discussion). *Econ. Geol.,* 33, 218-225.
BLANCHARD, R., 1939.—Significance of the iron oxide outcrop at Mt. Oxide, Queensland. *Proc. Aust. Inst. Min. Metall.,* n.s., 114, 21-50.
BLANCHARD, R., 1942.—Mt. Isa ore geology. *In* ORE DEPOSITS AS RELATED TO STRUCTURAL FEATURES, Ed. W. H. Newhouse, Princeton University Press, 148-154.
BLANCHARD, R., 1943.—The alleged mineral zoning at Mount Isa. *Tech. Publ. Amer. Inst. Min. metall. Engrs,* 1652.
BLANCHARD, R., 1948.—The alleged mineral zoning at Mount Isa. *Trans. Amer. Inst. Min. metall. Engrs,* 178, 107-133.
BLANCHARD, R., and HALL, G., 1937.—Mt. Isa ore deposition. *Econ. Geol.,* 32, 1042-1057.
BLANCHARD, R., and HALL, G., 1942.—Rock deformation and mineralisation at Mt. Isa. *Proc. Aust. Inst. Min. Metall.,* n.s., 125, 1-60.
BLASKETT, K. S., 1956a.—Preliminary concentration tests on uranium ore from the Skal prospect, Mt. Isa district, Queensland. *Sci. ind. Res. Org. Aust., Ore Dressing Invest.,* 501.
BLASKETT, K. S., 1956b.—Preliminary concentration tests on uranium ore from Anderson's Lode, Mt. Isa district, Queensland. *Ibid.,* 502.
BLASKETT, K. S., 1956c.—Preliminary concentration tests on uranium ore from the Mary Kathleen lease, Mt. Isa district, Queensland. *Ibid.,* 503.
BLASKETT, K. S., 1959.—Concentration of iron ores from Constance Range, Queensland. *Ibid.,* 568.
BROADHURST, E., 1936.—The Hampden copper mines, Kuridala, Cloncurry district. *Aer. Surv. N. Aust., Qld Rep.,* 14.
BROADHURST, E., 1953.—Duchess copper mine. *In* GEOLOGY OF AUSTRALIAN ORE DEPOSITS. *Fifth Emp. Min. metall. Cong.,* 1, 398-403.
BROOKS, J. H., 1956a.—Copper mining in the Cloncurry Mineral Field. *Qld Govt Min. J.,* 57, 891-921. Also issued as *Geol. Surv. Qld Publ.* 285.
BROOKS, J. H., 1956b.—Developments in the exploration of uranium deposits, Cloncurry Mineral Field, north-western Queensland, 1955. *Ibid.,* 57, 618-625.
BROOKS, J. H., 1956c.—Iron ore deposits of Queensland. Summary report. *Ibid.,* 57, 837-843. Also issued as *Geol. Surv. Qld Publ.* 283.
BROOKS, J. H., 1956d.—Silver Phantom mine, Kuridala, Cloncurry Mineral Field. *Ibid.,* 57, 306-307.
BROOKS, J. H., 1957a.—Big Beryl mine, Mount Isa, Cloncurry Mineral Field. *Ibid.,* 58, 605.
BROOKS, J. H., 1957b.—Joy cobalt prospect, Cloncurry. *Ibid.,* 58, 605-6.

BROOKS, J. H., 1957c.—Copper Blonde, calcite - copper deposit, Cloncurry Mineral Field. *Ibid.*, 58, 606.
BROOKS, J. H., 1957d.—King Solomon, copper deposit, Cloncurry Mineral Field. *Ibid.*, 58, 606-7.
BROOKS, J. H., 1958.—The Westmoreland uranium prospect, north-western Queensland. *Ibid.*, 59, 204-206.
BROOKS, J. H., 1960.—The uranium deposits of north-western Queensland. *Geol. Surv. Qld Publ.* 297.
BROOKS, J. H., (in press).—The occurrence of uranium in Queensland. *In* SYMPOSIUM ON THE PEACEFUL USES OF ATOMIC ENERGY IN AUSTRALIA, 1958, Sec. 1, Materials. *Atom. En. Comm. Aust.*
BROOKS, J. H., and SHIPWAY, C. H., 1960.—Mica Creek pegmatites, Mount Isa, north-west Queensland. *Qld Govt Min. J.*, October 1960.
BROWNE, W. R., 1949.—Metallogenetic epochs and ore regions in the Commonwealth of Australia. *J. Roy. Soc. N.S.W.*, 83, 96-113.
BRYAN, W. H., 1926.—Earth movements in Queensland. *Proc. Roy. Soc. Qld*, 37, 1-82.
BRYAN, W. H., and JONES, O. A., 1944.—A revised glossary of Queensland stratigraphy. *Pap. Univ. Qld Dep. Geol.*, 2(11).
BRYAN, W. H., and JONES, O. A., 1946.—The geological history of Queensland—a stratigraphical outline. *Ibid.*, 2(12).

CAMERON, W. E., 1900a.—On the Lawn Hill Silver-lead Company's properties, Mended Hill. *Geol. Surv. Qld Publ.* 138.
CAMERON, W. E., 1900b.—Recent developments in the copper mining industry in the Cloncurry district. *Ibid.*, 153.
CAMERON, W. E., 1901.—Geological observations in north-western Queensland. *Qld Dep. Min. Ann. Rep.* 1900-1902 (*Geol. Surv. Qld Publ.* 159), 186-191.
CAMERON, W. E., 1903.—Iron ores in Queensland. *Qld Govt Min. J.*, 4, 126.
CARTER, E. K., 1955a.—Cloncurry uranium. *Min. Mag.*, Nov. 1955.
CARTER, E. K., 1955b.—Radioactive occurrences, Cloncurry Mineral Field, Queensland. *Qld Govt Min. J.*, 56, 644-649.
CARTER, E. K., 1958.—Precambrian of north-west Queensland, Australia. *Geol. Rdsch.*, 47(2).
CARTER, E. K., 1959a.—New stratigraphic units in the Precambrian of north-western Queensland. *Qld Govt Min. J.*, 60, 437-441.
CARTER, E. K., 1959b.—Cloncurry — 4 mile geological series. *Bur. Min. Resour. Aust. Explan. Notes.* 13.
CARTER, E. K., 1959c.—Dobbyn—4-mile geological series. *Ibid.*, 15.
CARTER, E. K., 1959d.—Westmoreland — 4-mile geological series. *Ibid.*, 14.
CARTER, E. K., and BROOKS, J. H., 1955.—Mt. Philp iron deposit, Cloncurry district, Queensland. *Bur. Min. Resour. Aust. Rep.* 17.
CARTER, E. K., and BROOKS, J. H., 1960.—The Precambrian of north-western Queensland. *J. geol. Soc. Aust.*, 7, 21-62.
CARTER, E. K., and ÖPIK, A. A., (in press).—Lawn Hill 4-mile geological series. *Bur. Min. Resour. Aust. Explan. Notes*, 21.
CARTER, S. R., 1950a.—Mt. Isa geology, paragenesis and ore reserves. *Int. geol. Cong.*, 18*th Sess.* (*Lond.*), 7, 195-205.
CARTER, S. R., 1950b.—Operations at Mt. Isa. *Qld Govt Min. J.* 51, 408-425.
CARTER, S. R., 1953a.—Geology and exploration on Mt. Isa prospecting area. *Proc. Aust. Inst. Min. Metall.*, n.s. 171, 119-131.
CARTER, S. R., 1953b.—Mt. Isa mines. *In* GEOLOGY OF AUSTRALIAN ORE DEPOSITS. *Fifth Emp. Min. metall. Cong.*, 1, 361-377.
CARTER, S. R., 1958.—Notes on recent Mt. Isa ore discoveries. F. L. Stillwell Anniversary Volume, *Aust. Inst. Min. Metall.*, 61-65.
CHAPMAN, F., 1929.—On some trilobites and brachiopods from the Mt. Isa district, N.W. Queensland. *Proc. Roy. Soc. Vic.*, 41(2), 206-216.
CHAYES, F., 1952.—Notes on the staining of potash feldspars with sodium cobaltinitrite in thin section. *Amer. Miner.*, 37 (3 and 4), 337.
CHERRY, F. J., 1905.—Copper mining in the Corella River, Cloncurry. *Qld Govt Min. J.*, 6, 139.
CLARKE, W. B., 1868.—On the auriferous and other metalliferous districts of northern Queensland. *Trans. Roy. Soc. N.S.W.*, 1867, 42-57.
CONNAH, T. H., 1938.—Mica Creek collection of comparatively rare minerals. *Qld Govt Min. J.*, 39, 162.
CONNAH, T. H., 1954a.—Uranium discoveries, Mt. Isa. *Ibid.*, 55, 581-582.
CONNAH, T. H., 1954b.—Tunny's silver find, Kuridala, Silver Phantom. *Ibid.*, 55, 639.

CONNAH, T. H., 1958.—Summary Report. Limestone resources of Queensland. *Publ. geol. Surv. Qld*, 292.
C.S.I.R.O., 1954.—Survey of Barkley region, 1947-48. *Sci. ind. Res. Org. Aust., Land Res. Ser.* 3.
CUNNINGHAM, K. J., 1953.—Milling at Mount Isa. *Proc. Aust. Inst. Min. Metall.*, n.s. 171, 303-340.
DAINTREE, R., 1868.—Report on the Cape River diggings and the latest mineral discoveries in North Queensland. *By Authority, Brisbane.*
DAINTREE, R., 1870.—General report upon the Northern District. *By Authority, Brisbane.*
DAINTREE, R., 1872.—Notes on the geology of the Colony of Queensland. *Quart. J. geol. Soc. Lond.*, 28(3), 271-360.
DAVEY, P. T., DYSON, N. F., FAUDER, H. W., & SCOTT, T. R., 1955.—The extraction of uranium from ore from Mary Kathleen deposit, Queensland. *Sci. ind. Res. Org. Aust. ind. Chem. Sci. Div. Rep.*

DAVID, T. W. E., 1932.—EXPLANATORY NOTES TO ACCOMPANY A NEW GEOLOGICAL MAP OF THE COMMONWEALTH OF AUSTRALIA. Melbourne, C.S.I.R.
DAVID, T. W. E., (ed. W. R. BROWNE), 1950.—THE GEOLOGY OF THE COMMONWEALTH OF AUSTRALIA. London, Arnold.
DEBNAM, A. H., 1954-55.—Geochemical prospecting at Mt. Isa, Queensland. *Trans. Instn Min. Metall.*, 63.
DENMEAD, A. K., 1937a.—Mt. Kelly area, Lower Paradise Creek. *Qld Govt Min. J.*, 38, 277.
DENMEAD, A. K., 1937b.—Paradise valley. *Ibid.*, 38, 277.
DENMEAD, A. K., 1937c.—Silver prospect near Doughboy Creek, Kajabbi district. *Ibid.*, 38, 354 (corrig. 428).
DENMEAD, A. K., 1937d.—Tantalite at Mica Creek. *Ibid.*, 38, 355.
DENMEAD, A. K., 1938.—Copper discovery at Paradise Valley, Mt. Isa district. *Ibid.*, 39, 91-95.
DUNSTAN, B., 1904.—The iron bonus commission—evidence taken in Queensland. *Geol. Surv. Qld Publ.* 190(4), 12-25.
DUNSTAN, B., 1906.—Graphite in Queensland. *Qld Govt Min. J.*, 7, 73.
DUNSTAN, B., 1913.—Queensland mineral index. *Geol. Surv. Qld Publ.* 241.
DUNSTAN, B., 1919.—Mt. Oxide mine, Cloncurry. *Qld Govt Min. J.*, 20, 376-380.
DUNSTAN, B., 1920.—North-western Queensland. Geological notes on the Cloncurry-Camooweal-Burketown-Boulia area. *Geol. Surv. Qld Publ.* 265.
DUNSTAN, B., 1924.—Mt. Isa silver-lead deposits. *Qld Govt Min. J.*, 25, 200.
DUNSTAN, B., 1929.—Mt. Isa aerial survey and border geology. *Qld Dep. Min. Ann. Rep.* 1924, 140-141.
DUNSTAN, B., 1928.—Mt. Isa and Chillagoe as bases for geophysical prospecting. *Ibid.*, 1927, 133.

EARL, G. W., 1863.—A HANDBOOK FOR COLONISTS IN TROPICAL AUSTRALIA. (Published in London).
EDWARDS, A. B., 1938.—Some ilmenite microstructures and their interpretation. *Proc. Aust. Inst. Min. Metall.*, n.s. 110, 43.
EDWARDS, A. B., 1940.—On the mineral composition of the Mt. Oxide copper ore, Queensland. *Ibid.*, n.s. 118, 83-95.
EDWARDS, A. B., 1947.—TEXTURES OF THE ORE MINERALS. Melbourne, Aust. Inst. Min. Metall.
EDWARDS, A. B., 1953a.—The Lawn Hill silver-lead field. *In* GEOLOGY OF AUSTRALIAN ORE DEPOSITS. *Fifth Emp. Min. metall. Cong.*, 1, 378-383.
EDWARDS, A. B., 1953b.—The Mt. Oxide copper mine. *Ibid.*, 1, 391-395.
EDWARDS, A. B., 1954.—Radioactive ore from Mt. Isa, Queensland. *Sci. ind. Res. Org. Aust., mineragr. Inv. Rep.* 573.
EDWARDS, A. B., 1955a.—Drill core specimens from Mt. Cobalt mine, Selwyn, Queensland. *Ibid.*, 636.
EDWARDS, A. B., 1955b.—Silver rich ore from Mt. Isa Northern Leases, Queensland. *Ibid.*, 628.
EDWARDS, A. B., 1956.—The present state of knowledge and theories of ore genesis. *Proc. Aust. Inst. Min. Metall.*, n.s. 177, 69-116.
EDWARDS, A. B., 1957a-c.—Constance Range iron formation, I-III. *Sci. ind. Res. Org. Aust., mineragr. Inv. Rep.* 716, 718 and 719.
EDWARDS, A. B., 1959a.—Oolitic iron formation at Constance Range, IV: DDH 42B. *Ibid.*, 770.

EDWARDS, A. B., 1959b.—Oolitic iron formations from Constance Range; V: Analysed specimens. *Ibid.*, 776.
EDWARDS, A. B., and BAKER, G., 1954.—Scapolitisation in the Cloncurry district of north-western Queensland. *J. geol. Soc. Aust.*, 1, 1-33.
EDWARDS, A. B., and CARLOS, G. C., 1954.—The selenium content of some Australian sulphide deposits. *Proc. Aust. Inst. Min. Metall.*, n.s. 172, 31-63.
ETHERIDGE, R., and JACK, R. L., 1881.—CATALOGUE OF WORKS, PAPERS, REPORTS AND MAPS ON THE GEOLOGY, PALAEONTOLOGY, MINERALOGY, MINING, METALLURGY, ETC. OF THE AUSTRALIAN CONTINENT AND TASMANIA. London, Stanford.

FAUL, H., 1954.—NUCLEAR GEOLOGY. New York, Wiley.
FISHER, G. R., 1959.—Planning for growth by Mount Isa Mines Limited. *Qld Govt Min. J.*, 60 (690), 229-237.
FISHER, N. H., 1947a.—Lead. *Bur. Min. Resour. Aust. Summ. Rep.* 23, 10-11.
FISHER, N. H., 1947b.—Zinc. *Ibid.*, 33, 8-9.
FYSH, H., 1933.—TAMING THE NORTH. Sydney, Halstead Press.

GIBB, T., 1904.—The Cloncurry copper field, Queensland. *Qld Govt Min. J.*, 5, 554-558.
GOLDSCHMIDT, V. M., 1911.—Die Kontact-metamorphose in Kristianagebiet. *Videnskip. Skrift* 1, Mat - Mat Klasse 1.
GREGORY, A. C., 1861.—North Australian expedition. *S. Aust. parl. Pap.*, 3 (No. 170).
GREGORY, J. W., 1910-11.—Australia: Geology, *in* Encyclopaedia Britannica, 11th ed., 2, 944.
GRONDIJS, H. F., and SCHOUTEN, C., 1937.—A study of Mt. Isa ores. *Econ. Geol.*, 32, 407-450.

HALL, G., 1939.—Geology as applied to the mining of silver-lead-zinc ores at Mt. Isa. *Proc. Aust. Inst. Min. Metall.* n.s., 115, 215-234.
HALL, G., 1953.—The Crusader copper mine. *In* GEOLOGY OF AUSTRALIAN ORE DEPOSITS. *Fifth Emp. Min. metall. Cong.*, 1, 396-397.
HARKER, A., 1932.—METAMORPHISM. London, Methuen.
HARRIS, 1918-1919.—Resources of the Cloncurry Copper Field, N.Q. *Chem. Engng Min. Rev.*, 10 (122-123) and 11 (124).
HATCH, F. H., WELLS, A. K., and WELLS, M. K., 1949.—THE PETROLOGY OF THE IGNEOUS ROCKS. London, Murby.
HAYES, A. O., 1915.—Wabana iron ore of Newfoundland. *Canad. geol. Surv. Mem.* 78.
HILLS, E. S., 1945.—Some aspects of the tectonics of Australia. *J. Roy. Soc. N.S.W.*, 79, 67-91.
HODGKINSON, W. O., 1877.—Exploration in north-western Queensland, 1875-1876, *V. & P. Legis. Ass. Qld, Sess.* 1876, 3, 352-386.
HOLMES, A., and SMALES, A. A., 1948.—Monazite from Bodmin Moor, Cornwall: A study in geochronology. *Proc. Roy. Soc. Edinb., B.*, 63(2).
HONMAN, C. S., 1936a.—The Mount Freda-Canteen area, Soldiers Cap, Cloncurry district. *Aer. Surv. N. Aust., Qld Rep.* 1.
HONMAN, C. S., 1936b.—The Gilded Rose area, Cloncurry district. *Ibid.*, 2.
HONMAN, C. S., 1937a.—The Dugald River silver-lead lodes, Cloncurry district. *Ibid.*, 8.
HONMAN, C. S., 1937b.—The Bower Bird auriferous area, Cloncurry district. *Ibid.*, 19.
HONMAN, C. S., 1938a.—The Mt. Oxide copper mine, Cloncurry district. *Ibid.*, 15.
HONMAN, C. S., 1938b.—The Mt. Oxide area, Cloncurry district. *Ibid.*, 20.
HONMAN, C. S., 1938c.—Mt. Elliott-Hampden area, Cloncurry district. *Ibid.*, 22.
HONMAN, C. S., 1939.—The Soldiers Cap area, Cloncurry district (with portions by R. J. S. Clappison and E. O. Rayner, and appendix by A. O. Booth). *Ibid.*, 18.
HOOPER, R. P., 1932.—Some notes on diamond drilling practice at Mount Isa. *Proc. Aust. Inst. Min. Metall.* n.s., 88, 361-373.

IVANAC, J. F., and BRANAGAN, D. F., 1960.—A case history of geochemistry and prospecting in north-west Queensland. *Proc. Aust. Inst. Min. Metall.*, n.s. 195, 25-35.

JACK, R. L., 1885.—Six reports on the geological features of part of the district to be traversed by the proposed trans-continental railway. *Parliamentary paper*, reprinted with revisionary notes in 1898 as *Bull. geol. Surv. Qld*, 10 (*Publ.* 136).
JACK, R. L., 1886.—HANDBOOK OF QUEENSLAND GEOLOGY. Brisbane, Warwick and Sapsford.
JACK, R. L., 1888.—The mineral wealth of Queensland. Qld Comm. Centennial International Exhibition, Melbourne, 1888. *Geol. Surv. Qld Publ.* 48.
JACK, R. L., 1895.—Stratigraphical notes on the Georgina basin with reference to the question of artesian water. *Proc. Roy. Soc. Qld*, 11(2), 71-74.

JACK, R. L. and ETHERIDGE, R., JUN., 1892.—THE GEOLOGY AND PALAEONTOLOGY OF QUEENSLAND AND NEW GUINEA. Brisbane, Govt Printer; and London, Dulau.
JACKSON, A., 1862.—ROBERT O'HARA BOURKE AND THE AUSTRALIAN EXPLORING EXPEDITION OF 1860. London, Smith, Elder.
JENSEN, H. I., 1914.—Geological report on the Darwin mining district; the McArthur River district and the Barkly Tableland. *Bull. N. Terr. Aust.* 10.
JENSEN, H. I., 1920.—The geology, mineral prospects and future of north Queensland. *Qld Geogr. J.*, n.s. 34-35, 23-36.
JENSEN, H. I., 1940a.—The eastern portion of the Bower Bird district, Cloncurry district. *Aer. Surv. N. Aust., Qld Rep.* 48.
JENSEN, H. I., 1940b.—The Redbank (or Wollogorang) copper field, Northern Territory. *Ibid., N.T. Rep.* 50.
JENSEN, H. I., 1941a.—The Lawn Hill silver-lead-zinc field, Lawn Hill-Wollogorang district. *Ibid., Qld Rep.* 46.
JENSEN, H. I., 1941b.—The Lochness area, Cloncurry district. *Ibid., Qld Rep.* 37.
JONES, O. A., 1947.—Ore genesis in Queensland. *Proc. Roy. Soc. Qld*, 59, 1-91.
JONES. O. A., 1953.—The structural geology of the Precambrian in Queensland in relation to mineralization. *In* GEOLOGY OF AUSTRALIAN ORE DEPOSITS. *Fifth Emp. Min. metall. Cong.*, 1, 344-351.
JOPLIN, G. A., 1935.—The petrology of the Hartley district. III. The contact metamorphism of the Upper Devonian (Lambian) Series. *Proc. Linn. Soc. N.S.W.*, 60, 15-50.
JOPLIN, G. A., 1955.—A preliminary account of the petrology of the Cloncurry Mineral Field. *Proc. Roy. Soc. Qld*, 66(4), 33-67.
JOPLIN, G. A., 1956.—On the association of albitites and soda aplites with potash granites in the Precambrian and older Palaeozoic of Australia. *J. Roy. Soc. N.S.W.*, 90(2), 80-86.
JOPLIN, G. A., CARTER, E. K., and BURNETT, J. K., 1954.—Occurrence of sodium chloride and other soluble salts in the calcareous shales of Mt. Isa and Cloncurry, Queensland. *Aust. J. Sci.*, 17(3), 102.
JOPLIN, G. A. and WALKER, K. R. (in press).—The Precambrian granites of northwestern Queensland. *Proc. Roy. Soc. Qld.*

KNIGHT, C. L., 1953.—Regional geology of Mount Isa. *In* GEOLOGY OF AUSTRALIAN ORE DEPOSITS. *Fifth Emp. Min. metall. Cong.*, 1, 352-360.
KNIGHT, C. L., 1957.—Ore genesis—the source bed concept. *Econ. Geol.*, 52(7), 808-817.
KRUTTSCHNITT, J., 1952.—A brief history of Mt. Isa Mines' financial structure, its trials and tribulations. *Proc. Aust. Inst. Min. Metall.*, n.s., 171, 1-17.

LAING, A. C. M., and POWER, P. E., 1959.—New names in Queensland stratigraphy, Carpentaria Basin. *Aust. Oil Gas J.*, 5(9), 28.
LAING, A. C. M. and POWER, P. E., 1960.—Carpentaria Sub-basin. *In* THE GEOLOGY OF QUEENSLAND, Ed. D. Hill and A. K. Denmead. *J. geol. Soc. Aust.*, 7, 324-328.
LANDSBOROUGH, W., 1862.—JOURNAL OF LANDSBOROUGH'S EXPEDITION FROM CARPENTARIA, IN SEARCH OF BURKE AND WILLS. Melbourne, Wilson and Mackinnon.
LAWRENCE, L. J., 1955.—Uranium mineralization in the Cloncurry - Mt. Isa area. *Proc. Roy. Soc. Qld*, 66, 69-76.
LAWRENCE, L. J., 1957.—Davidites from the Mt. Isa-Cloncurry district, Queensland. *Econ. Geol.*, 52(2). 140-148.
LEES, W., 1899.—THE GOLDFIELDS OF QUEENSLAND. Brisbane, Outridge.
LEES, W., 1907.—THE COPPER MINES AND MINERAL FIELDS OF QUEENSLAND. Queensland Country Life Press, 45-60.
LEICHHARDT, L., 1847.—OVERLAND EXPEDITION FROM MORETON BAY TO PORT ESSINGTON. London, Boone.
LINDEN, E. B., 1887.—A catalogue of such minerals as are at present known in Queensland with their principal associations and places of occurrence. *Proc. Roy. Soc. Qld*, 4, 32-78.
LYON, R. J., and EDWARDS, A. B., 1955.—Ore from Mt. Cobalt mine, Selwyn, Cloncurry. *Sci. ind. Res. Org. Aust., mineragr. Inv. Rep.* 612.

McANDREW, J., 1957.—Natural radiation damage in albite. *Amer. J. Sci.*, 255(10), 715-723.
McANDREW, J., and EDWARDS, A. B., 1953.—Specimens from Gereta zinc prospect. *Sci. ind. Res. Org. Aust., mineragr, Inv. Rep.*, 553.
McANDREW, J., and EDWARDS, A. B., 1954a.—Radioactive ore from Mt. Isa, Queensland. *Ibid.*, 590.

McANDREW, J., and EDWARDS, A. B., 1954b.—Radioactive ore from Mt. Isa, Queensland. *Ibid.*, 603.
McANDREW, J., and EDWARDS, A. B., 1954c.—Radioactive ore from Mary Kathleen lease, Mt. Isa district, Queensland. *Ibid.*, 604.
McANDREW, J., and EDWARDS, A. B., 1955a.—Radioactive ore, Counter (Anderson's lode), Cloncurry district. *Ibid.*, 609.
McANDREW, J., and EDWARDS, A. B., 1955b.—Stillwellite, a new rare-earth mineral from the Mary Kathleen lease. *Ibid.*, 617.
McANDREW, J., and EDWARDS, A. B., 1956.—Cobalt-bearing specimens from Mt. Isa, Queensland. *Ibid.*, 667.
McANDREW, J., and EDWARDS, A. B., 1957a.—Radioactive specimens from the Cloncurry district, Queensland. *Ibid.*, 677.
McANDREW, J., and EDWARDS, A. B., 1957b. and c.—Radioactive ore from Milestone, north-western Queensland. [Northern Territory]. *Ibid.*, 680 and 721.
McANDREW, J., and SCOTT, J. R., 1955.—Stillwellite, a new rare-earth mineral from Queensland. *Nature*, 176, 509.
McGILLIVRAY, H. I., 1919.—Naumannite in the Cloncurry district. *Qld Govt Min. J.*, 505.
McKINLAY, J., circa 1863.—McKINLAY'S JOURNAL OF EXPLORATION IN THE INTERIOR OF AUSTRALIA. Melbourne, Bailliere.
MARSHALL, C. E., and NARAIN, H., 1954.—Regional gravity investigations in the eastern and central Commonwealth. *Univ. Sydney, Dep. Geol. Geophys., Mem.* 1954/2.
MATHESON, R. S., and SEARL, R. A., 1956.—Mary Kathleen uranium deposit, Mount Isa - Cloncurry district, Queensland, Australia. *Econ. Geol.*, 51(6), 528-40.
MORLEY, I. W., 1950.—The copper industry of Queensland. *Qld Govt Min. J.*, 51, 530-533.
MOTT, W. D., 1952.—Oil in Queensland. *Qld Govt Min. J.*, 53, 848-861.
MOUNT ISA MINES LIMITED.—Annual Reports, 1931 — date.
MÜLLER, W., 1891.—über Contact - erscheinungen an Glimmerschiefer der Schreekoppe. *Z. dtsch, geol. Ges.*, 43, 730-733.
MURRAY, W. J., and CARTER, S. R., 1959.—The source bed concept. Mount Isa - epigenetic or syngenetic. *Econ. Geol.*, 54, 953-956.
NIER, A. A., THOMPSON, R. W., and MURPHEY, B. F., 1941.—The isotopic composition of lead and the measurement of geological time. III. *Phys. Rev.*, 60, 112-116.
NIGGLI, P., 1954.—ROCK AND MINERAL DEPOSITS. San Francisco, Freeman.
NOAKES, L. C., 1956.—Upper Proterozoic and Sub-Cambrian rocks in Australia. *In* EL SISTEMA CAMBRICO, SU PALEOGEOGRAFIA Y EL PROBLEMA DE SU BASE, 2, 213-238. *Int. geol. Cong., 20th Sess., Mexico.*
NOAKES, L. C., CARTER, E. K., and ÖPIK, A. A., 1959.—Urandangi - 4-mile geological series. *Bur. Min. Resour. Aust. Explan. Notes* 1, 2nd ed.
NOAKES, L. C., and TRAVES, D. M., 1954.—Outline of the geology of the Barkly region. *In* SURVEY OF BARKLY REGION, 1947-48. *Sci. ind. Res. Org. Aust., Land Res. Ser.* 3.
NYE, P. B., 1947.—Cobalt. *Bur. Min. Resour. Aust. Summ. Rep.* 32, 7-9.
NYE, P. B., and RAYNER E. O., 1940.—The Cloncurry copper deposits, with special reference to the gold-copper ratios of the ores. *Aer. Sur. N. Aust., Qld Rep.* 35.
O'MALLEY, G. B., and McGHIE, R. R., 1939.—The mineralogy of the Black Star orebody and its relation to milling practice at Mt. Isa. *Proc. Aust. Inst. Min. Metall.*, n.s. 116, 459-486.
ÖPIK, A. A., 1956a.—Cambrian geology of Queensland. *In* EL SISTEMA CAMBRICO, SU PALEOGEOGRAFIA Y EL PROBLEMA DE SU BASE, 2, 1-24, *Int. geol. Cong.*, 20th *Sess., Mexico.*
ÖPIK, A. A., 1956b.—Cambrian palaeogeography of Australia. *Ibid.*, 2, 239-284.
ÖPIK, A. A., 1960.—Cambrian and Ordovician geology of Queensland. *J. geol. Soc. Aust.*, 7.
ÖPIK, A. A., 1961.—The geology and palaeontology of the headwaters of the Burke River, Queensland. *Bur. Min. Resour. Aust. Bull.* 53.
ÖPIK, A. A., and CARTER, E. K., (in press).—Camooweal—4-mile geological series. *Bur. Min. Resour. Aust. Explan. Notes*, 22.
ÖPIK, A. A., and CARTER, E. K., (in press).—Duchess—4-mile geological series. *Ibid.*, 23.
ÖPIK, A. A., CARTER, E. K., and NOAKES, L. C., 1961.—Mount Isa - 4 mile geological series. *Ibid.*, 20.
PHILLIPS, —, 1909.—Advisability of constructing railways and ports connecting therewith in the Gulf of Carpentaria. By Authority: Govt Printer, Brisbane (*Parliamentary Papers* printed during 1st Session of 18th Parliament. 2, 591-632).

QUEENSLAND DEPARTMENT OF MINES.—Annual Reports, 1878 - date.

QUEENSLAND GOVERNMENT MINING JOURNAL, 1901.—Mineral resources of Queensland. *Qld Govt Min. J.* (Glasgow Exhibition Number), 27-28, 50-52.

QUEENSLAND GOVERNMENT MINING JOURNAL, 1954.—Geological and geophysical surveys of the Lawn Hill, Mt. Isa, Cloncurry region, north-western Queensland. *Ibid.*, 55, 910-916.

QUEENSLAND GOVERNMENT MINING JOURNAL, 1956.—The Mary Kathleen project will hasten development of Queensland's uranium field. *Ibid.*, 57.

RAGGATT, H. G., 1959.—Australian code of stratigraphic nomenclature, 3rd ed. *J. geol. Soc. Aust.*, 6(1), 63-70.

RANDS, W. H., 1895.—Report on the Leichhardt goldfield and other mining centres in the Cloncurry district. *Geol. Surv. Qld Publ.* 104.

RAYNER, E. O., 1936.—The Silver Ridge auriferous lodes, Cloncurry district. *Aer. Surv. N. Aust., Qld Rep.* 10.

RAYNER, E. O., 1938.—Cobalt deposits of the Cloncurry district. *Ibid.*, 34.

RAYNER, E. O., 1953.—Cobalt mineralization in the Cloncurry district. *In* GEOLOGY OF AUSTRALIAN ORE DEPOSITS. *Fifth Emp. Min. metall. Cong.*, 1, 417-425.

RAYNER, J. M., and NYE, P. B., 1936a.—Geophysical report on the Soldiers Cap area, Cloncurry district. *Aer. Surv. N. Aust., Qld Rep.* 4.

RAYNER, J. M., and NYE, P. B., 1936b.—Geophysical report on the Trekelano area, Cloncurry district. *Ibid.*, 5.

RAYNER, J. M., and NYE, P. B., 1936c.—Geophysical report on the Dobbyn area, Cloncurry district. *Ibid.*, 6.

RAYNER, J. M., and NYE, P. B., 1936d.—Geophysical report on the Silver Ridge auriferous lodes, Cloncurry district. *Ibid.*, 11.

RAYNER, J. M., and NYE, P. B., 1937a.—Geophysical report on the Dugald River silver-lead lodes, Cloncurry district. *Ibid.*, 7.

RAYNER, J. M., and NYE, P. B., 1937b.—Geophysical report on the Trekelano area, Cloncurry district. (Supplementary to *Qld Rep.* 5). *Ibid.*, 17.

READ, H. H., 1955.—Granite series in mobile belts. *In* THE CRUST OF THE EARTH. *Geol. Soc. Amer. Spec. Pap.* 62, 409.

REID, J. H., 1921.—Cobalt in the Cloncurry district (the lode near Selwyn). *Qld Govt Min. J.*, 22, 12-14.

RICH, J. L., 1951.—Three critical environments of deposition, and criteria for recognition of rocks deposited in each of them. *Bull. geol. Soc. Amer.*, 62, 1-20.

RICHARDS, H. C., 1938.—The Mount Isa lead-zinc field. *Mine Quarry Engng*, 3, May 1938.

ROBERTSON, W. A., 1960.—Stromatolites from the Paradise Creek area, north-western Queensland. *Bur. Min. Resour. Aust. Rep.* 47.

ROYAL COMMISSION ON PUBLIC WORKS, 1917.—Proposed railway from Oona to Mount Oxide. By Authority: Govt Printer, Brisbane.
(*Parliamentary papers* printed during the 2nd session of the 20th Parliament, 3, 1297-1392).

ROYAL COMMISSION ON PUBLIC WORKS, 1919.—Proposed railways to open up Gulf districts. *Ibid.*, 2nd session 21st Parliament, 3, 859-994.

RUTHERFORD, W. P., and KITCHENER, ——, 1904.—COPY OF REPORT OF THE PRINCIPAL COPPER PROSPECTS AT CLONCURRY, NORTH QUEENSLAND. London, Moreton & Birt.

SAINT-SMITH, E. C., 1923.—Silver-lead lodes at Mount Isa, Cloncurry district. *Qld Govt Min. J.*, 24, 412-418.

SAINT-SMITH, E. C., 1924a.—Mount Isa (Cloncurry) silver-lead field, recent developments. *Ibid.*, 25, 9.

SAINT-SMITH, E. C., 1924b.—Note on the occurrence of Cambrian strata near Mount Isa, Cloncurry Gold and Mineral Field. *Ibid.*, 25, 411.

SAINT-SMITH, E. C., 1925a.—Lawn Hill silver-lead-zinc field, Burketown Mineral Field. *Ibid.*, 26, 91-92 and 303-307.

SAINT-SMITH, E. C., 1925b.—Mount Isa silver-lead field, recent developments. *Ibid.*, 26, 13.

SAINT-SMITH, E. C., 1925c.—Queen Sally cobalt mine, Koolamnarra, Cloncurry Gold and Mineral Field. *Ibid.*, 26, 281.

SAINT-SMITH, E. C., 1932.—Silver Ridge lode, near Mount Cuthbert. *Ibid.*, 33, 115-116.

SCHOUTEN, C., 1937.—Die erze der "Black Star" Grube (Mount Isa, Australien). *In* METASOMATISCHE PROBLEME. Amsterdam, Scheltema & Holkema's Boekhandel, S. 4-21.

SHEPHERD, S. R. L., 1931a.—Cloncurry Mineral Field. *Qld Govt Min. J.*, 32, 226.

SHEPHERD, S. R. L., 1931b.—Gilded Rose and Pinnacles areas, Cloncurry district. *Ibid.*, 32, 482.
SHEPHERD, S. R. L., 1931c.—Report on the Rio Grande lease, Mount Isa. *Ibid.*, 32, 481-482.
SHEPHERD, S. R. L., 1931d.—Silver Casket group of leases, Mount Isa. *Ibid.*, 32, 225-226.
SHEPHERD, S. R. L., 1931e.—Top Camp and Pumpkin Gully, Cloncurry Mineral Field. *Ibid.*, 32, 226.
SHEPHERD, S. R. L., 1931f.—Top Camp diggings, Cloncurry River. *Ibid.*, 32, 309-311.
SHEPHERD, S. R. L., 1932a.—Mount Isa silver-lead-zinc deposits, the Black Rock lode. *Ibid.*, 33, 377-383.
SHEPHERD, S. R. L., 1932b.—Notes on the Cloncurry Mineral Field. *Ibid.*, 33, 77-79.
SHEPHERD, S. R. L., 1932c.—Report on the Rio Grande lease, Mt. Isa. *Ibid.*, 33, 11-13.
SHEPHERD, S. R. L., 1932d.—The Gilded Rose area at Cloncurry. *Ibid.*, 33, 48.
SHEPHERD, S. R. L., 1933a.—Comstock mine, Soldiers Cap, Cloncurry district. *Ibid.*, 34, 162-163.
SHEPHERD, S. R. L., 1933b.—Mount Freda, Soldiers Cap, Cloncurry district. *Ibid.*, 34, 160-162.
SHEPHERD, S. R. L., 1933c.—Note to accompany preliminary structural map of the Mount Isa silver-lead-zinc deposits. *Ibid.*, 34, 313.
SHEPHERD, S. R. L., 1934.—Gold prospects at May Downs, Cloncurry Gold and Mineral Field. *Ibid.*, 35, 40.
SHEPHERD, S. R. L., 1935a.—Gold discovery at Mount Isa. *Ibid.*, 36, 417.
SHEPHERD, S. R. L., 1935b.—Jayah workings, near Dajarra. *Ibid.*, 36, 241.
SHEPHERD, S. R. L., 1936a.—Mount Isa silver-lead-zinc deposit (Black Star lode). *Ibid.*, 37, 269-272.
SHEPHERD, S. R. L., 1936b.—Mount Isa lode. *Ibid.*, 37, 342.
SHEPHERD, S. R. L., 1936c.—Trekelano copper mine, north-western Queensland. *Ibid.*, 37, 372-375.
SHEPHERD, S. R. L., 1938.—Mica Creek tin deposits near Mount Isa. *Ibid.*, 39, 95-96.
SHEPHERD, S. R. L., 1940.—Trekelano copper mine. *Ibid.*, 41, 236-238.
SHEPHERD, S. R. L., 1945a.—Cambrian oil shale, Camooweal. *Ibid.*, 46. 75-77.
SHEPHERD, S. R. L., 1945b.—Cloncurry water supplies. *Ibid.*, 46, 267-9.
SHEPHERD, S. R. L., 1946a.—Geological sketch map, Cloncurry area. *Ibid.*, 47, 144-146.
SHEPHERD, S. R. L., 1946b.—Mt. Oxide copper mine, Cloncurry Field. *Ibid.*, 47, 110-113.
SHEPHERD, S. R. L., 1946c.—Orphan copper mine, Dobbyn. *Ibid.*, 47, 113-114.
SHEPHERD, S. R. L., 1946d.—Some mines in the Cloncurry Field. *Ibid.*, 47, 45-52.
SHEPHERD, S. R. L., 1953a.—Geology of Cloncurry district. *In* GEOLOGY OF AUSTRALIAN ORE DEPOSITS. *Fifth Emp. Min. metall. Cong.*, 1, 384-390.
SHEPHERD, S. R. L., 1953b.—Trekelano copper mine. *Ibid.*, 1, 404-410.
SPRATT, R. N., 1953.—Notes on the Black Star copper orebody. *Proc. Aust. Inst. Min. Metall.*, n.s. 171, 57-64.
STANTON, R. L., and RUSSELL, R. D., 1959.—Anomalous leads and the emplacement of lead sulphide ores. *Econ. Geol.*, 54, 588-607.
STEWART, G. A., 1954.—Geomorphology of the Barkly region. *In* SURVEY OF BARKLY REGION 1947-48. *Sci. ind. Res. Org. Aust., Land Res. Ser.* 3, 42-58.
STILLWELL, F. L., 1938.—Copper-cobalt ore from the Success mine, near Cloncurry, Queensland. *Coun. sci. ind. Res. Aust., mineragr. Inv. Rep.* 122.
STILLWELL, F. L., 1943.—A tailings sample from Mt. Cobalt mine, Cloncurry, Qld. *Ibid.*, 293.
STILLWELL, F. L., and EDWARDS, A. B., 1945.—The mineral composition of the Black Star copper orebody, Mount Isa, Queensland. *Ibid.*, 319. (Published in *Proc. Aust. Inst. Min. Metall.*, n.s. 139, 149-159).
STILLWELL, F. L., and EDWARDS, A. B., 1947.—Zinc-lead ore from Dugald River, North Queensland. *Sci ind. Res. Org. Aust., mineragr. Inv. Rep.* 375.
STILLWELL, F. L., and EDWARDS, A. B., 1948.—Bore cores from Hampden Consols mine, near Cloncurry, Queensland. *Ibid.*, 397.
STILLWELL, F. L., and EDWARDS, A. B., 1949a.—Amphibolite specimens from Kuridala, Cloncurry district, Queensland. *Ibid.*, 429.
STILLWELL, F. L., and EDWARDS, A. B., 1949b.—Oxidised ore from Mount Oxide, Cloncurry district, Queensland. *Ibid.*, 430.
STILLWELL, F. L., and EDWARDS, A. B., 1949c.—Rocks from the Duchess area, Cloncurry district, Queensland. *Ibid.*, 412.
STILLWELL, F. L., and EDWARDS, A. B., 1949d.—Scapolite granulite from No. 1 drill core, Trekelano, Cloncurry district, Queensland. *Ibid.*, 424.
STILLWELL, F. L., and EDWARDS, A. B., 1950a.—Diamond drill samples from Kuridala, near Cloncurry, Queensland. *Ibid.*, 446.

STILLWELL, F. L., and EDWARDS, A. B., 1950b.—Rock and core specimens from Mount Isa, Queensland. *Ibid.*, 436.
STILLWELL, F. L., and EDWARDS, A. B., 1951.—Specimens from Mt. Elliott, Queensland. *Ibid.*, 478.
STILLWELL, F. L., and EDWARDS, A. B., 1952a.—Core samples from No. 2B and No. 3 diamond drill holes, Mt. Oxide, Queensland. *Ibid.*, 520.
STILLWELL, F. L., and EDWARDS, A. B., 1952b.—Core samples from No. 2 diamond drill hole, Mt. Elliott, Queensland. *Ibid.*, 521.
SULLIVAN, C. J., 1947.—Cadmium. *Bur. Min. Resour. Aust. Summ. Rep.* 21, 9.
SULLIVAN, C. J., 1953a.—Mount Elliott Mine. *In* GEOLOGY OF AUSTRALIAN ORE DEPOSITS. *Fifth Emp. Min. metall. Cong.*, 1,414-416.
SULLIVAN, C. J., 1953b.—The Hampden copper mines, Kuridala. *Ibid.*, 1, 411-413.
SULLIVAN, C. J., 1954.—Metallic melting point and ore deposition. *Econ. Geol.*, 49(6), 555-574.
SUNDIUS, H., 1915.—Geologie des Kirunagebiets, 14, *Vitensk Prokt. Unders. Lappland*, Uppsala, 195-224 (abstract in *Neues Jb. Min. Geol. Paläont.*, 1918, 225-227).

TILLEY, C. E., 1935.—Metasomatism of greenstone — hornfelses, Cornwall. *Miner. Mag.*, 24(151).
TRAHAR, W. J., 1959a.—Concentration of copper ore from Blockade mine, Argylla Range, Queensland. *Sci. ind. Res. Org. Aust., Ore-dress. Inv. Rep.* 580.
TRAHAR, W. J., 1959b.—Concentration of a uranium ore from Milestone, N.T. *Ibid.*, 582.
TURNER, F. J., 1947.—Determination of plagioclase with the four-axis universal stage. *Amer. Miner.*, 32, 389-410.
TURNER, F. J., and VERHOOGEN, J., 1951.—IGNEOUS AND METAMORPHIC PETROLOGY. N. Y., McGraw-Hill.
TWIDALE, C. R., 1956a.—Chronology of denudation in north-west Queensland. *Bull. geol. Soc. Amer.*, 67(7), 867-882.
TWIDALE, C. R., 1956b.—Pediments at Naraku. *Aust. Geogr.*, Nov. 1956.
TWIDALE, C. R., 1956c.—The physiography of North-western Queensland. *Geogr. Studies*, 3(1).
TWIDALE, C. R., (in preparation [1]).—Geomorphology of the Leichhardt - Gilbert area. Pt. 4 of GENERAL REPORT OF THE LEICHHARDT - GILBERT AREA, QUEENSLAND. *Sci. ind. Res. Org. Aust., Land Res. Ser.*
TWIDALE, C. R., (in preparation [2]).—Geomorphology of the Leichhardt - Gilbert area of north-west Queensland. *Sci. ind. Res. Org. Aust. Land Res. Spec. Rep.*

UHR, R. C. H., 1879-1886.—Annual reports of the Queensland Department of Mines for the years 1878-1885.

VERNON, R. H., and EDWARDS, A. B., 1958.—Oxidized silver-lead ore from Lilydale Springs, Lawn Hill district, Queensland. *Sci. ind. Res. Org. Aust., mineragr. Inv. Rep.* 765.

WALKER, K. R., (in preparation).—The basic igneous rocks of the Lower Proterozoic of north-western Queensland. *Bur. Min. Resour. Aust. Bull.*
WALKER, K. R., JOPLIN, G. A., LOVERING, J. F., and GREEN, R., 1960.—Metamorphic and metasomatic convergence of basic igneous rocks and lime-magnesia sediments of the Precambrian of north-western Queensland. *J. geol. Soc. Aust.*, 6(2), 149-177.
WALLER, G. A., 1906.—Report on John Moffat's options at Cloncurry (see BALL, L. C., 1908, 8).
WALPOLE, B. P., 1958.—The Source Bed Concept. *Econ. Geol.*, 53, 890-893.
WHITE, W. C., (in press).—The geology of the Selwyn area of north-western Queensland. *Bur. Min. Resour. Aust. Rep.* 45.
WHITEHOUSE, F. W., 1930.—The geology of Queensland. *In* HANDBOOK FOR QUEENSLAND. *Aust. Ass. Adv. Sci., Brisbane.*
WHITEHOUSE, F. W., 1936.—The Cambrian faunas of eastern Australia. Part I. Stratigraphic Outline. Part 2. Trilobita (Miomera). *Mem. Qld Mus.*, 11(1), 59-112. Reprinted as *Univ. Qld Dep. Geol.* Publ. 82.
WHITEHOUSE, F. W., 1940.—Studies in the late geological history of Queensland. *Pap. Univ. Qld Dep. Geol.*, n.s., 2(1).
WHITEHOUSE, F. W., 1950.—Clarke memorial lecture. *J. Roy. Sec. N.S.W.*, 83.
WHITEHOUSE, F. W., 1954.—Geology of the Queensland portion of the Great Artesian Basin. Appendix G of Artesian water supplies in Queensland. *Dep. of Co-ordinator General of Public Works, Queensland.*
WHITTLE, A. W. G., 1959.—The nature of davidite. *Econ. Geol.*, 54(1), 64-81.

WILLIAMS, K. L., and VERNON, R. H., 1959.—Bertrandite in a beryl-pegmatite from Mica Creek, near Mount Isa, Queensland. *Sci. ind. Res. Org. Aust. Inv., mineragr. Rep.* 800.

WILSON, A. F., COMPSTON, W., JEFFREY, P. M., and RILEY, G. H., 1960.—Radioactive ages from the Precambrian rocks in Australia. *J. geol. Soc. Aust.*, 6(2), 179-195.

WOOLNOUGH, W. G., 1912.—Report on the geology of the Northern Territory. *Bull. N. Terr. Aust.*, 4.

UNPUBLISHED REFERENCES

(Copies of many of these reports may be inspected at the Queensland Department of Mines or the Geological Survey of Queensland, Brisbane).

ALLEN, G., 1956.—Malbon area. *Mount Isa Mines Ltd.*

ALLEN, G., and BERESFORD, R., 1956.—May Downs. *Ibid.*

AUSTRALASIAN OIL EXPLORATION LTD., 1955a.—First progress report on the detailed geological mapping of the Anderson's lode area.

AUSTRALASIAN OIL EXPLORATION LTD., 1955b.—Report on Anderson's lode — Counter's Lease, Mt. Isa district, Queensland.

AUSTRALASIAN OIL EXPLORATION LTD., 1955c.—Geology of the Mary Kathleen uranium deposit, Mt. Isa, Queensland.

AUSTRALASIAN OIL EXPLORATION LTD., 1955d.—Miscellaneous leases in the Mt. Isa-Cloncurry area.

BALL, L. C., 1916.—Mount Oxide mines. *Geol. Surv. Qld.*

BALL, L. C., 1922.—Mount Quamby. *Ibid.*

BALL, L. C., 1936.—Blade and Robertson's Lone Hand Mine, Malbon. *Ibid.*

BALL, L. C., 1937.—Dugald River silver-lead freeholds. *Ibid.*

BALL, L. C., 1939a.—Dugald River borehole No. 1 cores. *Ibid.*

BALL, L. C., 1939b.—Dugald River borehole No. 2 cores. *Ibid.*

BALL, L. C., 1939c.—Trekelano drilling. *Ibid.*

BALL, L. C., 1940.—Black Star copper, Mt. Isa. *Ibid.*

BATTEY, G. C., 1956a.—Final Report Westmoreland A to P, 1956 field season. *Mount Isa Mines Ltd.*

BATTEY, G. C., 1956b.—Biotite Authority to Prospect. Progress report No. 6. *Ibid.*

BATTEY, G. C., 1957a.—Final report, Mt. Philp Authority to Prospect No. 96M. *Ibid.*

BATTEY, G. C., 1957b.—Final report, Pisa Authority to Prospect No. 88M. *Ibid.*

BENNETT, E. M., 1955.—Airborne scintillometer survey. *Ibid.*

BERESFORD, R. F., 1953a.—Mount Guide area. *Ibid.*

BERESFORD, R. F., 1953b.—Native Bee area. *Ibid.*

BERESFORD, R. F., 1953c.—Bernborough Authority to Prospect. *Ibid.*

BERESFORD, R. F., 1954.—Mount Novit area. *Ibid.*

BLANCHARD, R., 1935.—Ore geology of the Mount Isa deposit. *Ibid.*

BLANCHARD, R., 1938a.—Silica content of Mount Isa ore. *Ibid.*

BLANCHARD, R., 1938b.—Lawn Hill concession Authority to Prospect No. 100M. *Mining Trust Ltd.*

BLANCHARD, R., 1943.—Report on Crusader copper mine. *Mount Isa Mines Ltd.*

BLANCHARD, R., and FISHER, N. H., 1934.—Pyrrhotite-pyrite content of the Black Star sulphide ore. *Mount Isa Mines Ltd.*

BLANCHARD, R., and HALL, G., 1941.—Mount Isa ore deposition. *Ibid.*

BLANCHARD, R., and QUIRK, R., 1939.—Mount Oxide region, Cloncurry copper district, north-western Queensland. *Anglo-Queensland Mining Pty Ltd.*

BRAHAM, P. G., and CLAPPISON, R. J. S., 1955.—Uranium exploration. *Gold Mines of Australia Ltd.*

BROADHURST, E., and DUTTON, A. H., 1952.—Report on work under authority to prospect Duchess area. *Ibid.*

BROKEN HILL PROPRIETARY CO. LTD, 1957a.—Authority to Prospect No. 64M, Constance Range area, reports to 30/9/57.

BROKEN HILL PROPRIETARY CO. LTD, 1957b.—Authority to Prospect No. 64M, Nicholson River — Burketown area, report of activities to 30/9/1957.

BROKEN HILL PROPRIETARY CO. LTD, 1958.—Authority to Prospect No. 115M, Constance Range.

BROKEN HILL PROPRIETARY CO. LTD, 1959a.—Authority to Prospect No. 115M, Constance Range.

BROKEN HILL PROPRIETARY CO. LTD, 1959b.—Authority to Prospect No. 115M, Constance Range, final report of activities to 30/9/1959.

BROKEN HILL PROPRIETARY CO. LTD, 1959c.—Lawn Hill area, plans, Authority to Prospect No. 100M.
BROKEN HILL PROPRIETARY CO. LTD, 1960.—Constance Range area, plans, Authority to Prospect No. 151M.
BROKEN HILL SOUTH LTD, 1949-1952.—Report on the Kuridala copper mining area. (various authors). *Field investigation department.*
BROKEN HILL SOUTH LTD, 1949.—Trekelano area. *Ibid.*
BROKEN HILL SOUTH LTD, 1952.—Report on the Mount Elliott mine, Cloncurry district, N.W. Queensland. *Ibid.*
BROKEN HILL SOUTH LTD, 1955.—Authority to prospect, Broken Hill South Ltd, near Mount Elliott mine, Selwyn. *Ibid.*
BROOKS, J. H., 1954a.—Ballara Nos. 1-2 uranium leases. *Qld. Dep. Min.*, 54/2573.
BROOKS, J. H., 1954b.—Black Valley Nos. 1-2 uranium leases. *Ibid.*, 54/2567.
BROOKS, J. H., 1954c.—Counter group of uranium leases. *Ibid.*, 54/2598.
BROOKS, J. H., 1954d.—Eldorado, Thanksgiving, Easter Egg group of uranium leases. *Ibid.*
BROOKS, J. H., 1954e.—Elaine Mary, Lucky Charm and Lucky Bob uranium leases. *Ibid.*, 54/3434.
BROOKS, J. H., 1954f.—Hot Rocks Nos. 1-6 uranium leases. *Ibid.*
BROOKS, J. H., 1954g.—Huxey uranium lease. *Ibid.* 54/2782.
BROOKS, J. H., 1954h.—P. Attiola's claim. *Ibid.*, 54/2628.
BROOKS, J. H., 1954i.— Pile uranium lease. *Ibid.*
BROOKS, J. H., 1954j.— Queen's Gift, Queen's Gift No. 2 uranium leases. *Ibid.*, 54/2497.
BROOKS, J. H., 1954k.—Skal uranium lease. *Ibid.*, 54/2058.
BROOKS, J. H., 1954l.—Tinboll Nos. 1-7 uranium leases. *Ibid.*, 54/2807.
BROOKS, J. H., 1954m.—Water Supply, Cloncurry hospital. *Geol. Surv. Qld.*
BROOKS, J. H., 1955a.—Big Beryl mine, Mt. Isa. *Ibid.*
BROOKS, J. H., 1955b.—Exploration of the Mount Cobalt deposit, Selwyn, Cloncurry Mineral Field. *Ibid.*
BROOKS, J. H., 1955c.—Joy cobalt prospect, Cloncurry. *Ibid.*
BROOKS J. H., 1955d.—Milo lease, Cloncurry. *Qld. Dep. Min.*, 55/3032.
BROOKS, J. H., 1955e.—Monthly reports, inspections of uranium leases, Cloncurry Field, July-December 1955. *Geol. Surv. Qld.*
BROOKS, J. H., 1955f.— Recent developments, Mount Oxide copper mines, Cloncurry Mineral Field. *Ibid.*

CAMPBELL, C. B., 1954.—Preliminary report on the uranium deposits of north-western Queensland. *Geol. Surv. G.B., Atom. En. Div. Rep.* 172.
CAMPANA, B., 1958.—Report on Mary Kathleen ore horizon stratigraphic position, structural interpretation, economic potentialities. *Rio Tinto Australian Exploration Pty Ltd.*
CARRUTHERS, D. S., 1954a.—Amy and Diane uranium leases. *Qld Dep. Min.*, 54/3250.
CARRUTHERS, D. S., 1954b.—Carol uranium lease. *Ibid.*, 54/2934.
CARRUTHERS, D. S., 1954c.—Clot uranium lease. *Ibid.*, 54/3326.
CARRUTHERS, D. S., 1954d.—Coloured Rocks uranium lease. *Ibid.*, 54/3134.
CARRUTHERS, D. S., 1954e.—Diamond drilling, Tinboll leases. *Geol. Surv. Qld.*
CARRUTHERS, D. S., 1954f.—Diamond drill core from Gold Mines of Australia Tinboll leases. *Ibid.*
CARRUTHERS, D. S., 1954g.—Diamond drill core from Midnight uranium lease. *Ibid.*
CARRUTHERS, D. S., 1954h.—Diamond drilling at the Mary Kathleen uranium deposit. *Ibid.*
CARRUTHERS, D. S., 1954i.—Doris Norelle uranium lease. *Qld Dep. Min.*, 54/3340.
CARRUTHERS, D. S., 1954j.—Embla Ridge Nos. 1-5 uranium leases. *Ibid.*, 54/588.
CARRUTHERS, D. S., 1954k.—Gorge group of uranium leases. *Ibid.*, 54/2530.
CARRUTHERS, D. S., 1954l.—Hobby No. 2, Verpat and Dodge-Loane uranium leases. *Geol. Surv. Qld.*
CARRUTHERS, D. S., 1954m.—Janet Maude - Mount Harold group of uranium leases. *Qld Dep. Min.*, 54/249.
CARRUTHERS, D. S., 1954n.—Kironga - Black Reef group of leases. *Geol. Surv. Qld.*
CARRUTHERS, D. S., 1954o.—Millicent and Martha - Yvonne Theresa uranium leases. *Ibid.*
CARRUTHERS, D. S., 1954p.—Milo Nos. 1-3 uranium leases. *Ibid.*
CARRUTHERS, D. S., 1954q.—Morning Star No. 1 and No. 2. uranium leases. *Ibid.*
CARRUTHERS, D. S., 1954r.—Mount Spring - Mount Rover group of uranium leases. *Ibid.*
CARRUTHERS, D. S., 1954s.—Prize uranium claim. *Qld Dep. Min.*, 54/3144.

CARRUTHERS, D. S., 1954t.—Robert Heg uranium lease. *Geol. Surv. Qld.*
CARRUTHERS, D. S., 1954u.—Six Kangaroos and Comfort uranium leases. *Qld Dep. Min.*, 54/2515 and 54/2806.
CARRUTHERS, D. S., 1954v.—Southern, Batman and Duke group of uranium leases. *Ibid.*, 54/2480.
CARRUTHERS, D. S., 1954w.—Three Inkspots group. *Ibid.*, 54/3433.
CARRUTHERS, D. S., 1954x.—Underground workings, Mothers Day No. 3, Spear Creek area. *Geol. Surv. Qld.*
CARRUTHERS, D. S., 1954y.—Why Not, Gumbardo uranium leases. *Qld Dep. Min.*, 54/3224.
CARTER, E. K., 1955a.—Occurrences of beryl, Mt. Isa district. *Bur. Min. Resour. Aust. Rec.* 1955/70.
CARTER, E. K., 1955b.—Radioactive occurrences, Cloncurry Mineral Field, Queensland. *Ibid.*, 1955/26.
CARTER, E. K., 1955c.—Supplementary report on radioactive occurrences, Cloncurry Mineral Field, Queensland. *Ibid.*, 1955/111.
CARTER, E. K., 1955d.—The Precambrian of north-western Queensland. *Ibid.*, 1955/74.
CARTER, E. K., 1956.—Review of stratigraphic nomenclature for the Precambian of north-western Queensland. *Ibid.*, 1956/58.
CARTER, E. K., 1957.—The Precambrian orogenic belt of North-western Queensland. *Ibid.*, 1957/1.
CARTER, E. K., 1959.—Kohinoor copper deposit, Cloncurry Mineral Field, Queensland. *Ibid.*, 1959/155.
CARTER, S. R., 1950.—Mount Isa district (76.5 square miles). *Mount Isa Mines Ltd.*
CASEY, J. N., DOW, D., REYNOLDS, M. A., PRITCHARD, P. W., VINE, R. R., and PATEN, R., 1960.—The geology of the Boulia area, western Queensland. *Bur. Min. Resour. Aust. Rec.*, 1960/12.
CLARK, A. B., 1956.—Preliminary exploration activities on Rita, Buffer and Rary, M.K.U. area. *Rio Tinto Australian Exploration Pty. Ltd*, 4/1956.
CLARKE, G. F., 1955.—Report on radiometric bore logging in the Mount Isa - Cloncurry district for the Geological Survey of Queensland. *Bur. Min. Resour. Aust. Rec.*, 1955/122.
CONNAH, T. H., 1938a.—Examination of core from No. 1 borehole, Trekelano. *Geol. Surv. Qld.*
CONNAH, T. H., 1938b.—Examination of core from No. 3 borehole, Trekelano. *Ibid.*
CONNAH, T. H., 1938c.—Cores from Trekelano. *Ibid.*
COATS, R., 1958.—Observations of regional geology, Mary Kathleen area, Authority to Prospect No. 101M. *Rio Tinto Australian Exploration Pty Ltd.*
CORDWELL, K. S., and WILSON, G. I., 1960.—Geological report on M.L. 5364—Authority to Prospect 70M, Mount Isa. *Mining Corporation (Aust.) N.L.*
CRABB, D. M., 1957.—Pisa Authority to Prospect No. 88M., geochemical investigation, Mt. Leviathan hematites. *Mount Isa Mines Ltd.*
CRESPIN, I., and DICKINS, J. M., 1955.—Fossiliferous rocks from the Cloncurry district, Queensland. *Bur. Min. Resour. Aust. Rec.*, 1955/13.

DALLWITZ, W. B., 1953.—Petrographic report on rock specimens from the Soldiers Cap area, Cloncurry district. *Bur. Min. Resour. Aust. Rec.*, 1953/83.
DEBNAM, A. H., 1953.—Geochemical prospecting at Mount Isa. *Bur. Min. Resour. Aust. Rec.*, 1953/90.
DENMEAD, A. K., 1937a.—Referee Mine, Kajabbi. *Geol. Surv. Qld.*
DENMEAD, A. K., 1937b.—Biotite vein at Mica Creek. *Ibid.*
DENMEAD, A. K., 1940a.—Trekelano copper mine. *Ibid.*
DENMEAD, A. K., 1940b.—Trekelano-O'Grady's workings. *Ibid.*
DE VRIES, H., 1958.—Redtree area, Authority to Prospect No. 122M, progress report No. 2. *Mount Isa Mines Ltd.*
DE VRIES, H., 1959.—Final report, Authority to Prospect No. 122M, Redtree drilling. *Ibid.*
DIXON, L. H., 1956.—Reconnaissance geology, Gulf of Carpentaria. A progress report. *Frome-Broken Hill Pty Ltd, Rep.*, 5100 G.3.
DUNSTAN, B., 1919.—Mt. Oxide copper mine. *Geol Surv. Qld.*

GIBSON, C. G., no date.—A report on the mining properties of the Hampden- - Cloncurry Copper Mines Ltd in the Cloncurry district, north Queensland. *Hampden - Cloncurry Copper Mines Ltd.*
GLASSON, K. R., 1954a.—Concise report of Broken Horseshoe lease No. 4420. *Mineral Ventures N.L.*
GLASSON, K. R., 1954b.—Report on Mineral Ventures N.L. up to 21/11/54. *Ibid.*
GLASSON, K. R., 1954c.—Report No. 2, Mount Isa area. *Ibid.*

437

GLASSON, K. R., 1955a.—Mount Isa uranium report No. 4. *Ibid.*
GLASSON, K. R., 1955b.—Mount Isa report No. 6. *Ibid.*
GLASSON, K. R., 1955c.—Preliminary report, Armstrong North lease, No. 4799. *Mining and Prospecting Services Pty Ltd.*
GUSTAFSON, J. K., 1938.—Report on Mt. Oxide and Orphan copper mines, Cloncurry district. Unpubl. company report held by *Geol. Surv. Qld.*

HANEY, T., 1955.—Mount Cobalt. *Mount Isa Mines Ltd.*
HANEY, T., 1957a.—Native Companion. *Ibid.*
HANEY, T. H., 1957b.—Beryl Authority to Prospect No. 90M, final report *Ibid.*
HANEY, T. H., 1957c.—Lawlor Authority to Prospect, Mount McCabe, final report. *Ibid.*
HEALY, P., 1951a.—Kings Cross copper mine. *Geol. Surv. Qld.*
HEALY, P., 1951b.—New Bernborough, M.L. 3865. *Ibid.*
HILL, A. and STEWART, —, 1906.—Report on the properties of the Queensland Exploration Co. Ltd. (see Ball, L. C., 1908, p. 8).
HONMAN, C. S., 1938.—The Ballara area, Cloncurry district (with portions by M. L. Wade). *Aer. Surv. N. Aust. Qld Rep.* 21 (unpubl.).
HORVATH, J., 1952.—Are there possibilities for a geophysical survey in the Cloncurry district? *Bur. Min. Resour. Aust. Rec.*, 1952/6.
HORVATH, J., 1955.—The comparison of geochemical and geophysical results at the Labour Victory mine, near Selwyn. *Ibid.*, 1955/82.
HORVATH, J., and LANGRON, W. J., 1956a.—Geophysical survey of the Northern Prospect, (Tombstone Hill area), Mount Isa, Queensland. *Ibid.*, 1956/118.
HORVATH, J., and LANGRON, W. J., 1956b.—Geophysical test survey at Greta and Corella prospects, Cloncurry Mineral Field, Queensland. *Ibid.*, 1956/151.
HORVATH, J., and TATE, K. H., 1954.—Geophysical survey at the Labour Victory mine, Kongula, near Selwyn. *Ibid.*, 1954/2.

IVANAC, J. F., 1953a.—Investigation for lead, zinc and copper deposits — interim reports covering the period July 1st, 1953, to September 30th, 1953. *National Lead Company. Titanium Alloy Manufacturing Division.*
IVANAC, J. F., 1953b.—*Idem* for period October 1st, 1953, to December 31st, 1953. *Ibid.*
IVANAC, J. F., 1954a.—*Idem* for period January 1st, 1954, to March 31st, 1954. *Ibid.*
IVANAC, J. F., 1954b.—*Idem* for period April 1st, 1954, to June 30th, 1954. *Ibid.*
IVANAC, J. F., 1954c.—*Idem* for period July 1st, 1954, to September 30th, 1954. *Ibid.*
IVANAC, J. F., 1954d.—*Idem* for period October 1st, 1954, to December 31st, 1954. *Ibid.*

JACK, R. H., 1954.—Spear Creek and Stone Axe Authority to Prospect. *Mount Isa Mines Ltd.*
JENSEN, H. E., 1958.—Great Central copper deposit, Ballara, Authority to Prospect No. 84M. *Rio Tinto Australian Exploration Pty Ltd.*
JENSEN, H. I., 1941.—Report on portion of north-western Queensland adjacent to Northern Territory border. *Aer. Surv. N. Aust., Qld Rep.* 47 (unpubl.).
JONES, W. R., 1957.—Authority to Prospect 70M, Mount Isa progress reports. *Metals Exploration N.L.*

KEYSER, F. de, 1958.—Geology and mineral deposits in Paradise Creek area, north-western Queensland. *Bur. Min. Resour. Aust. Rec.*, 1958/100.
KNIGHT, C. L., 1938a.—Examination of core from No. 1 borehole, Trekelano. *Geol. Surv. Qld.*
KNIGHT, C. L., 1938b.—Examination of core from No. 3 borehole, Trekelano. *Ibid.*
KNIGHT, C. L., 1953a.—Cloncurry investigation, Queensland — Final Report. *Enterprise Exploration Co. Pty Ltd.*
KNIGHT, C. L., 1953b.—The Dugald River prospect. *Ibid.*
KNIGHT, C. L., 1955.—Progress report, Malbon prospecting area. *Mount Isa Mines Ltd.*
KNIGHT, C. L., and ZACHENKO, V., 1948.—Dugald River prospect. *Ibid.*
KRIEWALDT, M., 1957.—Three Threes authority to prospect No. 81M. Final report. *Mount Isa Mines Ltd Tech. Rep.* 9, 9.

LANGRON, W. J., 1956.—Geophysical survey of the Southern Prospect (Mount Novit area), Mount Isa, Queensland. *Bur. Min. Resour. Aust. Rec.*, 1956/119.
LESLIE, R. B., 1956.—Summary report of activities to 30/11/1956, Authority to Prospect No. 29M. *Enterprise Exploration Co. Pty Ltd.*
LESLIE, R. B., 1957a.—Summary report of activities to 31/5/1957, Authority to Prospect No. 29M. *Ibid.*

LESLIE, R. B., 1957b.—Final report, Authority to Prospect No. 29M Area No. 3, Mount Oxide. *Ibid.*

LESLIE, R. B., 1957c.—Final report, Selwyn hematites, Authority to Prospect No. 29M. *Ibid.*

LESLIE, R. B., 1957d.—Supplementary report, Dugald River, Authority to Prospect No. 29M area 1. *Ibid.*

LESLIE, R. B., 1958.—Final report, Mt. Dore portion of the Selwyn area, North Western Queensland. *Ibid.*

LEVINGSTON, K. R., 1954.—Uranium occurrences, Mount Isa - Cloncurry district. *Geol. Surv. Qld.*

LEVINGSTON, K. R., 1955a.—Bill's Folly uranium lease. *Ibid.*

LEVINGSTON, K. R., 1955b.—Elaine Dorothy uranium lease. *Ibid.*

LEVINGSTON, K. R., 1955c.—Helafels and Sierra Rada uranium leases. *Qld Dep. Min.*, 55/1641-2.

LEVINGSTON, K. R., 1955d.—Lady Rachel uranium lease. *Geol. Surv. Qld.*

LEVINGSTON, K. R., 1955e.—Mariposa uranium lease. *Ibid.*

LEVINGSTON, K. R., 1955f.—Mary Lou uranium lease. *Ibid.*

LEVINGSTON, K. R., 1955g.—Mount Dore uranium lease. *Ibid.*

LEVINGSTON, K. R., 1955h.—Percol Creek uranium lease. *Ibid.*

LEVINGSTON, K. R., 1955i.—Present state of developments in Cloncurry - Mount Isa uranium field. *Ibid.*

LEVINGSTON, K. R., 1955j.—Rich John uranium lease. *Ibid.*

LEVINGSTON, K. R., 1955k.—The Springs uranium lease. *Ibid.*

MATHESON, R. S., 1959a.—Cloncurry district Authority to Prospect Nos. 128M, 141M, progress report to 31/3/59. *Rio Tinto Australian Exploration Pty Ltd.*

MATHESON, R. S., 1959b.—Cloncurry district Authority to Prospect Nos. 128M, 141M, progress report to 30/9/59. *Ibid.*

McALISTER, L. T., 1956a.—Biotite Authority to Prospect, progress report No. 1. *Mount Isa Mines Ltd.*

McALISTER, L. T., 1958.—Final report, Quartzite Authority to Prospect No. 27M. *Ibid.*

McASKILL, A. F., 1939.—Suggested establishment of a central treatment plant for copper ores, Cloncurry. Report to Queensland Minister for Mines.

McBRIDE, B., 1958.—Final report, Authority to Prospect No. 94M, Mount Isa area. *United Uranium N.L.*

McCARTHY, E., and PINNEY, R., 1959a.—Geophysical surveys — North Mount Isa area. *Rio Tinto Australian Exploration Pty Ltd.*

McCARTHY, E., and PINNEY, R., 1959b.—Review of geophysical surveys 1959 field season. *Ibid.*

McEWAN, R. C., 1956.—Biotite Authority to Prospect, progress report No. 2. *Mount Isa Mines Ltd.*

McKEAGUE, E. J., and HOCKIN, H. W., 1957.—Primary uranium mineralization of the Counter lease, Queensland. *Univ. Qld, Dep. of Min. Engng.*

MILES, K. R., 1955.—Summary final report. Anderson's Lode — Counter lease Mt. Isa, Queensland. *Australasian Oil Exploration Ltd.*

MINERAL VENTURES NO LIABILITY, 1954a.—Mount Isa uranium report No. 3.

MINERAL VENTURES NO LIABILITY, 1954b.—Petrological laboratory report No. 6/55.

MINERAL VENTURES NO LIABILITY, 1954c.—Petrological laboratory report No. 78/54.

MINERAL VENTURES NO LIABILITY, 1954d.—Radiometric assay results and remarks.

MINERAL VENTURES NO LIABILITY, 1955a.—Mount Isa-Cloncurry report No. 5.

MINERAL VENTURES NO LIABILITY, 1955b.—Petrological report sample No. U4/15380.

MINERAL VENTURES NO LIABILITY, 1955c.—Report Olive lease, ML4711.

MINERAL VENTURES NO LIABILITY, 1955d.—Report to Mining Warden at Cloncurry.

MINING AND PROSPECTING SERVICES PTY LTD, 1955a.—Preliminary report Armstrong North lease, No. 4799.

MINING AND PROSPECTING SERVICES PTY LTD, 1955b.—Report on Skal lease, Mount Isa.

MORRIS, C. W., 1955.—Pumpkin Gully area. Authority to Prospect No. 7M. *Davis Contractors Pty Ltd.*

MORTON, C. C., 1954.—Mary Kathleen leases, Mount Isa. *Geol. Surv. Qld.*

MUCENIEKAS, E., 1958.—Geochemical report on Canso area 5, Dajarra Authority to Prospect No. 97M. *Rio Tinto Australian Exploration Pty Ltd.*

MUCENIEKAS, E., 1959.—Report on geochemical investigations during 1959. *Ibid.*

MURRAY, W. J., 1953a.—Mount Isa district (76.5 square miles). *Mount Isa Mines Ltd.*

MURRAY, W. J., 1953b.—Stone Axe area. *Ibid.*

MURRAY, W. J., 1954a.—Geochemical survey. Lawn Hill authority to prospect. *Ibid.*

MURRAY, W. J., 1954b.—Lawn Hill authority to prospect. *Ibid.*

MURRAY, W. J., 1959.—Biotite area, final report, Authority to Prospect No. 32M. *Mount Isa Mines Ltd.*

NOAKES, L. C., 1955.—Ore reserves at Mount Isa, Queensland. *Bur. Min. Resour. Aust. Rec.*, 1955/59.

NOAKES, L. C., and CASEY, J. N., 1953.—Underground water on Morstone station, north-west Queensland. *Ibid.*, 1953/78.

ÖPIK, A. A., 1948a.—Preliminary report on Cambrian fossils from the Barkly Tableland and adjacent areas in Queensland and Northern Territory. *Bur. Min. Resour. Aust. Rec.*, 1948/73.

ÖPIK, A. A., 1948b.—Re-examination of fossils of locality B68 (20.4 miles west of Dajarra) with a note on the palaeogeography of the Middle Cambrian. *Ibid.*, 1948/84.

ÖPIK, A. A., 1951.—Progress in the study of Cambrian fossils from the Northern Territory and Northern Queensland. *Ibid.*, 1951/26.

OSTLE, D., 1955a.—Report on an inspection of the Mary Kathleen leases. Mount Isa district, Queensland. *Aust. Atomic Energy Commission.*

OSTLE, D., 1955b.—Report on uranium prospects in the Mount Isa-Cloncurry district of Queensland. *Bur. Min. Resour. Aust. Rec.*, 1955/113.

PARKINSON, W. D., 1956.—Airborne scintillograph test survey in the Cloncurry-Mount Isa district, Queensland, by DC3 aircraft. *Bur. Min. Resour. Rec.*, 1956/109.

PEARSON, S. E., no date.—The prospector of Argylla.

PENNEBAKER, E. N., 1955.—Final report on the area held under authority to prospect, Cloncurry Gold and Mineral Field, Queensland, Australia. *Titanium Alloys Manufacturing Co. Pty Ltd.*

PITMAN, D., 1954a.—Pamela lease, No. 4452, *Mineral Ventures* N.L.

PITMAN, D., 1954b.—Preliminary report on Elaine Dorothy lease, No. 4569. *Ibid.*

PITMAN, D., 1954c.—Preliminary report on Janelle lease, No. 4418. *Ibid.*

PITMAN, D., 1954d.—Preliminary report on leases. *Ibid.*

QUIRK, R., 1953.—Investigation for lead-zinc and copper deposits. Interim Report covering the period March 31st 1953 to June 30th 1953. *National Lead Company - Titanium Alloys Manufacturing Division.*

REED, W. G., 1954.—Reconnaissance survey of the Carpentaria area. *Frome-Broken Hill Pty Ltd, Rep.*, 5100-G-1.

RHEINHOLD, J., 1957.—Biotite lease — Authority to prospect. *Mount Isa Mines Technical Rep.*

RIDGWAY, J. E., 1960.—Anderson's lode, Mount Isa, geological report, Authority to Prospect No. 136M. *Queensland Mines Ltd.*

RIO TINTO AUSTRALIAN EXPLORATION PTY LTD, 1959.—Cloncurry-Mount Isa district Canso radioactive anomaly inspection sheets.

RIO TINTO AUSTRALIAN EXPLORATION PTY LTD, 1960.—Cloncurry-Mount Isa Canso electro-magnetic inspection sheets. Authority to Prospect No. 101M.

RISELY, B. G., 1957a.—Progress report, Duchess area, Authority to Prospect No. 92M. *Enterprise Exploration Co. Pty. Ltd.*

RISELY, B. G., 1957b.—Final report, Dobbyn area. *Ibid.*

ROWELL, K. A., 1960.—Constance Range, report of activities to 30/9/1960, Authority to Prospect No. 151M. *Broken Hill Proprietary Co Ltd.*

SAINT-SMITH, E. C., 1918.—Mount. Leviathan iron ore. *Geol. Surv. Qld.*

SAINT-SMITH, E. C., 1921.—Silver Ridge lode, near Mount Cuthbert. *Ibid.*

SAINT-SMITH, E. C., 1925a.—Mount Isa silver-lead-zinc field, Lena group. *Ibid.*

SAINT-SMITH, E. C., 1925b.—Notes on the Lawn Hill silver-lead field, Burketown district. *Ibid.*

SAINT-SMITH, E. C., 1925c.—Out-on-her-own, Mount Isa, carbonate ore. *Ibid.*

SEARL, R. A., 1952a.—Geology of the Western Syncline, Kuridala. *Bur. Min. Resour. Aust. Rec.*, 1952/38.

SEARL, R. A., 1952b.—The geology of the Mount Elliott copper mine, Selwyn. *Ibid.*, 1952/27.

SEARL, R. A., 1952c.—The geology of the Crusader copper mine, Dobbyn. *Ibid.*, 1952/41.

SEARL, R. A., 1956.—Notes on the Elaine Dorothy prospect, M.K.U. area. *Rio Tinto Australian Exploration Pty Ltd*, 3/1956.

SEARL, R. A., 1959a.—Cloncurry district, Authority to Prospect Nos. 128M, 141M, progress report to 30/9/1959. *Ibid.*

SEARL, R. A., 1959b.—Review of geological activities, October 1958 - November 1959. *Ibid.*

SEARL, R. A., and FRASER, R. B., 1956a.—Geological investigations Mary Kathleen area. *Ibid.*, 2/1956.

Australia. *Ibid.*, 8/1958.

SEARL, R. A., and MCCARTHY, E., 1958.—Use of helicopter in uranium prospecting in

SEARL, R. A., and FRASER, R. B., 1956b.—Investigation of limestone deposits, Mary Kathleen area. *Ibid.*, 5/1956.

SEARLE, P. G., 1958.—Duchess — Mount Hope area, Authority to Prospect No. 92M, area 3, Cloncurry district. *Enterprise Exploration Co. Pty Ltd.*

SEFTON, I. M., 1958.—Geochemical surveys, Mount Dore area. *Enterprise Exploration Co. Pty Ltd.*

SHEPHERD, J. H., 1957.—Report on Authority to Prospect No. 94M. Mount Isa area. *United Uranium N.L.*

SHEPHERD, S. R. L., 1928.—Notes and maps prepared as a result of a geological traverse from the Templeton River through Mount Isa, West Leichhardt and Argylla to Cloncurry, made in 1927, with petrological descriptions by A. K. Denmead. *Geol. Surv. Qld.*

SHEPHERD, S. R. L., 1932.—Preliminary notes on ore reserves, Cloncurry copper mines. *Ibid.*

SHEPHERD, S. R. L., 1933a.—Carbonate ore reserves, Cloncurry district. *Ibid.*

SHEPHERD, S. R. L., 1933b.—May Downs prospecting. *Ibid.*

SHEPHERD, S. R. L., 1933c.—Top Camp, Cloncurry district. *Ibid.*

SHEPHERD, S. R. L., 1933d.—Top Camp exploration workings. *Ibid.*

SHEPHERD, S. R. L., 1934a.—Notes on mica deposit near Mount Isa. *Ibid.*

SHEPHERD, S. R. L., 1934b.—Preliminary notes on the Gilded Rose area. *Ibid.*

SHEPHERD, S. R. L., 1935a.—Copper-gold-lead prospect, Mount Isa rifle range. *Ibid.*

SHEPHERD, S. R. L., 1935b.—Moonlight gold-copper dtposit, Mount Merlin. *Ibid.*

SHEPHERD, S. R. L., 1936.—Top Camp alluvial gold. Proposed drilling. *Ibid.*

SHEPHERD, S. R. L., 1938.—Mount Isa town water supply. *Ibid.*

SHEPHERD, S. R. L., 1939a.—*Cobalt, Cloncurry. Ibid.*

SHEPHERD, S. R. L., 1939b.—Investigation of copper reserves, Kajabbi-Dobbyn area, Cloncurry Mineral Field. *Ibid.*

SHEPHERD, S. R. L., 1941.—Short notes on some Cloncurry mines. *Ibid.*

SHEPHERD, S. R. L., 1942.—Hampden Consols, Mount Elliott Ltd. *Ibid.*

SHEPHERD, S. R. L., 1943a.—Bore site for water supply at Mount Isa sanitary depot. *Ibid.*

SHEPHERD, S. R. L., 1943b.—Cloncurry town water supply — selection of bore site. *Ibid.*

SHEPHERD, S. R. L., 1943c.—Dajarra water supply. *Ibid.*

SHEPHERD, S. R. L., 1943d.— Mica occurrence, Naraku siding. *Ibid.*

SHEPHERD, S. R. L., 1943e.—Water supply in Chatsworth station, via Selwyn. *Ibid.*

SHEPHERD, S. R. L., 1944.—Notes on selection for bore sites for water on Chatsworth, Burnholme and Hillingdon, 30 miles south of Selwyn. *Ibid.*

SMITH, J. W., and ROBERTS, H. G., 1960.—Explanatory notes to the Mount Drummond 4-mile area, Northern Territory. *Bur. Min. Resour. Aust., Rec. Unpubl.*

SOLOMON, M., 1958.—Reconnaissance geological mapping of the area west of Dajarra, Authority to Prospect No. 97M. *Rio Tinto Australian Pty Ltd.*

STURMFELS, E. K., 1952.—Geology of the surroundings of the Dugald River lead-zinc prospect. Preliminary report. *Enterprise Exploration Co. Pty Ltd.*

SULLIVAN, C. J., 1952a.—The Mount Elliott mine, Selwyn. *Bur. Min. Resour. Aust. Rec.* 1952/32.

SULLIVAN, C. J., 1952b.—Possibility of discovery of new lead-zinc-copper deposits, Mount Isa. *Ibid.*, 1952/48.

SULLIVAN, C. J., and DUTTON, A. H., 1952.—The Great Australia Mine. *Broken Hill South Ltd Field Investigation Department.*

SULLIVAN, C. J., and MATHESON, R. S., 1950.—The Kuridala copper deposits, Cloncurry district. *Bur. Min Resour. Aust. Rec.*, 1950/53.

SUMMERS, K. W., 1954.—Preliminary investigations, Mount Isa area. *Mineral Ventures No Liability.*

SUMMERS, K. W., 1955a.—Crocodile lease, Mount Isa. *Ibid.*

SUMMERS, K. W., 1955b.—Mount Inter mineral lease. *Ibid.*

SYVRET, J. N., 1957.—Report of Redtree mineralization (Westmoreland). *Mount Isa Mines Ltd.*

TOWNLEY, K. A., BENNETT, E. M., and GATES, D. J., 1952.—Preliminary report on the Precambrian rocks of the Lawn Hill, Camooweal and Dobbyn sheets. *Bur. Min. Resour. Aust. Rec.*, 1952/47.

WALKER, K. F. H., 1947.—Reconnaissance report Mount Oxide copper mine. *Broken Hill South Ltd Field Investigation Department.*

WALKER, K. F. H., 1954.—Report on the investigation of the Mount Oxide copper mines, Cloncurry district. *Ibid.*

WALKER, K. R., 1956.—An attempt to distinguish between calc-silicate and basic igneous rocks in the Mary Kathleen mine area, north-west Queensland. *Bur. Min. Resour. Aust. Rec.*, 1956/107.

WALKER, K. R., 1958.—A study of the basic igneous rocks of the Lower Proterozoic of north-western Queensland, with special reference to their metamorphism and metasomatism in relation to the geological sequence of events. *Unpubl. Thesis, Aust. Nat. Univ.*

WALKER, K. R., 1960.—The geology of the Duchess-Trekelano area, north-western Queensland. *Bur. Min. Resour. Aust. Rec.*, 1960/41.

WALPOLE, B. P., 1957.—Report on inspection of uranium occurrences and airborne radiometric anomalies. *Bur. Min. Resour. Aust. Rec.*, 1957/40.

WHITE, M., 1957.—Fossil plants from near Selwyn, Cloncurry district, N.W. Queensland. *Bur. Min. Resour. Aust. Rec.*, 1957/66.

WHITE, W. C., 1957.—Preliminary report on the geology of the Selwyn area of N.W. Queensland. *Bur. Min. Resour. Aust. Rec.*, 1957/94.

WHITTLE, A. W. G., 1954.—Radioactive rocks from the Mount Isa-Cloncurry district. *S. Aust. Dep. Min. petrol. Lab. Rep.*, 49/54.

WHITTLE, A. W. G., 1955a.—A new borosilicate of the lanthanons. *Ibid., Resour. Devel. Br. Rep.*, 13.

WHITTLE, A. W. G., 1955b.—Preliminary report on the mineralogy of the Mary Kathleen deposit. *Ibid.*, R 4001.

APPENDIX I

PETROGRAPHICAL DESCRIPTIONS OF SELECTED ROCK SPECIMENS

By K. R. WALKER.

SPECIMENS FROM THE LEICHHARDT METAMORPHICS

Several varieties of acid volcanics with a fairly wide range of composition occur in the Leichhardt Metamorphics. They are divisible into four broad groups, under which they are described: (1) Those containing roughly equal amounts of potash feldspar, plagioclase and quartz, with ferromagnesian minerals absent, or subordinate; (2) those with plagioclase and quartz more abundant than potash feldspar, and ferromagnesian minerals absent or subordinate; (3) those in which plagioclase is dominant, ferromagnesian minerals are fairly abundant, and some quartz is present, but potash feldspar is rare; (4) tuffs.

(1) *Specimen nos:* R7212, R7213, R7214.*

Thin section nos: 2379, 2380, 2381.

Localities: Lat. 20°36'40" S, long. 139°52'40" E.
Lat. 20°41'35" S, long. 139°54'40" E.

Hand specimens: The porphyritic acid metalavas are pink, cream, or light grey, and commonly show flow-banding, and quartz grains which protrude above the weathered rock surfaces. The lavas break with a conchoidal fracture and reveal quartz and feldspar phenocrysts (2 mm.) set in a buff-grey or dark grey aphanitic groundmass.

Thin sections: The thin sections are porphyritic; phenocrysts of plagioclase, potash feldspar, and quartz, in roughly equal numbers, measure from 0.5 to 3 mm. Grain margins of euhedral phenocrysts are sharp, but in intensely altered rocks the margins of quartz may be nibbled and rounded by corrosion. Fractured grains occur in some thin sections; those in the groundmass are similar to shards in a tuffaceous acid volcanic. The groundmass shows incipient recrystallization, probably from a glassy base, or is fine-grained and granoblastic. It cannot always be completely resolved, but much of it consists of granular quartz. Grain-size increases with degree of alteration and grains range up to 0.2 mm. Flow structures are best preserved in the least altered rocks. The thin sections consist mainly of small quartz and feldspar grains in roughly equal amounts and some sections contain a few large biotite, chlorite, or sericite flakes and some calcite and opaque iron mineral.

Most phenocrysts of potash feldspar are anhedral, and measure from 0.5 to 3 mm., with some phenocrysts up to 8 mm.; but a few are euhedral. Potash feldspar, including microcline, also forms part of the fine-grained groundmass. It either shows twinning typical of microcline or can be recognized by its low refractive index and negative 2V.

Plagioclase phenocrysts measure from 0.5 to 1mm. across, and are commonly euhedral or subhedral. They are twinned mostly according to the albite law, but a few penetration twins may be seen, particularly in glomeroporphyritic patches of euhedral crystals. The plagioclase ranges from albite to albite-oligoclase in the phenocrysts, and is generally albite in the groundmass. Plagioclase has a positive optical sign and a refractive index generally less than, or equal to, that of Canada balsam. Alteration of plagioclase has resulted in light brown clouding or flecking with sericite flakes.

---

* Specimens whose numbers are prefixed by R are in the Bureau of Mineral Resources Museum, and those marked J are in the Australian National University, Department of Geophysics collection. Some of the descriptions given include observations on thin sections other than those of the rock or rocks listed.

Quartz phenocrysts measure between 0.5 and 1 mm., are commonly cracked and corroded, and show undulose extinction. Quartz is also an important mineral in the groundmass. Veins of mosaic quartz cut some of the more altered rocks.

Micaceous minerals where present are represented by a few sericite, and less commonly biotite or chlorite, flakes that contain inclusions of groundmass minerals, which were probably enclosed during growth. Chlorite flakes are rare. White mica flakes measure up to 0.3 mm. Accessory minerals are calcite, sphene, and opaque iron mineral.

The rocks are best described as *meta-rhyolite.* However, phenocrystic microcline is an unusual form of potash feldspar in a rhyolite. Moreover, as ferromagnesian minerals are rare or absent, the rocks are very acid types in which microcline was apparently the stable feldspar. The rocks have been altered mainly by thermal metamorphism.

(2) *Specimen nos:* R3268, R3266, R3267.

Thin section nos: 2386, 2387, 2388.

Localities: Between lat. 19°59′10″S, long. 139°55′E, and lat. 19°59′40″S, long. 139° 58′10″E.

Hand specimens: The hand specimens are medium grey and contain facets of pink feldspar phenocrysts which measure up to 3 mm. Rather smaller clear quartz phenocrysts are also present. The rocks break with an uneven fracture and reveal an aphanitic groundmass. They generally weather rusty-brown or buff-pink, and where they are slightly sheared they decay and shed their phenocrysts.

Thin sections: Thin sections are characterized by the abundance of plagioclase phenocrysts, almost to the exclusion of potash feldspar. Other phenocrysts are of quartz. Chlorite flakes form glomeroporphyritic patches. Phenocrysts are mostly euhedral and subhedral, range from 0.5 to 3mm., and occur in a fine-grained granoblastic groundmass. Quartz phenocrysts are corroded and commonly cracked. The groundmass consists mostly of small quartz and feldspar grains and contains biotite, chlorite, and sericite flakes, and also some opaque iron mineral. The grainsize of the groundmass is coarser in the most intensely altered rocks; but the groundmass of some rocks shows only incipient recrystallization, and is extremely fine-grained and not in every thin section completely resolvable.

Plagioclase phenocrysts range from 0.5 to 2 mm.; most are twinned according to the albite law, but penetration twins are seen in glomeroporphyritic patches. Some of the euhedral crystals show a rather unusual twinning that forms a checker pattern, not unlike that shown by chessboard albite (Niggli, 1954, p. 86). Most of the plagioclase is albite, but in some of the least-metamorphosed rocks oligoclase-andesine occurs instead.

In one thin section of a rock from between Mount Cuthbert and Oona railway siding, microcline phenocrysts were partly albitized; albite now surrounds irregular patches of microcline that contains delicate cross-hatched twinning, and which probably represents remnants of original phenocrysts. The euhedral outline of relict potash feldspar phenocrysts can be recognized in plane-polarized light; these crystals can be seen under crossed nicols to be partly replaced by the fine-grained groundmass.

Altered plagioclase shows a brown clouding and is flecked with sericite, and this, with chlorite, may be abundant.

Potash feldspar phenocrysts are not common and staining by sodium-cobalti-nitrite (Chayes, 1952, p. 337) did not reveal much potash feldspar occluded in the base of the thin sections examined.

Quartz phenocrysts measure from 0.5 to 2 mm. and most are cracked and strained. They also contain arcuate fractures, filled with trains of minute inclusions. The groundmass in many specimens is not completely resolvable, but much of it consists of granular quartz.

Chlorite is the main dark mineral, but biotite may also be common. The chlorite occurs in groups of criss-cross flakes up to 1mm. across, which may pseudomorph an original ferromagnesian mineral, and in some cases it may result from retrogressive alteration. Trains of biotite flakes on the other hand in the deformed rocks conform to the general lineation of the other mineral grains. The individual biotite flakes are generally less than 0.1 mm. across and are pleochroic from straw-yellow to dark green-brown and show some alteration to chlorite. Hornblende, although only present in small amounts, is common in the more highly metamorphosed rocks.

Accessory minerals are zircon and apatite. Opaque iron mineral forms grains up to 0.5 mm. and is associated with sphene in places, but most of it is finely granular and is evenly distributed throughout the groundmass.

These rocks are probably described best as *metarhyodacites,* as the feldspar appears to be mainly plagioclase and ferromagnesian minerals are rare or absent. As many original textural features are preserved, a fairly strong thermal effect probably accompanied regional metamorphism.

(3) *Specimen nos:* R7219, R7220.
Thin section nos: 2391, 2392, 2393, 2394.
Localities: Lat. 20°25′50″S, long. 139°49′20″E, and between lat. 19°59′10″S, long. 139°55′E, and lat. 19°59′40″S, long. 139°58′10″E.

Hand specimens: The rocks are generally dark grey. They are porphyritic and contain phenocrysts of clear quartz and flesh-coloured feldspar, which measure up to 3 mm. These are enclosed in a dark groundmass which is either aphanitic or fine to medium-grained. In the latter case, biotite, and possibly some other micas, can be recognized between the grains of feldspar and translucent quartz in the groundmass.

Thin sections: The rock is porphyritic; few phenocrysts exceed 2 mm. in size, but those that do measure up to 4 mm. are euhedral. The phenocrysts are mostly plagioclase, less commonly quartz, and rarely potash feldspar. Biotite is the main dark mineral; it forms groups of criss-cross flakes from 0.5 to 2 mm. across. The groundmass of some thin sections is too fine to be resolved. It ranges in size from finely granoblastic quartz and feldspar grains averaging 0.1 mm. diameter to a groundmass in which incipiently recrystallized quartz can be recognised; the coarser groundmass is found in the most highly altered rocks. Small feldspar laths are preserved in the groundmass of some rocks. Other constituents in the recrystallized groundmass are biotite, sericite, chlorite, and opaque iron mineral, and rarely sphene, apatite, zircon, and hornblende in the most altered rocks. In one rock sericite flakes replace plagioclase and form up to half of the groundmass. Epidote and calcite occur in some sheared rocks, particularly along cracks or fissures. In some of the sheared rocks, granular quartz tends to accumulate at the ends of phenocrysts so that they appear to conform to the structural trend of the other mineral grains.

Plagioclase phenocrysts measure up to 5 mm. The composition ranges from albite to oligoclase-andesine; albite is quite abundant and crystals containing simple albite twins are commonest. However, both penetration and other complex twins also occur. An unusual twinning similar to chessboard albite characterizes some euhedral crystals. The alteration of plagioclase resulted mainly in brown clouding, and most grains are flecked with small sericite flakes. In sheared rocks calcite is also an alteration product, and the development of biotite, chlorite, epidote, or amphibole along cleavages is fairly common.

Potash feldspar, on the other hand, is not abundant; it is represented by a few phenocrysts or relict patches in albitized grains. All the potash feldspar seen is microcline; alteration to sericite is common.

Quartz phenocrysts measure up to 2 mm. and are generally corroded and, therefore, mostly subhedral. Arcuate fractures occur in some grains and the cracks may be filled with small amphibole and calcite grains. Undulose extinction is common. Quartz in the groundmass shows incipient recrystallization or forms granular, unevenly distributed, aggregates.

Bitotite is the main ferromagnesian mineral, and forms groups of criss-cross flakes that are pleochroic from straw-yellow to olive-green. Some of the biotite aggregates possibly pseudomorph hornblende. Individual flakes measure up to 0.4 mm., but most are less than 0.1 mm. Lesser amounts of chlorite and grains of epidote, calcite, and opaque iron mineral are commonly present. These minerals are also found near fractures.

Opaque iron mineral and sphene occur mainly amongst the groups of biotite flakes, and most grains measure between 0.1 and 0.5 mm.

Because these rocks are richer in ferromagnesian minerals and contain less quartz and potash feldspar than the metarhyolites described above, they are considered to be *metadacites*. They are all regionally metamorphosed, but mostly to a low grade, and, therefore, many original characteristics of the rocks are preserved.

(4) *Specimen no.:* R6943.
Thin section no.: 2092.
Locality: Lat. 19°59′20″S, long. 139°56′45″E.

Hand specimen: The rock is dark grey and flinty, and breaks with a conchoidal fracture. It is aphanitic and finely banded, the bands being 1 mm. wide.

Thin section: The thin section examined is composed mainly of microcline, quartz, and minor plagioclase. There is a complete range in mineral fragment sizes from sub-microscopic to 0.5 mm.; nearly all fragments are cuspate. The shards have fractured concave edges and show very little sorting, other than a banded distribution corresponding to bedding. They occur in a turbid base that cannot be completely resolved, but in which centres of incipient silica crystallization, and small mica flakes, can be seen. The bands are of finer and coarser quartz fragments, with sericite and rare biotite flakes. Siliceous and potash feldspar veins cut the thin section and most quartz fragments show strain. Rare pyrite cubes (0.2 mm.) and rock fragments have been observed.

Plagioclase fragments show simple twinning, and cross-hatched twinning is common in microcline. The plagioclase is mostly albite whose refractive index equals that of Canada balsam. Alteration is mainly to sericite. Small patches of chlorite, and evenly distributed fine grains of opaque iron mineral, are fairly common.

The rock is an *acid tuff*.

Specimens from the Argylla Formation

All the thin sections of the various rocks described are porphyritic or porphyroblastic, or both; many are moderately to strongly metasomatized. They include microcline and plagioclase-rich types. The acid volcanics contain quartz, plagioclase, and microcline phenocrysts in various proportions; some lavas contain only two types, or more rarely one type, of phenocryst. Quartz phenocrysts are larger and more abundant in the potash-rich than in the soda-rich lavas, from some of which they are absent. The dark minerals biotite, chlorite, and rarely hornblende, are generally more common in the soda-rich than in the potash-rich rocks.

Specimen nos: R6940, R7224.
Thin section nos: 2089, 2405.
Localities: Lat: 20°41′05″S, long. 139°53′45″E. Lat. 21°15′25″S, long. 139°47′40″E.

Hand specimens: These porphyritic rocks contain pink and red phenocrysts of feldspar that measure from 2 to 10 mm. and, less commonly, up to 20 mm. Quartz phenocrysts average 1mm. and are clear or a distinctive translucent blue. The groundmass ranges from red-brown to dark grey and from aphanitic to very fine-grained. Colour of hand specimen is not indicative of composition; a range of rock types that occurs within small areas of outcrop shows differences in the proportions and sizes of phenocrysts.

Thin sections: The thin sections are porphyritic and contain roughly equal numbers of quartz and microcline phenocrysts, but generally only a few plagioclase phenocrysts. Micro-

cline phenocrysts are anhedral, whereas most of the quartz and plagioclase phenocrysts are subhedral. Some of the quartz crystals show corrosion embayments and many others have been recrystallized and form a mosaic of interlocking grains. The grainsize of most phenocrysts ranges from 0.5 to 1 mm., but many of the microcline phenocrysts are larger and are up to 4 mm. across. The groundmass is granoblastic and consists of roughly equal amounts of feldspar and quartz. Small grains of calcite, hornblende, opaque iron mineral, sphene, apatite, and zircon, and flakes of biotite, chlorite, and sericite occur throughout. Grains in the groundmass average 0.2 mm., but range from extremely fine to fine, and form an even-grained granoblastic base containing microcline, quartz, and plagioclase. Many grains show internal fracturing and have undulose extinction.

The anhedral microcline phenocrysts measure from 2 to 4 mm. and, together with the abundant small microcline grains in the groundmass, show typical gridiron twinning. Inclusions of chlorite and biotite are fairly common, particularly along cleavage traces.

Secondary microcline is represented by fresh veins that cut phenocrysts of primary microcline, and rarely of plagioclase. There are also some large irregular grains, and aggregates of smaller grains, which are fresh and show coarse gridiron twinning. These are probably porphyroblasts developed during metasomatism, because their freshness contrasts with the alteration of the primary microcline—which has a white film (possibly of kaolin) in reflected light.

Plagioclase phenocrysts that range from 0.5 to 1 mm. have numerous albite twin lamellae and show strain. There are other grains with chessboard twinning and still others which contain inclusions of microcline, apparently from the groundmass. The composition, where determined, is albite, and the presence of the inclusions, and the twinning, suggest that some of the plagioclase may have formed by replacement (see Niggli, 1954, p. 86). Turbid brown alteration products mask the plagioclase more than the microcline.

The quartz phenocrysts range from 0.5 to 1 mm., and are commonly transgressed by trains of small inclusions, whose arcuate traces may reflect conchoidal fracturing. Where pre-existing phenocrysts have been reconstituted into a mosaic of interlocking grains the inclusions cut across the margins of the grains in the newly formed mosaic. Undulose extinction is fairly common.

The ferromagnesian minerals are mainly biotite and some chlorite. Where the biotite flakes are fairly abundant in the groundmass they tend to lie parallel; they are 0.1 to 0.3 mm. long. Opaque iron mineral and sphene are associated with biotite, particularly with those flakes which are aligned in biotite-rich bands in the partly deformed rocks. In many of the thin sections, however, the opaque iron mineral grains are dusted throughout.

Microcline is unusual as the primary potash feldspar in acid volcanics: possibly some resulted from a later potash metasomatism — microcline veins cut some fractured phenocrysts. On the other hand, some of the primary microcline has been albitized. As potash feldspar appears to be more abundant than plagioclase, and the presence of quartz indicates that these lavas are fairly acid, they are probably *metarhyolites* which show the effects of both regional metamorphism and subsequent metasomatism.

Specimen nos.: R5703, R5791, R6940, R7229, R7230.
Thin section nos: 2089, 2385, 2389, 2410, 2411.
Localities: Lat. 19°55′50″S, long. 140°00′00″E. Lat. 19°56′S, long. 140°00′00″E. Lat. 20°41′05″S, long. 139°53′45″E. Lat. 20°47′55″S, long. 139°48′50″E.

Hand specimens: The rocks are mostly red-brown to grey-brown, and have a sub-conchoidal fracture. Freshly broken surfaces expose glistening facets of pink or red feldspar phenocrysts up to 3 mm. long, and smaller clear or translucent blue quartz phenocrysts, set in an aphanitic groundmass. Because of differential weathering of the groundmass phenocrysts commonly protrude from the iron-stained weathered surface.

Thin sections: The thin sections are porphyritic and contain plagioclase, quartz, and rarely potash-feldspar phenocrysts. Phenocrysts range in size from 0.5 to 4 mm. across, and

some of those of quartz have corrosion embayments. Some phenocrysts show features similar to chessboard albite (Niggli, 1954, p. 86), or to microcline, or rarely to both, suggesting that some microcline has been albitized. Phenocrysts are set in a groundmass that ranges from extremely fine-grained and not always entirely resolvable, to a fine-grained granoblastic base consisting of grains between 0.05 to 0.2 mm. The groundmass consists mostly of plagioclase and quartz, with lesser amounts of potash feldspar. Other minerals include opaque iron mineral, calcite, biotite, chlorite, sericite, hornblende, sphene, zircon, and apatite.

Plagioclase phenocrysts are euhedral or subhedral and are 0.5 to 6.4 mm. long. Some of the euhedral crystals show simple and complex twinning and some form glomeroporphyritic patches containing penetration twins. Their composition ranges from albite to oligoclase. The other euhedral and anhedral grains are of albite showing chessboard twinning, and therefore may be secondary. Microcline inclusions are common in some of these; the microcline possibly forms relict patches where albitization of the original grain is incomplete. Alteration of plagioclase is shown by turbid brown coloration and by flecking with sericite.

Quartz phenocrysts are generally corroded and range in size from 0.5 to 1 mm. Where crystal margins are not extensively rounded, they are subhedral, and where reconstitution has taken place, a mosaic of interlocking grains commonly replaces the original crystal.

Muscovite, where present, forms colourless or slightly greenish flakes, some of which retain inclusions of groundmass minerals incorporated during growth. In some thin sections, however, micas are almost absent and only small sericite flakes are scattered throughout. Biotite, on the other hand, is widely distributed; other dark minerals include chlorite and rarely hornblende. Biotite flakes range in size up to 0.2 mm. and in deformed rocks are strung out and form parallel threads of flakes.

Calcite grains are extremely abundant in some thin sections, particularly near fractures, and are up to 1 mm. across. In other thin sections calcite is an accessory mineral.

Opaque iron mineral varies in amount and may be banded or evenly distributed throughout as small grains in the groundmass. Sphene is particularly abundant in those rocks rich in calcite.

As the rocks appear to contain mostly plagioclase feldspar, and commonly more ferromagnesian mineral and less quartz than the metarhyolites described above, they are probably *metadacites.* Most of them appear to have been reconstituted, and less commonly deformed, during metamorphism. The effects of metasomatism are evident, but they apparently escaped extensive potash metasomatism and the consequent development of microcline.

Specimen nos: R6941, R7221, R7222.

Thin section nos: 2090, 2396, 2397.

Localities: South of Wimberu Granite in the Argylla Formation; lat. 21°29′15″S, long. 139°43′45″E; lat. 19°37′S, long. 139°47′15″E.

Hand specimens: The rock is dark grey and very fine-grained. It breaks with a semi-conchoidal fracture and reveals small quartz and feldspar phenocrysts which are about 0.5 mm. across. The phenocrysts are set in an aphanitic groundmass.

Thin sections: The thin sections consist mainly of euhedral phenocrysts and angular fragments of quartz, sericitized feldspar, and altered ferromagnesian minerals, in an extremely fine-grained turbid groundmass. The grainsize of phenocrysts ranges up to 2 mm. The thin sections are porphyritic and flow structure around phenocrysts can be seen in plane-polarized light. Corrosion embayments and conchoidal fractures are common in many quartz crystals.

The groundmass is extremely fine grained, and some of it may be cryptocrystalline, as it cannot be completely resolved; many small centres of silica crystallization can be seen and small mica flakes are common. Rarely euhedral zircon crystals and red-brown tourmaline grains occur in the base. The groundmass is fractured by arcuate and irregular cracks, and some thin sections are cut by silica-filled veins.

Quartz phenocrysts range from 0.2 to 2 mm. and most are euhedral. Some are strained, and contain fractures filled with calcite. Apart from the phenocrysts, smaller quartz grains, and possibly occluded silica, occur in the groundmass.

Plagioclase phenocrysts that measure from 0.2 to 1.5 mm. are mostly heavily sericitized and therefore it is difficult to determine their composition. However, they can be identified as plagioclase, and a few relict patches of twinning indicate that some phenocrysts are albite. A faint cross-hatching characteristic of microcline can be recognized in some phenocrysts of a rock from immediately south-west of Butru railway siding; these phenocrysts are optically negative and have a refractive index less than that of Canada balsam.

The original ferromagnesian minerals are altered and pseudomorphed by biotite or chlorite or, in some cases, by a serpentine-like mineral. Patches of these minerals measure from 0.2 to 1.5 mm. across and average about 0.5 mm. Biotite flakes form groups pleochroic from a straw-yellow to green-brown. Chlorite, on the other hand, generally forms individual flakes or patches of flakes which show purple birefringence colours typical of penninite. In the rocks that contain chlorite, chlorite and sericitized feldspar occur in roughly equal amounts. Chlorite has also formed along the cleavage traces of some feldspar phenocrysts.

Epidote, opaque iron minerals, and sphene are mostly associated with groups of mica flakes, and in particular with biotite.

Although it is impracticable to establish the proportion of potash feldspar to plagioclase, the estimation of each from relict grains, and the abundance of quartz, suggest that these rocks may be *dacites,* subjected to a very low grade of metamorphism which has nevertheless been sufficient to mask many of their distinctive features.

Specimen no.: R6942.
Thin section no.: 2091.
Locality: Lat. 21°33′40″S, long. 139°37′20″E.

Hand specimen: The rock is fine-grained and green-grey. Facets of flesh-coloured feldspar (1 mm.) and clear quartz (1 mm.) grains can be recognized in the aphanitic groundmass. The rock breaks with a poor conchoidal fracture.

Thin section: The thin section is typically tuffaceous and contains shards of quartz, plagioclase, and microcline, up to 2 mm. long. The shards are cuspate and randomly distributed, and there are also corroded, or sub-rounded and rarely euhedral, quartz and feldspar grains which may be phenocrysts.

The base cannot be completely resolved owing to lack of recrystallization, but very small cuspate quartz and feldspar fragments can be recognized, in addition to small amounts of chlorite, sericite, and altered feldspars. There are also small clots of chlorite flakes up to 1 mm. across, which probably replaced pre-existing ferromagnesian minerals.

The rock is an *acid tuff* that shows only slight low-grade metamorphism.

Quartz-Feldspar Porphyroblastic Rocks from Various Formations

The quartz-feldspar porphyroblastic rocks of the type described occur in various formations, but mainly in the Corella Formation, the Argylla Formation, and the Mount Guide and Ballara Quartzites. Where a rock from a volcanic succession could be identified as originally igneous, it has been excluded—for example, the metamorphosed and metasomatized acid volcanics described above. However, the presence of sparsely, and in some cases densely, distributed waterworn pebbles in the Mount Guide and Ballara Quartzites indicate that the rocks in these formations were originally sediments, and therefore that the large irregular feldspar grains present are porphyroblasts.

The following is a collective description of rocks of this type from several formations.

Specimen nos: R7236, R7237, R7238, R7239, R7240, R7241.
Thin section nos: 2418, 2419, 2420, 2421, 2422, 2423.
Localities: Lat. 21°25′05″S, long. 139°54′45″E. Lat. 20°54′20°S, long. 139°59′E. Lat. 20°58′40″S, long. 139°34′10″E.

Hand specimens: Rocks from the Argylla and Corella Formations are red-brown and have large quartz and flesh-coloured feldspar grains set in an extremely fine-grained indurated groundmass. However, the matrices of conglomeratic rocks show more variation. One from quarter of a mile east of Three Threes mine is similar to other rocks in the Argylla Formation, whereas that from two miles south-west of Rifle Creek dam contains large quartz and white feldspar grains in a fine-grained dark grey base which is flecked with numerous small mica flakes. Commonly the weathered surface of these rocks is rusty brown, and protruding above the base are grains of quartz and feldspar. The matrix of the conglomerate in the Ballara Quartzite has a dark flesh colour, and contains large pink feldspar grains in an extremely fine-grained base which includes numerous small flakes of a dark micaceous mineral.

Thin sections: The diversity shown by the hand specimens is also apparent in the thin sections. The rock is porphyroblastic and contains large grains of feldspar, and less commonly of quartz, between 0.5 and 2 mm. long, in a fine-grained granoblastic groundmass. All grains are xenoblastic, and the large porphyroblasts have particularly irregular margins; some of them contain inclusions of mica flakes and quartz incorporated from the groundmass during growth. The groundmass is either quartzose, quartzo-feldspathic, or feldspathic, but also contains some biotite, chlorite, muscovite, epidote, calcite, and opaque iron minerals. Poor schistosity, including a poor lepidoblastic fabric, is common in the more micaceous rocks. In deformed rocks the biotite flakes are strung out into parallel bands, and quartz grains are concentrated into elongated aggregates which are separated by bands or patches of finer-grained quartz. Some of the patches may represent altered rock fragments. Many of the other mineral grains are angular, and if they were detrital sorting was poor.

Microcline forms xenoblastic porphyroblasts up to 2 mm. long. Glomeroporphyritic microcline patches are also common. Microcline is fresh and shows gridiron twinning. Other fresh grains occur in the groundmass and also surround relict feldspar grains; this is particularly noticeable in the matrix of the conglomerate in the Ballara Quartzite. Some of the relict feldspar grains show turbid alteration, and are probably derived by recrystallization of an originally feldspathic sediment.

Quartz occurs as large xenoblastic grains or forms aggregates of grains. Individual grains and most aggregates are up to 1.5 mm. across, but some aggregates are larger and possibly represent reconstituted grains. Trains of fine inclusions cut across newly-formed grain margins; this suggests that the aggregates formed by recrystallization of single grains. Possibly the original grains were detrital quartz from an igneous rock. Some of the grains are surrounded only by a rim of smaller interlocking quartz grains and retain features not unlike corrosion embayments. The quartz grains show undulose extinction.

Micaceous minerals are absent or sparsely scattered through many of the rocks. However, biotite and muscovite are fairly abundant in the rocks from south-west of Rifle Creek dam. The biotite is pleochroic from light to medium green-brown and most flakes are about 0.1 mm. long, whereas most colourless muscovite flakes are up to 0.5 mm. long. The few larger muscovite flakes (up to 1 mm.) incorporate inclusions of groundmass minerals; they may have grown within the groundmass.

Accessory minerals are abundant in some rocks, and particularly in those from south-west of Rifle Creek dam, where considerable calcite and rare small epidote, apatite, and sphene grains occur. Opaque iron mineral forms sparsely distributed grains and cubes up to 0.5 mm. In the rocks that contain little micaceous mineral, small grains of iron oxide may be scattered throughout the groundmass.

These rocks are metasomatized sediments; some were probably originally argillaceous. Potash and possibly soda metasomatism has contributed to their formation, and generally the rocks neither contain minerals in igneous proportions nor retain relict structures from which the original nature of the rocks can be petrographically identified. The rocks are best described as *quartz-feldspar porphyroblastic rocks.*

Specimens from the Soldiers Cap Formation

Specimen nos: R7183, R7184, J659.

Thin section nos: 2345, 2346, J659.

Localities: Lat. 20°47′S, long. 140°39′30″E. Lat. 20°46′50″S, long. 140°37′30″E.

Hand specimens: The rocks are buff-coloured fine-grained schists with well developed false cleavage. In one of the specimens examined a lineation due to false cleavage occurs at 70° to that due to schistosity. The finely micaceous rock has a soapy feel on planes of schistosity; it is iron-stained on weathered surfaces.

Thin sections: The thin sections are lepidoblastic and show distinctive false cleavage. Those of low metamorphic grade consist mainly of chlorite, biotite, muscovite, and quartz, and lesser amounts of opaque iron mineral. In rocks of slightly higher metamorphic grade small colourless garnet and green tourmaline crystals are found. Quartz and micas occur in roughly equal amounts as even, fine-grained crystals; grains and flakes range up to 0.1 mm. Quartz grains show undulose extinction.

In most thin sections muscovite and biotite are about equally common and evenly distributed. Quartz grains tend to be concentrated into bands that conform to the schistosity, and in these cases mica-rich bands have also developed. The largest biotite flakes are 0.3 mm. across, and are rare; biotite mostly cuts across the schistosity and generally is partly altered to chlorite. However, chlorite is abundant in rocks of lesser alteration.

Opaque iron mineral is not abundant, but forms small grains, some of which stain the rocks in places.

These rocks are *quartz-muscovite-chlorite schist* which become *quartz-muscovite-biotite* and then *quartz-muscovite-biotite-garnet schist* with increasing metamorphic grade. They are all in the greenschist facies, with the possible exception of the garnet-bearing schist, which may have reached the albite-epidote-amphibolite facies.

Specimen nos: J678, J680, R6927, R7199.

Thin section nos: J678, J680, 2077, 2362.

Locality: Lat. 20°56′45″S, long. 140°41′E.

Hand specimens: The rocks are silver-grey micaceous schists and contain andalusite porphyroblasts up to 5 cm. long, which protrude above the base. Small red-brown garnets (1 mm.) occur throughout the micaceous base (Pl. 28, fig. 2).

Thin sections: Textural features include false cleavage and poikiloblastic porphyroblasts; most of the schistose rocks are lepidoblastic (Pl. 31, fig. 2; Pl. 32, fig. 1). The largest porphyroblasts of andalusite are 4 cm. long, whereas most garnets are between 1 and 2 mm. in diameter. The mica flakes in the base are 0.1 to 0.5 mm. long and are mainly biotite and muscovite. Quartz and lesser amounts of opaque iron mineral occur throughout.

Andalusite porphyroblasts are characteristically poikiloblastic and contain abundant small inclusions of biotite, muscovite, quartz, opaque iron mineral, and rarely garnet, which have a random orientation unrelated to the schistosity. They are commonly enveloped by a rim of muscovite flakes about 1 mm. wide and surrounded, in turn, by a narrower border of biotite flakes.

Garnet idioblasts also contain inclusions, mainly quartz grains that are concentrated towards the centre of the crystals. Many of the garnet crystals are extensively cracked, especially in marginal zones. They show a faint red tint and are probably rich in the almandine molecule, as their refractive index is 1.79 and their specific gravity 4.0.

Biotite and muscovite occur in roughly equal amounts and are generally evenly distributed. Flakes of biotite are up to 1 mm. long; a few contain grains (possibly zircon) which are surrounded by pleochroic haloes. In the schistose rocks the directional arrangement of biotite and muscovite flakes has resulted in banding; commonly biotite-rich alternate with muscovite-rich bands, and quartz grains are distributed through them. In the false-cleaved specimens, quartz grains are concentrated in the troughs and crests of the mica crenulations.

The rocks are *garnet-andalusite-biotite-muscovite schist* or pelitic rocks which show regional metamorphism equivalent to the amphibolite facies. However, the abundance of andalusite probably indicates a strong thermal factor in this metamorphism.

Specimen no.: J482B.
Thin section no.: J482B.
Locality: Lat. 20°59′20″S, long. 140°43′E.

Hand specimen: The rock is massive, fine-grained, and somewhat indurated, and contains porphyroblasts of red garnet (2 mm.) and sporadically distributed bundles (20 mm. long) of an acicular mineral.

Thin section: The thin section contains porphyroblasts of garnet, up to 3 mm. across, bundles of anthophyllite, and probably some large irregular grains of cordierite, in a finely granoblastic quartz-rich base. Quartz grains in the base are even-grained and less than 0.05 mm. Small grains of opaque iron mineral and apatite are evenly distributed throughout; rare epidote grains occur.

Idioblastic garnet grains, 2 mm. in diameter, are irregularly cracked and have a poor parallel cleavage and a pink tint. Numerous inclusions of small quartz grains tend to be concentrated towards the centre of the garnet grains. The refractive index of the garnet is 1.795, but in the absence of sufficient material the specific gravity is not known. Paragenesis suggests that the garnet is one rich in the almandine molecule, as the anthophyllite is an iron-rich variety.

Lanceolate needles of anthophyllite are 2.5 mm. long and 0.2 mm. wide, and have a poor directional trend and sporadic distribution. Some crystals are oriented parallel to the thin section; others are at right angles to it. The end sections show a typical basal cleavage at 120°. The parallel sections are moderately pleochroic from colourless to pale steel-grey and show straight extinction. The anthophyllite is an iron-rich variety and has a positive 2E of 76° $\pm$ 2° (3 universal stage determinations) and $n\delta$ of 1.675. Quartz inclusions are scattered throughout.

Cordierite forms large xenoblastic grains enclosing many inclusions, most of which are irregular grains of quartz. Other inclusions are apatite and green tourmaline. Faint yellowish pleochroic haloes surround grains, possibly of zircon, and these in conjunction with large negative 2V suggest that the mineral is cordierite. Fine cracks radiate from the grains into the cordierite. Alteration to finely fibrous pinite can be seen in places.

Flakes of chlorite have formed abundantly along and adjacent to small fractures. They are from 0.1 to 2.7 mm. long, and many contain small pleochroic haloes surrounding ?zircon grains. Probably the formation of chlorite results from retrogressive alteration. Sericite is probably also secondary.

The rock is a *garnet-anthophyllite-cordierite-quartz rock* that is probably a product of regional metamorphism with a strong thermal factor, equivalent to the amphibolite facies. The abundance of quartz is unusual in rocks with this assemblage. The rock was probably rich in quartz, with a dolomitic cement and with sufficient iron for the formation of the iron-rich metamorphic minerals.

Specimen no.: R6931.
Thin section no.: 2080.
Locality: 20°49′30″S, long. 140°45′20″E.

Hand specimen: The translucent white rock is aphanitic and has a conchoidal fracture and a flinty habit.

Thin section: The thin section is extremely fine-grained; it is almost completely composed of small grains of reconstituted silica. A few narrow quartz veins (0.1 mm.), and in one place a vein partly filled with chlorite, cut the thin section. Although very small, the quartz grains show a rough semblance of a parallel arrangement and numerous small unidentified grains are also evenly distributed throughout.

The rock is a partly crystallized *chert.*

Specimen nos: R7000, 7063.
Thin section nos: 2152, 2216.
Localities: Lat. 20°56′40″S, long. 140°43′40″E. Lat. 20°47′S, long. 140°39′30E.

Hand specimens: The rocks have a rusty-brown weathered surface; but the freshly broken rock is medium grey to green-grey, extremely fine-grained and basaltic-looking. Individual minerals cannot be distinguished, but in some specimens greenish soapy feldspar grains up to 5 mm. across can be seen.

Thin sections: The fabric of the thin sections is controlled by abundant xenoblastic hornblende grains separated mainly by feldspar. Where stress has strongly influenced metamorphism a distinct schistosity is shown by the parallel arrangement of elongated hornblende grains. Other minerals include opaque iron mineral, sphene, and rare grains of epidote and quartz. However, in some of the low-grade rocks calcite, epidote, and chlorite are more common and grains are up to 0.4 mm. across. The grainsize of minerals in thin sections ranges from 0.05 mm. to 0.3 mm. The rocks show complete metamorphic reconstitution except that rare relict feldspar laths may be found in some thin sections.

The hornblende ranges from light to medium green and is pleochroic: X = pale yellow-green, Y = grass-green, Z = blue-green, X < Y < Z. Grains are xenoblastic, rarely columnar, and up to 0.2 mm. across.

The few relict feldspar laths are sparsely distributed and are up to 0.5 mm. long. Xenoblastic feldspar grains are widespread and evenly distributed between the amphibole grains. Their refractive index is generally between those of Canada balsam and quartz, indicating a composition of oligoclase-andesine. In the low-grade rocks the feldspar is slightly more acid and approaches albite. Xenoblastic grains range from 0.05 to 0.3 mm. and are rarely twinned; in the relict laths twinning is indistinct, and the laths show undulose extinction, and contain numerous inclusions of amphibole and epidote. Some laths are clouded by alteration products.

Accessory apatite occurs in the least altered rocks. Opaque iron mineral is evenly distributed throughout and some grains contain veins of sphene. Grains are up to 0.2 mm. across.

The mineral percentages, estimated visually, are: amphibole about 75% and feldspar most of the remainder. Small amounts of opaque iron mineral, sphene, quartz, calcite, epidote, and chlorite together compose up to 5% of the thin sections.

These basic igneous rocks are regionally metamorphosed and were probably basaltic, but are now best described as *amphibolites.* Little noticeable change is apparent with increasing metamorphic grade. The low-grade rocks contain small amounts of chlorite, epidote, and calcite, whereas rocks of moderate grade consist essentially of hornblende and plagioclase. The plagioclase ranges from albite in the low-grade rocks to oligoclase-andesine in the rocks of moderate grade.

Specimens from the Marraba Volcanics

Specimen nos: R6992, R6993.
Thin section nos: 2144, 2145.
Localities: Lat. 20°56′S, long. 140°07′40″E. Lat. 20°52′50″S, long. 140°18′45″E.

Hand specimens: The rocks are dark green-grey and basic; they are fine and fairly even-grained. The freshly broken surface exposes a few feldspar grains (2 mm.) in some rocks, and clots of chlorite and actinolite up to 5 mm. long. The rocks mostly have an irregular fracture, and a poor schistosity.

Thin sections: A variety of textural and mineralogical types occurs amongst the basaltic rocks in the Marraba Volcanics. In some thin sections original textures are preserved; in others textures are metamorphic. Deformation has been primarily responsible for the destruction of original textures, and the rocks are mostly low-grade hornblende, and less commonly chlorite, schists, which also contain feldspar and quartz grains evenly dispersed throughout. Where stress was insufficient to destroy original textures the rocks consist of plentiful actinolite and hornblende needles and wisps of chlorite, between groups of oriented feldspar laths

which show undulose extinction and bent and ruptured twin lamellae. A rude nematoblastic fabric is developed in which relict igneous structures also include fractured glomeroporphyritic patches of feldspar up to 3 mm. across. The grainsize of minerals in the groundmass ranges from 0.05 to 0.5 mm. Both actinolite and green chlorite form concentrations around amygdules, which are filled with a mosaic of quartz grains.

Feldspar laths are subhedral and up to 0.5 mm. long and 0.5 mm. across, whereas phenocrysts are equigranular and up to 1 mm. across. The feldspar has a composition in the range An_{30} to An_{10}. Most crystals are cracked, strained, and twinned according to both simple and complex laws. Veins of soda feldspar occur in some thin sections. All crystals are pitted with turbid brown alteration products.

The amphibole is columnar or fibrous, forms needles up to 0.3 mm. long, and shows X = pale straw-green, Y= lettuce-green, Z = blue-green, $X < Y < Z$.

Opaque iron mineral forms discrete grains that measure up to 0.5 mm.; many small grains (0.1 mm.) are scattered throughout. A few xenoblastic quartz grains occur.

A visual estimate of the percentages of minerals is 55 to 65% feldspar, up to 30% chlorite or actinolite or both, and about 5% opaque iron mineral. With increasing metamorphism, mainly under stress, much of the chlorite and opaque iron mineral was transformed to actinolite wherever lime was available. The rocks are probably *andesitic metabasalts* which show low-grade regional metamorphism.

Specimens from the Eastern Creek Volcanics

Specimen nos: J9A, J321A, B, and C.
Thin section nos: J9A, J321A, B, and C.
Localities: Lat. 20°38'S, long. 139°24'40"E. Lat. 21°35'30"S, long. 139°18'10"E.

Hand specimens: Rocks from north-west of Sulieman Bore are grey to pink-grey and are either micaceous and contain bands or streaks of cordierite between foliations of muscovite and biotite, or consist essentially of cordierite and exhibit an irregular surface with a resinous lustre in which small amounts of mica can be distinguished; the rocks are schistose or massive and weather rusty-brown. Hand specimens of rocks from the Old Slaughter Yards are fine-grained and extremely micaceous, and are silver-grey. They consist mainly of fine muscovite flakes with some quartz; these schists contain porphyroblasts of cordierite which are up to 20 mm. long and 6 mm. across.

Thin sections: The thin sections consist mainly of cordierite, muscovite, biotite, and quartz, but some also contain sillimanite, and a few andalusite crystals have been observed. The texture of the thin sections is mostly coarsely granoblastic and grains are generally poikiloblastic, particularly those of cordierite. However, where sillimanite and mica are common constituents, poor lepidoblastic texture has developed. Grainsize varies considerably: porphyroblasts range up to 15 mm. and minerals in the base to 1 mm., but most grains are much smaller. Accessory minerals are plagioclase, apatite, tourmaline, rutile, and opaque iron mineral.

Poikiloblastic cordierite is extremely abundant in some thin sections and contains inclusions of quartz, plagioclase, biotite, apatite, or opaque iron mineral. Inclusions in the cordierite grains of the coarse-grained rocks may be up to 1 mm.; in the fine-grained rocks there are abundant small inclusions, some of which show a parallel arrangement, possibly reflecting original bedding. Yellow pleochroic haloes are fairly common; some of these surround small crystals, perhaps of zircon. Secondary pinite, and some other chloritic mineral, fill irregular cracks across grains.

Sillimanite mostly forms fibrous bundles or individual fibres. It occurs in cordierite, quartz, and muscovite, and has a high relief and a low positive 2V. Rare andalusite may be identified by its length-fast character and high negative 2V. Where it is adjacent to cordierite it shows sharp contrast in relief.

Biotite flakes that are not strongly pleochroic are light brown; other flakes show fairly strong pleochroism from straw-yellow to coffee-brown. Pleochroic haloes surround ?zircon grains and are common.

Quartz is a common mineral in the base of most of the rocks and forms grains up to 0.3 mm.

Amongst the accessory minerals green tourmaline is distinctive. It forms small idioblastic crystals which are strongly pleochroic from colourless to medium-green. Rutile, apatite, and opaque iron mineral are other, minor, accessories. However, tourmaline, apatite, and rutile are abundant in some of the coarse-grained rocks. The finely divided grains of opaque iron mineral in the fine-grained rocks form a rough banding which conforms to the parallel arrangement of other mineral grains, particularly quartz and biotite.

In one thin section small idioblasts of colourless garnet occur.

The rocks are *sillimanite-muscovite-biotite-cordierite schist,* which are products of moderate to high-grade metamorphism; regional effects with a strong thermal, and possibly metasomatic, factor influenced the alteration. Slight retrogressive alteration has given rise in a few cases to the formation of a fibrous chloritic mineral.

Specimen nos: R6970, R6974.

Thin section nos: 2118, 2123.

Locality: Lat. 20°50′40″S, long. 139°30′50″E.

Hand specimens: The rocks are dark grey to dark green-grey and basic; they are compact, even, and fine-grained, and have a rusty-brown weathered surface. They have a poor conchoidal fracture, but because of their fine grain, only facets of feldspar can be confidently identified in hand specimens.

Thin sections: Some sections retain original igneous textures; in others the pre-existing fabric has been destroyed by low-grade metamorphism or deuteric alteration. Rocks with original textures preserved are intergranular and commonly porphyritic or glomeroporphyritic. Where textures have been destroyed, reconstitution has resulted in a growth of xenoblastic metamorphic minerals, many of which are fibrous. Most specimens are not schistose.

Thin sections of rocks that retain original textural features contain tabular feldspar phenocrysts up to 3 mm. long in a groundmass which consists mainly of feldspar laths. These, in places, show a rude orientation suggestive of flow. The grainsize of the groundmass ranges from 0.1 mm. to 0.5 mm. The other minerals are interstitial, and are chlorite, calcite, sericite, and epidote, and also biotite and fibrous amphibole where metamorphism is apparent. Feldspar is altered, mainly to epidote, chlorite, and albite, particularly in those rocks in which the original texture has been destroyed.

The feldspar crystals in rocks with intergranular texture are euhedral and range from andesine to albite; it is not unusual for compositional variations to occur within a single thin section. However, few crystals are zoned, and the composition of the feldspar in the groundmass differs little from that of the phenocrysts. This suggests that alteration may have caused a diminution in the lime content of the feldspar and the attendant development of a fairly uniform composition. Otherwise the feldspar has shown a very definite resistance to alteration, although some crystals are flecked with sericite. The freshness of the feldspar in many thin sections, despite the almost ubiquitous chloritization and epidotization, is a distinctive feature.

No original ferromagnesian minerals remain in any of the thin sections examined. Chlorite is the main coloured mineral and forms plentiful flakes with ragged edges, and also patches (1 mm.) that were possibly pre-existing vesicular cavities. Where metamorphism has been sufficient to affect the mineral assemblage that possibly resulted from deuteric alteration, green-brown biotite and actinolitic hornblende have commonly developed. The actinolite shows X = colourless, Y = pale yellow-green, Z = pale blue-green, $X < Y < Z$. It generally has a fibrous habit, and grains are up to 0.5 mm. across.

X

Epidote is abundant in some thin sections, but most rocks include only a few idioblastic crystals, up to 0.3 mm., or other finely disseminated grains. Grains of calcite up to 0.5 mm. across like epidote, vary widely in abundance.

Sphene and opaque iron mineral grains are common; they either form widely distributed discrete grains or are extremely fine and dust the thin sections. Some of the euhedral and subhedral crystals of opaque iron mineral, which are up to 0.5 mm. in diameter, contain narrow bands of sphene set in parallel and equilateral triangular patterns. This suggests that ilmenite blades formed by exsolution from magnetite along the 111 plane, and were converted by metamorphism to sphene.

Accessory minerals are rare quartz and apatite. Quartz occurs as interstitial grains in the mesostasis, and also lines amygdules.

Many of the rocks similar to those described above are veined by narrow chlorite and calcite, and less commonly epidote, veins, from 0.1 to 0.5 mm. wide.

A visual estimate indicates that the thin sections consist of 40 to 50% feldspar (or products of its alteration) 50 to 40% of dark mineral (mostly of actinolitic amphibole or chlorite and biotite or all three) and 5 to 15% opaque iron mineral.

These rocks are deuterically altered *basalt,* but also include *metabasalt* produced by extremely low-grade regional metamorphism in which stress was insufficient to show its effect on textural features.

Specimens from the Corella Formation

Specimen no.: R6928.
Thin section no.: 2078.
Locality: 20°54′40″S, long. 139°55′25″E.

Hand specimens: The specimens of this rock are buff, fawn, or silver-grey; all of them contain idioblasts of staurolite and red-brown garnet, and some contain small books of biotite flakes (Pl. 29, fig. 1). The porphyroblasts protrude above the finely micaceous base, which may show false cleavage in places. Staurolite crosses are up to 3 cm. across and garnet crystals up to 1 mm.

Thin sections: Idioblastic staurolite and garnet porphyroblasts occur in a lepidoblastic base of biotite, muscovite, and quartz. In the thin section examined the staurolite porphyroblasts are up to 7 mm. and the garnet up to 1 mm. (Pl. 32, fig. 2), whereas grains and mica flakes in the base are mostly extremely small (up to 0.1 mm.).

The staurolite crystals are idioblastic and have thrust aside the groundmass minerals during growth. The micas, in particular, are concentrated in the angle zones of the crystals. The porphyroblasts show simple twinning and one or two well-developed cleavages. Small inclusions of groundmass minerals, mainly quartz and lesser amounts of opaque iron mineral, give rise to poikiloblastic structure; they may be characteristically segregated along diagonals, and many crystals are surrounded by a rim about 0.1 mm. wide, which is relatively free of such inclusions.

The garnet porphyroblasts are mostly idioblastic and have a pale pink tint. They are irregularly cracked, particularly in the margins. Small granular inclusions of quartz are common, and are most noticeable in the central portions of the grains. Paragenesis suggests that these garnets are rich in the almandine molecule.

Biotite and muscovite are equally common, forming flakes that are evenly distributed amongst the granular quartz grains of the base. Small grains of opaque iron mineral and possibly some finely divided carbonaceous mineral also dust the base. Rarely some secondary chlorite occurs.

The rock is a *garnet-staurolite-muscovite-biotite-quartz schist,* which was probably produced from an iron-rich pelite raised by regional metamorphism to the staurolite-kyanite subfacies of the amphibolite facies.

Specimen no.: J421B.

Thin section no.: J421B.

Locality: Lat. 20°23′30″S, long. 140°03′15″E.

Hand specimen: The hand specimen consists of muscovite, biotite, and sillimanite. It is schistose and strongly foliated. Porphyroblasts of sillimanite up to 4 mm. across are dispersed among micaceous flakes that show a poorly developed false cleavage.

Thin section: The thin section consists mainly of muscovite, biotite, sillimanite, and opaque iron mineral, and the fabric is poorly lepidoblastic, as the directional arrangement of minerals is not pronounced. The grainsize ranges mostly between 0.2 and 1 mm.

Muscovite is the most abundant mineral. Groups of mica flakes have an almost decussate arrangement in places. Biotite shows pleochroism from straw-yellow to coffee-brown and contains pleochroic haloes that surround ?zircon grains.

Sillimanite forms a fine mat of needles within flakes of muscovite and is apparently derived from it. It also forms stout prisms and columnar crystals up to 2.5 mm. long which have straight extinction and a positive 2V of about 25°.

The rock is a *sillimanite-biotite-muscovite schist* which is probably a product of regional metamorphism.

Specimen no.: R6935.

Thin section no.: 2084.

Locality: Lat. 20°44′30″S, long. 139°58′20″E.

Hand specimen: The rock is a dark green-grey crystalline metamorphic rock. Cordierite occurs as a grey resinous mineral between sheaves of a radiating fibrous amphibole to form a fairly coarse-grained rock.

Thin section: The thin section consists mainly of radiating sheaves of anthophyllite and large irregular grains of cordierite. Cordierite porphyroblasts are up to 10 mm. across and the sheaves of anthophyllite are up to 10 mm. long. The groundmass is granoblastic and consists mostly of quartz, but includes opaque iron mineral, biotite, sericitized feldspar, and rarely scapolite (Pl. 33, fig. 1). The grainsize ranges from 0.1 to 1 mm. Grains of opaque iron minerals form distinct bands, which possibly reflect original iron-rich sedimentary planes, and pass through the large anthophyllite porphyroblasts. Radiating anthophyllite crystals are broken by radial fractures.

Sheaves and columnar crystals of anthophyllite are pleochroic from yellow-green to grey-green; the sheaves are well-cleaved and fibrous. Anthophyllite has a positive 2V of 70° $\pm$ 1° (universal stage determination) and straight extinction. Inclusions of small quartz grains, flakes of biotite, and opaque iron mineral occur. Chlorite, which forms flakes up to 2 mm. long, may be a product of retrogressive alteration.

Cordierite is poikiloblastic and occurs as xenoblastic porphyroblasts up to 4 mm. across. It contains abundant inclusions of quartz, feldspar, and opaque iron mineral. Yellow pleochroic haloes and penetration twins are common. Cordierite is partly altered to a fibrous and micaceous mineral, probably pinite, along cracks.

The opaque iron mineral forms grains up to 1 mm. across. In addition to bands, dense aggregates occur in some cordierite grains.

The rock is a *cordierite-anthophyllite rock* either derived from a magnesia-rich sediment or produced by magnesia metasomatism. Mineralogically, its assemblage is typical of the cordierite-anthophyllite subfacies of the amphibolite facies, which suggests that its metamorphism was predominantly thermal.

Specimen no.: R7207.

Thin section no.: 2373.

Locality: 200 yards east of the Mary Kathleen uranium mine.

Hand specimen: The rock is a fine-grained dark grey amphibolite with a poor conchoidal fracture. The minerals are too small to identify in hand specimen.

Thin section: The thin section has a granular texture and consists mainly of scapolite, hornblende, pyroxene, plagioclase, and sphene. The grainsize ranges from 0.1 to 2 mm., but many of the apparently large grains are aggregates of smaller ones that average about 0.2 mm. Both plagioclase and scapolite grains are up to 1 mm. and are poikiloblastic, the inclusions being pyroxene and hornblende.

Hornblende occurs within, and along the margins of, pyroxene grains, and also forms aggregates of smaller xenoblastic grains about 0.1 mm. across. It shows X = yellow-green, Y = grass-green, Z = blue-green, X < Y < Z. Some grains are particularly blue and therefore may be a soda-rich variety.

Most pyroxene grains are xenoblastic and about 0.1 mm. long, but some grains are up to 1 mm. in size. The pyroxene is a light green variety which developed at the expense of hornblende.

Plagioclase grains are fresh and contain many albite twin lamellae. The extinction of the lamellae and the refractive index of the plagioclase indicate a composition of andesine, about An_{38}. Plagioclase is partly replaced by irregular poikiloblastic grains of scapolite.

Sphene forms idioblastic and xenoblastic grains up to 1 mm. across. The accessory minerals also include apatite, epidote, and a turbid brown alteration product which forms part of a few isolated patches of saussurite.

The rock is a *plagioclase-pyroxene-hornblende-scapolite granulite* which is probably derived by metamorphism and by soda and chlorine metasomatism of an impure calcareous rock; alteration apparently took place under conditions of low to moderate-grade metamorphism (see Edwards & Baker, 1954).

Specimen no.: R6933.

Thin section no.: 2082.

Locality: Lat. 21°15′20″S, long. 140°44′00″E.

Hand specimen: The rock is finely banded, with an overall grey colour; some bands are greenish. The bands are 1 mm. wide and probably represent original bedding. The rock has an uneven fracture and is too fine-grained to distinguish the various minerals.

Thin section: The thin section has a banded granular texture and consists mainly of microcline, plagioclase, scapolite, quartz, hornblende, and opaque iron mineral. The accessory minerals are sphene, calcite, biotite, and apatite. Grainsize ranges from 0.1 to 0.5 mm. The pronounced banded arrangement of minerals is distinctly shown in the thin section: bands rich in ferromagnesian minerals alternate with microcline and quartz-rich ones. These are 1 to 2 mm. wide. Opaque iron mineral grains also form bands which may represent original iron-rich sedimentary bands. Most of the feldspar is microcline: its typical twinning distinguishes it from quartz, with which it forms a granoblastic base. Plagioclase grains show turbid brown alteration and are flecked with sericite. Despite extensive alteration the extinction of albite twin lamellae can be measured; this indicates a feldspar composition of about An_{30}. Scapolite grains occur in bands and are irregularly cracked. They are also slightly altered. Hornblende is the main dark mineral and grains measure up to 7 mm. It shows X = pale yellow-green, Y = light grass-green, Z = light blue-green, X < Y < Z. Small biotite flakes up to 0.1 mm. long show pleochroism from light yellow-brown to green-brown. Flakes contain brown pleochroic haloes. The rare chlorite flakes present may have formed as a result of retrograde metamorphism. The opaque iron mineral shows slight alteration to leucoxene and is associated with a few grains of sphene and possibly some rutile.

The rock is a *hornblende-plagioclase-scapolite-microcline granulite* that has probably developed from a calcareous sandstone; its alteration shows the effects of chlorine, soda, and finally potash metasomatism.

Specimen no.: R6876.
Thin section no.: 2026.
Locality: Lat. 21°21′50″S, long. 139°51′10″E.

Hand specimen: The hand specimen is a fine to medium-grained, dark grey, gabbroic-looking rock, in which grains of dark green pyroxene and hornblende, and white translucent feldspar, can be recognized. Brown grains of sphene can also be distinguished. Relict banding, representing original bedding, can be seen in some parts of the outcrop from which the specimen was taken.

Thin section: The thin section has a granoblastic texture and consists mainly of plagioclase, pyroxene, scapolite, hornblende, and sphene, but also includes apatite and quartz as accessory minerals. The grainsize is fairly even and averages about 1 mm.

The plagioclase forms xenoblastic grains which contain a few simple twin lamellae. Extinction of albite twins indicates that its composition is An_{37}. Turbid brown alteration products and strain shadows are fairly common.

The pyroxene is a clear pale green and is prominently cleaved. Some grains are subidioblastic against the xenoblastic plagioclase and quartz grains. The pyroxene has $2E = 59° \pm 1°$ (average of 3 universal stage determinations), and $n\beta = 1.700 \pm .005$. This corresponds fairly closely to the pyroxene determinations made by Edwards & Baker (1954, p. 10) in other rocks from Duchess, and possibly the pyroxene is a similar ferriferous augite.

Hornblende grains are xenoblastic and subidioblastic, and occur around the margins of pyroxene grains and also within them, which suggests that the pyroxene developed at the expense of hornblende. Hornblende shows X = yellow-green, Y = olive-green, Z = dark blue-green, $X < Y < Z$.

Scapolite forms discrete grains amongst grains of plagioclase, but also, in places, partly replaces plagioclase. It is strongly cleaved and has a tendency towards a fibrous habit.

For a rock that was originally a sediment sphene is noticeably abundant; grains measure up to 2 mm. Apatite is common and is widely distributed as grains about 1 mm. in size. The only opaque iron mineral is hematite.

Pyroxene is about as common as plagioclase, and hornblende as scapolite.

The rock is a *scapolite-hornblende-pyroxene-plagioclase granulite,* produced by metamorphism and by soda and chlorine metasomatism of an impure calcareous rock (see Edwards & Baker, 1954). The metamorphic grade is probably equivalent to that of the amphibolite facies.

Specimen nos: R7209, R7210.
Thin section nos: 2376, 2377.
Localities: Duchess, and lat. 20°47′S, long. 140°39′30″E.

Hand specimens: The specimens are from an outcrop of 'red rock' (see Edwards & Baker, 1954) and from a fissure. The 'red rock' is fine-grained and brick-red. It is composed mainly of red feldspar, whose individual grains are difficult to distinguish, and of fine-grained green ferromagnesian mineral uniformly distributed throughout in lesser amounts. 'Red rock' filling fissures adjacent to 'red rock' outcrops mostly contains red feldspar, green hornblende, and calcite.

Thin sections: The thin section of 'red rock' is granoblastic and consists mainly of plagioclase, pyroxene, and hornblende. The plagioclase is distinctively coloured rusty-red by impregnation with finely-divided hematite. Accessory minerals are apatite, calcite, sericite, and opaque iron mineral. The grainsize is fairly even and ranges between 0.1 and 0.3 mm., but in the vein material it is from 0.5 to 2 mm.

Plagioclase grains are xenoblastic, and most contain numerous albite twin sub-individuals. The maximum extinction angle of albite twin lamellae approaches 16° and the refractive index is greater than that of Canada balsam; the composition, therefore, is about An_{34}. Alteration mainly involved coloration by small hematite inclusions. The red feldspar from

the vein material is mainly albite, which is similarly impregnated by finely-divided hematite. Twinning cannot be recognized through the red-brown colour; grains have a mottled appearance and a refractive index below that of Canada balsam.

The main ferromagnesian mineral in the 'red rock' is hornblende. It is a pale variety that shows X = colourless, Y = pale grass-green, Z = pale blue-green, X < Y < Z. The amphibole from the vein is also extremely pale and only faintly pleochroic.

The pyroxene in the 'red rock' is a clear green variety which forms xenoblastic grains.

Calcite and quartz are widely distributed in the vein material, and vermicular intergrowths between quartz and calcite, and hornblende and quartz, are fairly common. Sericite flakes are large (0.5 mm.) or are grouped into bundles of smaller flakes. Other accessory minerals in the vein material are sphene, apatite, and opaque iron mineral, apart from hematite, which are evenly distributed throughout.

The 'red rock' described is a *hornblende-pyroxene-plagioclase rock* and the vein material is a *calcite-quartz-hornblende-albite rock*. Edwards & Baker (1954) have shown that the 'red rock' is a product of hydrothermal alteration that involved the leaching of MgO and much of the CaO and FeO from para-amphibolites, that is, from rocks similar to the scapolite-hornblende-pyroxene-plagioclase granulite described above, except that some of the FeO was redistributed in a finely divided state, impregnating the feldspar and colouring it nearly opaque red.

Specimen from the Charley Creek Formation

Specimen no.: R6932.

Thin section no.: 2081.

Locality: 20°41′10″S, long. 139°46′40″E.

Hand specimen: The dark-grey banded rock is fine-grained and breaks with a conchoidal fracture. The bands are rich in scapolite, and small white scapolite grains protrude above the groundmass on weathered surfaces.

Thin section: The thin section is porphyroblastic and contains numerous irregular, and roughly circular, poikiloblastic grains of scapolite from 0.5 to 1.5 mm. across in a base of biotite, calcite, and quartz. It has a spotted appearance (Pl. 33, fig. 2). The base is even-grained and grains average less than 0.05 mm. in diameter. Part of the thin section is rich in calcite, lacks quartz and biotite, is coarser-grained, and has more opaque iron mineral, than the remainder.

The large scapolite grains are commonly fractured by parallel cracks which are not unlike a poor cleavage. However, the cracks in different grains are parallel and, as the grains are not in optical continuity, the cracks probably formed by stress. Inclusions are abundant; they have been incorporated from the base of the rock during growth of the porphyroblasts.

Half of the fine equigranular base consists of small biotite flakes; the remainder is of quartz and calcite grains. In the lower grade rocks chlorite takes the place of biotite.

Grains of opaque iron mineral, up to 0.25 mm. in diameter, occur at random throughout the thin section.

The rock is a spotted *scapolite-biotite-calcite rock* derived from a calcareous shale or other limy sediment. Scapolite probably developed as a result of chlorine metasomatism.

Specimens from the Myally Beds

Specimen nos: R3224, R7245.

Thin section nos: 2427, 2428.

Localities: Sandy Creek, west of Overshot Waterhole; Lat. 19°05′55″S, long. 139°19′20″E.

Hand specimens: The specimen is a very fine-grained siliceous rock; it is flesh-coloured and has a poor conchoidal fracture. Some clear quartz grains about 1 mm. in diameter occur

throughout its aphanitic groundmass. Some other specimens are brick-red; the feldspar and quartz phenocrysts in these are up to 10 mm. and 5 mm. respectively.

Thin sections: The thin sections contain phenocrysts of quartz and of potash and plagioclase feldspar. The phenocrysts range from 1 to 3 mm. in some thin sections and from 5 to 10 mm. in others. They are set either in a fine-grained holocrystalline groundmass that consists of small quartz grains, or in a groundmass too fine to resolve completely. In the holocrystalline sections silicification by veining and the development of rosettes in the phenocrysts suggest a chalcedonic filling. The others are characterized by brown clouding throughout, owing, probably, to finely divided opaque iron mineral which delicately outlines, by local concentrations, possible flow structure. Two other features are discernible: one is the incipient crystallization of quartz that forms abundant and closely arranged rosettes characteristic of chalcedony; the other is the presence of aggregates of quartz grains which appear to be infilled vesicles.

Both feldspar and quartz phenocrysts have corrosion embayments. The potash feldspar phenocrysts have rounded grain margins and contain siliceous inclusions. Brown clouding is more characteristic of the plagioclase than of the potash feldspar phenocrysts.

These rocks are probably *rhyolite,* but hydrothermal alteration and silicification, combined with weathering, have masked many of their features by staining.

Specimen no.: R6947.

Thin section no.: 2096.

Locality: Near Mount McLeod copper mine, about lat. 19°51′06″S, long. 139°09′30″E.

Hand specimen: The hand specimen is flesh-coloured and contains numerous quartz crystals, up to 2 mm., in an aphanitic groundmass. The rock is cut by many fine siliceous stringers about 0.5 mm. wide. It breaks with a poor conchoidal fracture.

Thin section: The thin section contains some corroded crystals of quartz and potash feldspar, which measure up to 3 mm. and 2 mm. respectively; they occur in a base composed of many angular quartz fragments that are probably shards, and also of small chlorite flakes, feldspar grains, and secondary opaque iron mineral. Most of the potash feldspar crystals are altered: impregnation with finely divided iron particles has clouded them, but they are also flecked with sericite.

The rock is probably an *acid tuff.* Low-grade alteration, mainly hydrothermal, has masked many of its original features.

Specimen no.: R6979.

Thin section no.: 2130.

Locality: Lat. 19°09′50″S, long. 139°34′35″E.

Hand specimen: The rock is blue-brown and fine-grained and contains amygdules filled with amorphous silica. It is a heavily weathered basic volcanic.

Thin section: The thin sections of the rock consist predominantly of feldspar laths and opaque iron mineral grains; iron-staining has extensively masked many features. The texture was probably originally intergranular or hyalopilitic, but some thin sections are almost trachytic. Quartz xenocrysts, up to 4 mm. across, are a distinctive feature in a few thin sections, particularly as they are angular, fractured, and not surrounded by reaction rims. Interstices between feldspar laths are occupied mostly by opaque iron mineral, which was either precipitated from an iron-rich glassy base or introduced after crystallization. Amygdules were probably filled with chalcedony, as some remains in a few; others are lined with spherulitic quartz, and yet others have been reconstituted to a mosaic of crystalline quartz grains. Quartz also forms small irregular interstitial grains and also occurs in veins. Apatite grains are rare. The grainsize of the groundmass is even and the feldspar laths are up to 3 mm. long.

The feldspar laths are oligoclase, and generally iron-staining is so heavy that twinning can only be distinguished with difficulty. Alteration has also given rise to small sericite

flakes and rarely to chlorite and grains of calcite. Apparently alteration was essentially hydrothermal, and leached out lime and redistributed, or possibly introduced, some iron and silica. Weathering has probably been responsible for the extensive iron-staining of the rocks.

The rock is *quartz-xenocryst basalt* (see Hatch, Wells & Wells, 1949, p. 300); it was probably extruded through arenaceous strata from which the quartz xenocrysts were caught up.

Specimen no.: R3200.
Thin section no.: 2429.
Locality: Fiery Creek, approximately lat. 19°08′S, long. 140°10′E.

Hand specimen: The hand specimen consists of small angular and sub-rounded fragments of a red siliceous rock, amongst which occur numerous dark brown fragments flecked with grey metallic-looking crystals that are probably hematite. Rare patches of dull green interstitial material may be chlorite.

Thin section: The thin section contains fragments of basic rock, and many shards and sub-rounded quartz grains, set in feldspathic material, calcite, and chlorite. Rosettes of silica radiate from small quartz nuclei in the base. Blebs of chalcedony about 1 mm. across are scattered through the section and much opaque iron mineral occurs throughout the base, including discrete grains from 0.1 to 1 mm. across.

The feldspathic material in the base shows turbid brown alteration similar to that of the feldspar laths in the basic volcanic rock fragments. In the rock fragments, the opaque iron mineral occupies interstices between feldspar laths, but in the base of the tuffaceous rock, it forms only discrete grains. Probably, therefore, abundant interstitial opaque iron mineral is an inherent and typical feature of alteration of the basic volcanic (see description of specimen R6979 above).

The rock is a *basic tuff.*

Specimen from the Judenan Beds

Specimen no.: J104.
Thin section no.: J104.
Locality: 21°03′S, long. 139°21′30″E.

Hand specimen: The rock is porphyritic, slightly sheared and flesh-pink. Quartz phenocrysts up to 3 mm. and feldspar phenocrysts are set in a fine-grained groundmass.

Thin section: The thin section consists of relict quartz and microcline phenocrysts in a base that is partly micaceous and partly xenoblastic quartz. The micaceous minerals, mostly biotite and sericite, wrap, or are concentrated, around the deformed phenocrysts and give rise to a pseudo-gneissic fabric. Pseudo-inclusions and corrosion embayments are retained by many of the relict phenocrysts, particularly those of quartz. Granulation and fracturing are also characteristic of most phenocrysts. The deformed quartz and feldspar phenocrysts measure up to 3 mm. and 6 mm. respectively. The groundmass has, in part, been reconstituted to form patches of fine granoblastic quartz between layers of more abundant micaceous minerals. It also contains many cuspate quartz fragments up to 0.5 mm. long. Biotite is the more abundant mica, and is golden-brown.

Potash feldspar phenocrysts are the least altered of the feldspars, but brown clouding is widespread. Flakes of biotite are commonly included in the feldspar grains. Some of the feldspar phenocrysts have been replaced by aggregates of quartz grains similar to those in the groundmass, but the original outline of the feldspar crystals is retained.

The rock is probably a *rhyolite* that has been deformed by dislocation metamorphism.

Specimens from the Cliffdale Volcanics

Specimen no.: R6954.
Thin section no.: 2103.
Locality: Lat. 17°43′40″S, long. 137°58′05″E.

TABLE I

METAL AND MINERAL PRODUCTION FROM THE CLONCURRY AND MOUNT ISA GOLD AND MINERAL FIELDS

	Gold		Copper		Silver		Lead		Zinc		Cadmium		Cobalt			Bismuth		Scheelite		Limestone		Ironstone		Mica		Beryl		Total Value
	Oz.	Value	Tons	Value	Oz.	Value	Tons	Value	Tons	Value	Tons	Value	Tons	Value		Cwt.	Value	Tons	Value	Tons	Value	Tons	Value	Cwt.	Value	Tons	Value	
1872-		£		£		£		£		£		£		£	1872-		£		£		£		£		£		£	£
-1899	21,433	75,016	457	33,777											-1899												108,791
1900	86	365	13	780	29	3									1900												1,148
1901	116	492	236	14,868	65	7									1901												15,367
1902	250	1,064	51	2,550	191	19									1902												3,633
1903	87	372	148	8,584	456	47									1903												9,003
1904	132	560	403	23,796	13	1									1904												24,357
1905	162	688	456	31,806	556	64									1905												32,558
1906	62	263	590	53,663											1906												53,926
1907	24	104	692	57,944											1907												58,048
1908	273	1,160	1,321	75,200											1908												76,360
1909	1,777	7,548	2,361	138,964	795	79									1909												146,591
1910	3,666	15,572	3,429	185,162	4,445	479									1910												201,213
1911	12,605	53,543	8,511	477,346	29,514	3,073									1911					3,269	2,713	9,873	4,343					541,018
1912	13,039	55,386	10,435	761,755	40,394	4,712									1912					1,974	1,938	7,774	4,057					827,848
1913	7,250	30,796	9,772	681,843	60,705	6,829									1913					5,573	2,879	11,263	4,642					726,989
1914	4,892	20,780	8,215	497,098	56,550	5,891									1914					13,620	8,832	6,782	3,974					536,575
1915	4,595	19,518	9,880	716,796	70,232	7,023	2	42							1915	3.5	61			22,309	13,873	4,213	1,671					758,984
1916	3,420	14,527	9,908	1,149,328	59,337	7,664	3	93							1916					34,578	24,723	8,427	2,745					1,199,080
1917	2,647	11,244	10,189	1,181,953	46,246	7,804									1917					40,193	30,992	1,627	667					1,232,660
1918	3,851	16,358	11,625	1,278,786	29,496	5,777									1918					31,370	23,254	10,635	7,982					1,332,157
1919	969	4,116	4,346	415,653	15,284	3,947									1919					6,573	4,760	1,345	924					429,400
1920	2,799	11,889	7,672	748,041	28,452	7,321									1920					22,252	15,120	9	4					782,651
1921	54	229	89	6,178	206	32							85.0	21,332	1921												27,771
1922	207	880	325	20,475	206	31							101.5	20,332	1922									1.5	55		41,773
1923	178	756	518	35,776	7,046	1,027	98	2,628					217.5	43,449	1923												83,636
1924	43	183	261	17,617	13,911	2,115	217	7,307					197.3	39,461	1924												66,683
1925	329	1,397	982	63,830	24,210	3,328	330	11,830					90.0	18,014	1925									10.0	700		99,099
1926	277	1,176	1,098	66,444	8,882	1,110	76	2,372					28.0	5,719	1926												76,821
1927	1,359	5,773	2,905	169,942	15,314	1,786	19	451					2.3	531	1927									1.0	50		178,533
1928	675	2,867	2,339	148,526	9,418	1,079							7.8	1,562	1928												154,034
1929	1,300	5,522	3,377	265,110	13,731	1,510							20.0	4,165	1929												276,307
1930	626	2,659	2,169	128,841	9,908	783	30	537					2.8	577	1930							1,268	1,238				134,635
1931	818	3,475	2,317	93,357	1,027,907	71,893	17,128	230,003					1.0	280	1931	2.7	33	1.5	97	5,287	5,125	3,758	4,461					408,724
1932	526	2,793	2,597	90,162	2,237,343	177,566	47,633	572,829					3.0	636	1932			0.6	34	10,893	12,156	5,897	6,873					863,049
1933	1,088	5,778	2,088	74,094	2,166,752	174,500	45,038	526,385					10.3	1,903	1933					13,417	13,337	7,119	7,259					803,256
1934	1,276	10,932	1,878	61,974	2,199,613	202,505	42,437	462,980					8.0	1,259	1934	1.5	36			13,716	9,957	2,343	2,364					752,007
1935	1,042	9,074	1,417	49,609	2,356,750	277,909	32,900	470,480	4,411	68,863					1935	3.0	21	1.0	111	11,520	9,723	173	152					885,942
1936	1,543	13,438	1,862	78,649	3,019,912	264,243	35,728	628,630	30,443	453,356					1936	3.0	59			13,008	11,826	65	64					1,450,265
1937	1,486	13,006	2,720	163,200	3,185,983	277,687	38,121	879,723	27,598	606,150					1937			0.5	170	15,029	12,105	189	186					1,952,227
1938	943	8,357	1,562	71,462	3,465,828	292,669	41,147	627,280	23,735	329,464					1938			0.1	11	15,570	11,189							1,340,432
1939	1,204	11,606	2,084	104,185	3,818,447	318,813	45,266	685,448	29,092	415,571					1939					13,502	13,411							1,549,034
1940	1,127	11,892	1,688	104,637	4,308,015	430,802	48,118	905,968	29,584	554,703					1940					17,113	17,976							2,025,978
1941	813	8,689	1,645	143,885	3,802,382	501,233	43,273	814,795	27,437	514,437					1941					15,100	18,224							2,001,263
1942	730	7,630	1,283	127,850	3,001,675	396,472	33,512	630,977	21,035	394,412					1942					11,194	14,757							1,572,098
1943	162	1,693	6,636	696,759	757,655	99,443	8,579	129,109	5,077	76,158					1943					2,664	4,387					7.0	112	1,007,661
1944			12,421	1,304,170	86,927	11,409									1944			1.4	471							5.9	105	1,316,155
1945	2	18	11,763	1,176,270	88,611	14,030									1945													1,190,318
1946			3,597	359,708	949,626	201,490	12,737	626,736	11,361	519,124					1946											8.9	272	1,707,330
1947	12	131	57	6,945	2,064,507	371,994	29,437	2,471,963	25,216	1,738,600					1947					13,904	19,868							4,609,501
1948	11	117	16	2,515	2,269,780	413,632	30,484	2,973,508	21,593	1,687,325					1948					10,697	15,874					12.0	440	5,093,411
1949	9	98	1,619	180,236	2,832,373	575,191	37,507	4,115,823	21,241	1,954,199					1949					18,526	36,850					9.5	385	6,862,782
1950	9	131	735	106,919	2,911,455	972,632	39,115	5,024,900	25,800	3,757,368					1950					19,806	25,642					6.0	609	9,888,201
1951	53	813	362	69,459	2,731,776	1,082,739	32,883	6,485,166	21,743	4,550,686	4.8	7,754			1951			1.2	1,991	20,384	29,982					10.3	934	12,229,524
1952	6	88	528	121,076	3,383,515	1,304,062	39,016	6,505,815	23,683	4,471,637	2.2	1,948			1952			6.3	7,163	23,836	30,881							12,442,670
1953			16,185	4,840,938	2,859,317	1,090,532	35,787	3,476,116	19,944	1,817,123	3.9	2,664			1953			0.1	158	21,560	51,370							11,278,901
1954			20,623	6,465,450	3,367,753	1,278,681	40,561	4,902,207	19,615	1,912,208	4.3	2,099			1954					34,448	102,249					7.2	1,251	14,664,145
1955			22,472	9,650,272	3,735,408	1,496,836	40,309	5,340,710	17,151	1,940,315					1955					23,473	70,419							18,498,552
1956			29,694	12,758,999	3,889,399	1,599,538	43,220	6,299,661	16,331	2,005,243					1956					29,891	83,463							22,746,904
1957			29,627	8,137,446	4,243,494	1,713,510	50,251	6,070,883	19,445	1,984,568					1957					39,409	97,010					1.2	170	18,003,587
1958			39,321	10,186,278	5,210,359	2,064,012	59,559	5,478,716	17,484	1,436,921					1958					49,617	148,535					11.5	1,902	21,891,222
Totals	102,043	472,562	333,570	66,684,936	76,518,154	17,749,564	970,521	67,362,071	459,019	33,188,431	15.2	14,465	775	159,220		13.7	210	12.7	10,206	645,275	995,400	82,760	53,606	12.5	805	79.5	6,180	189,272,790

Hand specimen: The rock is a porphyritic lava. It breaks with a sub-conchoidal fracture and exposes greenish-cream feldspar phenocrysts up to 4 mm. across; these are set in a dark grey aphanitic groundmass. The weathered surface is pitted and rusty-brown.

Thin section: The thin section shows individual feldspar crystals as well as glomeroporphyritic feldspar patches in a groundmass mainly of feldspar microlites. The phenocrysts and glomeroporphyritic patches are up to 4 mm., but are mostly from 1 to 2 mm. across. The microlites form around the altered feldspar phenocrysts and show poor flow-banding. They are small plagioclase laths which are less than 0.1 mm. long. A fine intergrowth of quartz and feldspar occurs between some microlites. However, quartz, in the groundmass, is less abundant than feldspar, and forms xenoblastic grains, up to 0.2 mm. across. Accessory minerals are opaque iron mineral, epidote, sericite, and chlorite. Fine epidote veins less than 0.1 mm. wide cut the thin section.

The phenocrysts and glomeroporphyritic patches are all plagioclase that is mostly sericitized. The indistinct relict patches of plagioclase are unsuitable for the determination of composition. Where plagioclase is saussuritized, the main alteration products are flecks of sericite and fine grains of epidote.

Alteration of the rock, and grainsize of the groundmass, make an estimate of relative mineral abundance, and consequently naming of the rock, difficult. The rock has a low ferromagnesian mineral content but contains appreciable plagioclase and more than 10 percent of quartz. *Dacite* is probably the best name for it.

Specimen no.: R6955.
Thin section no.: 2104.
Locality: Lat. 17°48′55″S, long. 137°57′00″E.

Hand specimen: The rock breaks with a sub-conchoidal fracture exposing a dark brown-grey surface in which pink feldspar phenocrysts, up to 3 mm. across, are sparsely distributed. These are set in an aphanitic groundmass. The weathered surface is iron-stained and pitted.

Thin section: The thin section is porphyritic and consists essentially of altered feldspar phenocrysts set in a groundmass of feldspathic and siliceous material. Most of the phenocrysts range from 0.5 to 2 mm. across. The groundmass is extremely fine-grained and is dusted, in places, with opaque iron mineral grains; it may partly be devitrified glass as cracks are common and minute grains of opaque iron mineral form poorly-defined bands suggestive of flow. The thin section is cut by roughly parallel epidote veins about 0.2 mm. wide. The accessory minerals are sericite, chlorite, calcite, epidote, apatite, sphene, and opaque iron mineral.

Most of the feldspar phenocrysts appear to be of plagioclase, but are so altered that they cannot be identified. The phenocrysts are flecked with sericite and also contain some chlorite and finely granular epidote. Chlorite is generally concentrated around some of the extensively altered phenocrysts.

Accurate naming is difficult because of alteration. The thin section is not unlike 2103 in that it has a low ferromagnesian mineral content, and contains appreciable feldspar and probably more than 10 percent quartz; thus *dacite* is probably the best name for it also.

Specimen from the Peters Creek Volcanics

Specimen no.: R6953.
Thin section no.: 2102.
Locality: Lat. 17°42′40″S, long. 138°28′05″E.

Hand specimen: The rock is orange-brown, fine-grained, and breaks with a poor conchoidal fracture. It contains amygdules, filled with a bright green mineral, in an aphanitic groundmass. The amygdules are 3 to 4 mm. across.

Thin section: The thin section contains a few feldspar phenocrysts in an intergranular groundmass of feldspar laths. The amygdules are filled with a chloritic mineral. The euhedral phenocrysts are up to 2 mm. across and the laths in the groundmass average 0.5 mm. long;

interstices between the laths are occupied by small quartz grains. One part of the thin section is a band of finely tuffaceous material which includes numerous small quartz shards and mica flakes. The thin section is so extensively altered that a heavy brown coloration masks most features. This is probably iron-staining; it affects the feldspathic material most extensively.

Crystalline quartz lines nearly all the amygdules, forming a rim 2 mm. wide; this suggests that the vesicles were originally lined with amorphous silica. Where the quartz rim has been ruptured the amygdule has been filled with a fine-textured bright green mineral, probably chlorite. This mineral also veins the thin section and shows that the development of the amygdules occurred after the recrystallization of the silica-lined vesicles. Small amounts of chloritic material, and evenly distributed opaque iron mineral grains, less than 0.1 mm. in diameter, occur throughout the thin section.

The rock is an iron-stained and slightly silicified *basic volcanic.*

SPECIMEN FROM THE COLLESS VOLCANICS

Specimen no.: R6952.

Thin section no.: 2101.

Locality: Head of Colless Creek—approximately lat. 18°38′50″S, long. 138°15′55°E.

Hand specimen: The rock is a fine-grained, strongly vesicular lava, which is weathered brown as a result of iron-staining.

Thin section: The thin section has an intergranular fabric, but heavy alteration masks minor textural and mineralogical features. It consists mostly of feldspar laths and opaque iron mineral and the grainsize averages about 0.7 mm. It is abundantly vesicular, and an isotropic mineral, possibly opal, lines some of the cavities. Other cavities are lined with what appears to be a red-brown micaceous mineral, which cannot be identified with certainty. This mineral is also associated with angular quartz grains which represent incipient amygdules.

Feldspar laths up to 1 mm. long show undulose extinction, and multiple twinning which is indistinct because of iron-staining and flecking with sericite. Interstices between laths are occupied mainly by indeterminable alteration products and opaque iron mineral. A few red-brown, high-relief, mineral grains, which may be iddingsite, occur, but their small size and paucity makes their identification difficult. However, their presence suggests the possibility that the rock originally contained olivine. Original ferromagnesian minerals have been destroyed; their place is probably taken by the opaque iron minerals.

The rock is an altered *basic lava* whose alteration apparently resulted from slight hydrothermal activity and subsequent weathering; no evidence of metamorphism can be seen.

APPENDIX II
TABLES OF PRODUCTION

by

J. H. BROOKS

CONTENTS

			page
Table	I:	Metal and Mineral Production from the Cloncurry and Mount Isa Gold and Mineral Fields	299
Table	II:	Production of Individual Mines	
	A:	Copper	301
	B:	Silver-Lead in the Mount Isa Area (omitting Mount Isa Mines)	315
	C:	Cobalt	315
	D:	Gold	316
	E:	Miscellaneous	318
	F:	'Limestone' Flux	319
Table	III:	Treatment of Copper Ores from the Cloncurry Field	
	A:	Mount Elliott Smelter	320
	B:	Hampden Smelter	320
	C:	Mount Cuthbert Smelter	321
	D:	Small Smelters	321
	E:	Smelters off the Field	322
	F:	Ore purchased by Mount Isa Mines Limited	324
Table	IV:	Mount Isa Mines Limited: Production	
	A:	Metals	325
	B:	Mill and Smelters	326
	C:	Copper Dross	327
Table	V:	Lawn Hill Area	
	A:	Metal Production	328
	B:	Production from Individual Mines, 1948-58	329
Production Graphs			330

Table I — Explanatory Notes

The production figures were obtained from the Annual Reports of the Queensland Department of Mines. The figures refer to the metallic contents of ores with the exception of figures for scheelite, beryl, and mica, which refer to hand-picked concentrates.

In addition to the figures tabulated above 250.9 tons of uranium oxide (U_3O_8) valued at £2,566,818 and 941 tons of manganese valued at £8,040 were produced in 1958. Nine hundred and seventy-six tons of quartz valued at £276 were produced in 1920. The amounts of £2,574,858 and £276 have been included in the 1958 and 1920 totals respectively, and in the grand total.

The figure for the production of gold prior to 1900 was obtained from gold returns given in official reports by Hodgkinson (1877) and Rands (1895), in addition to figures in the Annual Reports of the Department of Mines. The figures probably refer to gold bullion and the value was calculated at £3/10/0 per oz. Subsequent to 1898 the figures refer to fine ounces of gold and the values were calculated at £4.4.11 5/11 per ounce up to 1931. From 1931 to 1952 the gold premiums have been added to the nominal values of £4.4.11 5/11 per ounce. Of the total gold recorded 28,184 oz. came from alluvial and reef sources and 73,916 oz. from copper-gold ores.

Limestone and ironstone produced between 1911-20 were used as flux by copper smelters at Mount Elliott, Hampden, and Mount Cuthbert. Limestone and ironstone produced from 1931 to 1958 has been used as flux at the lead and copper smelters at Mount Isa.

Figure 21

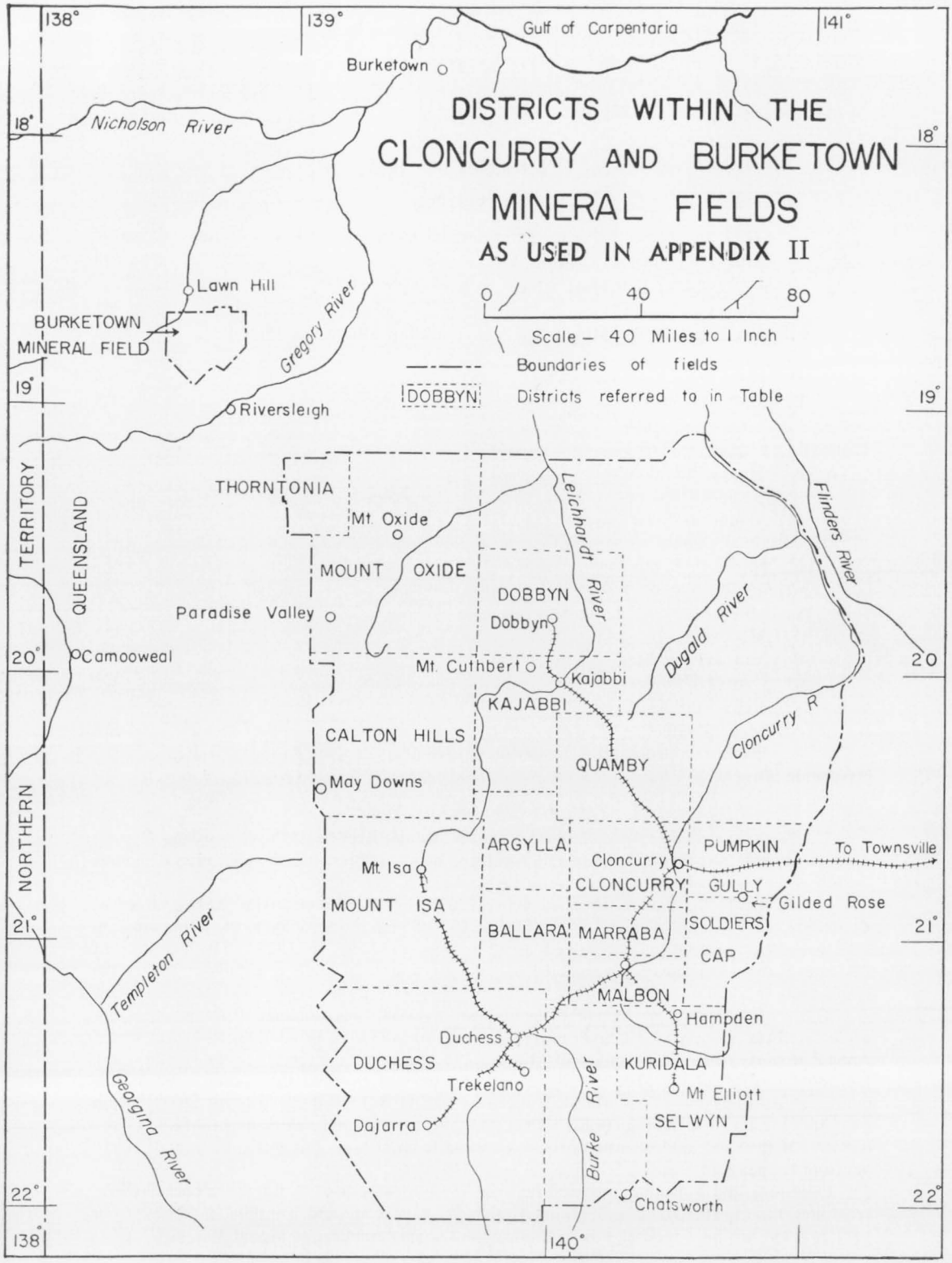

DISTRICTS WITHIN THE
CLONCURRY AND BURKETOWN
MINERAL FIELDS
AS USED IN APPENDIX II
Scale – 40 Miles to 1 Inch
Boundaries of fields
DOBBYN Districts referred to in Table
138°
139°
141°
Gulf of Carpentaria
Burketown
18°
Nicholson River
Lawn Hill
BURKETOWN
MINERAL FIELD
Gregory River
19°
Riversleigh
TERRITORY
QUEENSLAND
NORTHERN
THORNTONIA
Mt. Oxide
MOUNT OXIDE
Paradise Valley
Camooweal
20°
DOBBYN
Dobbyn
Leichhardt River
Flinders River
Dugald River
Mt. Cuthbert
Kajabbi
KAJABBI
CALTON HILLS
May Downs
QUAMBY
Cloncurry R
ARGYLLA
Mt. Isa
MOUNT ISA
Cloncurry
PUMPKIN
To Townsville
CLONCURRY
GULLY
Gilded Rose
SOLDIERS CAP
BALLARA
MARRABA
21°
Templeton River
MALBON
Hampden
Duchess
DUCHESS
Trekelano
Dajarra
KURIDALA
Mt Elliott
SELWYN
Burke River
Georgina River
Chatsworth
22°
138°
140°

TABLE II A.

PRODUCTION OF COPPER MINES AND LOCALITIES IN THE MINERAL PROVINCE OF NORTH-WESTERN QUEENSLAND.

Explanatory Notes

This Table is designed to bring up to date Table II in Report No. 35 of the Aerial, Geological and Geophysical Survey of Northern Australia (Nye & Rayner, 1940). Information additional to that table (i.e. from 30th June 1936 onwards) has been obtained from Annual and Monthly Reports of the Mining Warden, Cloncurry. The figures have been taken up to the end of 1958. All mines with a recorded production of more than one ton of copper or 10 tons of ore have been listed. The mines which have produced in the 1953-8 period have been distinguished by italics. A locality reference map accompanies the Bulletin.

A total of 515 mines and 60 localities is listed. Of these 16 mines, namely, the Mount Isa, Duchess, Mount Elliott, Trekelano, Hampden, Mount Oxide, Mount Cuthbert, Kalkadoon, Dobbyn. Orphan, Wee MacGregor, Great Australia, Hampden Consols, St Mungo, Rosebud, and Mighty Atom produced more than 1,000 tons of copper.

The production of gold recorded from copper ores has been shown, but these figures are largely incomplete. The gold content was usually only 1-2 dwt per ton, though higher values were recorded from mines in the south-eastern portion of the Cloncurry Field, notably at Mount Elliott, where the gold averaged 4.2 dwt per ton. As the amount of gold in Mount Isa copper ore is negligible no account is taken of the gold content of ore which is purchased by Mount Isa Mines Ltd from small copper mines. Thus the gold content of copper ores is of no significance at present as practically all copper ores are being treated at Mount Isa. Some copper ore contained appreciable amounts of silver, but usually the content was very low and the figures have not been given except for mines which have produced more than 1,000 oz of silver. The Hampden, Mount Oxide, Ivena, Mount Norna, Federal, Duchess, St. George, Success, Apple Pie and Southern Cross mines averaged more than 1 oz of silver per ton.

Production figures for early years are somewhat incomplete. In cases where ore production has been recorded without the metallic contents, the total production of ore has been given in brackets after the production of ore for which copper contents are available, e.g. Answer mine: 8,133 (8,488).

"(loc.)" indicates that the name refers to a locality and not a mine.

"(C)" indicates that the copper and/or gold contents and grade were calculated in part from smelter returns.

"E" indicates that the metallic contents of the ore have been estimated from an approximate or estimated figure for the grade of ore in the Mining Warden's records.

(Ni) indicates that more than 0.01% nickel has been found in assays of parcels of ore from the mine.

Name of Mine or Locality		Location	Ore (tons)	Copper (tons)	Gold (oz.)	%Cu
Ace		Quamby	86	10.5	0.5	12
Adelaide		Malbon	8(42)	2.4		32
Afterthought		—	12	3.0E		25
Agnes (Lady Agnes)		Ballara	390	63.5	35.8	16
Aitchell		„	23	1.7		7
All Blue		Kajabbi	8	1.6		20
Amy North		Ballara	32	3.1	1.2	10
Amy South		„	31	4.5	2.6	14
Angel		Mount Isa	45	3.4		8
Answer		Selwyn	8,133(8,488)	828.5	355.6	10
Anyway		—	9	2.1	0.5	24
Apple Pie	(Ni)	Argylla	117	20.4	5.9	18
Arbitration		—	48			
Ardmore		Duchess	13	0.6		5
Argent		Mount Isa	24	1.3		5
Argyle		„	85	4.8		6
Argylla (see Blockade)		Argylla	156 (451)	32.6		21
Asia	(Ni)	Marraba	438	106.5	0.9	24
Austin	(Ni)	Argylla	10	1.2		12
Australian Flag		Ballara	(14)			
Australian Margaret		Cloncurry	550	71.8E		13
Azurite		Kajabbi	17	3.3		19
Balfour		Marraba	14	4.5	0.5	32
Ballara (loc.)		Ballara	890	149.8	29.7	17
Bauhenia		Dobbyn	8	1.7	0.9	22
„		Soldiers Cap				
Bean Tree		Kajabbi	(32)			
Beauty	(Ni)	Duchess	94	16.5	7.2	18
Bedford		Quamby	573	55.7	3.4	10
Bedford North		„	see North	Bedford		
Belgium		Selwyn	354	88.7		25
Bell Bird		„	20	3.2	4.6	16
Big Beauty (see Beauty)						
Big Hill			23	0.9		4
Billybong		Cloncurry	47	8.3	3.7	18
*Binna Burra**		Duchess	638	48.4		8
Birthday		Malbon	276	30.0	15.1	11
Black Cat		Argylla	60	6.8		11
Black Rock			10	3.0E		30
Black Swan		—	6	1.8E		30
Block 14	(Ni)	Cloncurry	26	3.0E	1.0	11
„ 88		„	5	1.0	0.3	21
„ 15		Kuridala	5	1.4E		30
Blockade+		Argylla	4,493	417.8		9
Blockade North		„	693	65.2		9
Blockade South		„	776	68.0		9
Blue Beauty		Duchess	31	7.8	1.6	25
Blue Bell		Marraba	16	2.0	1.1	12
Blue Bell	(Ni)	Riversleigh	23	2.5		11
Blue Bird		Mount Isa	213	15.5	2.1	7
Blue Bottle		Soldiers Cap	45	3.9	6.0	9
Blue Hills		Mount Isa	180	12.7		7
Blue Mantle		„ „	103	8.6	0.6	8
Blue Moon	(Ni)	Argylla	156	13.1		9
Blunder		—	20	6.9E		35
Bobby Dazzler North		Kajabbi	19	3.3	0.5	17

*In *Mt. Hope* Group of leases

+ The *Blockade* leases were formerly held under the *Argylla* Freehold.

Name of Mine or Locality	Location	Ore (tons)	Copper (tons)	Gold (oz.)	% Cu
Bohemian Girl	Quamby	253	23.4	5.9	9
Bonza (Ni)	Ballara	65	6.8		10
Bonza South	„	74	5.9		8
Boomerang	Marraba	27	4.0E		15
Bonny Doon	Duchess	23	4.1	0.7	18
„ „	Kajabbi				
Bosca (Bostock)	Soldiers Cap	41	9.4	7.2	23
Bottle Field		(11)			
Boundary	Dobbyn	8	2.4E		30
Bower Bird (loc.)	Kajabbi	19	3.3	1.0	17
Brightlights	Duchess	208	27.2	4.1	13
Brilliant	Soldiers Cap	243	19.2	120.5	8
„	Marraba				
British Wonder		(29)			
Brydons	Ballara	17	2.6E		22
Bull Creek (loc.)	Soldiers Cap	26	7.9	0.2	34
Bullock	Cloncurry	13	1.0	0.8	8
Burke and Wills	Duchess	560	82.6	11.8	15
Bushy Park	Duchess	381	35.9	2.0	9
Butcher Bird	Cloncurry	8	2.4E		30
Butcher's Creek (loc.)	„	17	5.1E		30
Butru (loc.)	Duchess	44	3.0	1.8	7
Buttercup	Marraba	29	8.3	0.4	29
Calton Hills (loc.)	Calton Hills	18	5.4E		30
Cameron (Ni) (Cameronian)	Argylla	16	0.8		5
Cameron Ck. (loc.)	„	10	3.0E		30
Carioca	Argylla	12	2.2		18
Carlotta (Ni)		23	1.7		
Carnival	Soldiers Cap	5	1.2	0.3	23
Castle Bar	Malbon	12	2.3	0.5	19
C.B.	Quamby	9	1.4	0.5	16
Celestial	Marraba	25	2.3	1.9	9
Cerebos	Cloncurry	11	1.9	0.6	17
Chance	Kajabbi	64	8.7	4.2	14
Chance, The	Duchess	see The Chance			
*Chinaman**	Marraba	643(926)	49.0	2.7	8
Chum	Cloncurry	334(353)	31.2	3.9	9
Chum Victoria	Duchess	6(95)	0.5	0.3	9
Claim 24	—	10	3.5E		35
Clare South	see South Clare				
Cloncurry (loc.)	Cloncurry	1,483	178.8	47.9	12
Cloncurry Dumps	see Dumps, Cloncurry				
Cluny	Mount Isa	16	1.1		7
Cockatoo	Malbon	5(9)	1.0	0.4	21
Companion (see also Native Companion)	Quamby	81	7.0	7.3	9
Cone Creek (loc.)	Marraba	77	24.3E		32
Consols	see Hampden Consols				
Coolan's Hope	Mount Isa	17	2.0		12
Coolullah (loc.)	Dobbyn	34	11.9E		35
Copper Blonde	Argylla	7,531	37.4	(Cupriferous limestone flux)	
Copper Coy.		46	8.2	2.8	18
Copper King	Mount Isa	28	4.7		17

*Also produced 954 tons of cupriferous silica flux.

Name of Mine or Locality	Location	Ore (tons)	Copper (tons)	Gold (oz.)	% Cu
Copper Quarry	Pumpkin Gully	3(39)	0.8		30
Corella (loc.)	Cloncurry	284(410)	87.3		30
Cornet (Coronet)	Marraba	(122)			
Cosmopolitan (formerly Little Wonder-Mussolini)	Kajabbi	164	19.5		12
Countess	Duchess	5	1.6E		32
Cresswell	Calton Hills	12	0.8		7
Croxham Park	Thorntonia, now called O.P.?				
Crusader (Ni)	Dobbyn	3,648	380.5	39.9	10
Crusader Endeavour	,,	387	43.2		11
Cu-Co	Quamby	15	1.4	1.4	9
Dahlia	Marraba	267	30.9	7.1	12
Daisy	Marraba	125	37.4E		30
Dajarra (loc.)	Duchess	9	1.9		21
Dandy	Malbon	10(28)	4.1E		41
Deadlock	Marraba	30	9E		30
Deep Lead	Marraba	5	1.1		20
Deborah Robyn	Kuridala	133	5.7		4
Della Joy	Mount Isa	32	3.2		10
Denham	see Digby Denham				
Devil's Own	Kajabbi	26(71)	4.9	2.9	19
Diagonal	Marraba	219	56.9	3.9	26
Diamond Horseshoe	Dobbyn	10	2.0		20
Digby Denham*	,,	16	1.4		9
Dinkum Digger	Kajabbi	98	19.2	7.2	19
Dobbyn	Dobbyn	16,581	2,819.6	375.4†	17
Dobbyn North	,,	45	5.4	1.3	12
Dobbyn South	,,	82	10.3	3.7	12
Dobbyn (loc.)	,,	12	3.5	—	29
Dollubeet (loc.)	Kajabbi	57	9.1		16
Dolly Varden	Duchess	18	2.0		11
Dolomite+	Cloncurry	934(1,576)	130.1	28.0	14
Don, The	Kajabbi	7	2.0E		30
Doolan (Tim Doolan)		(12)			
Double A	Cloncurry	13	2.7	5.0	21
Double Oxide	Marraba	214	20.6	11.5	10
Doubtful	Kajabbi	9	1.4	0.5	16
Dronfield (loc.)	Duchess	16	1.7	0.7	11
Dry Dog	Kajabbi	14	1.9	0.8	14
Duchess (C)	Duchess	201,468 (203,468)	24,747	2,448‡	12
,, Dumps	see Dumps, Duchess				
,, (loc.)		7	1.2		17
,, (abandoned)		6	1.1		18
Duck Creek (loc.)	Marraba	452(529)	162.5		36
Dugald (loc.)	Quamby	43(118)	13.0E		30
Dulcie	Mount Isa	22	1.4		6
Dumps, Cloncurry		8	1.1	0.6	14
,, Duchess		148	8.4		6
,, Kajabbi		30	3.7	0.5	12
,, Quamby		31	3.5	5.8	11
Dundee	Cloncurry	29	3.0	0.3	10

* Also produced cupriferous limestone flux

\+ 643 tons of cupriferous limestone produced in 1953.

† Also produced 1,733 oz of silver.

‡ Also produced 1,988 oz of silver.

Name of Mine or Locality	Location	Ore (tons)	Copper (tons)	Gold (oz.)	% Cu
Eaglehawk	Pumpkin Gully	39	7.8E	2.5	20
Eagle's Nest	Mount Isa	19	1.5		8
Easter Gift	Marraba	26	5.9E		23
Echo	Argylla	153	14.0		9
Eclipse	Dobbyn	130(337)	29.3	19.2	23
Eclipse West	,,	16	3.5	3.7	22
Edison Record	,,	40	2.9		7
*Edna May** (formerly Wills-burgh)	Ballara	1,756	226.9		13
Eiffel Tower	Kajabbi	7	1.0	0.3	14
Elder, The	Soldiers Cap	37	10.8E	0.5	29
Elsie	Dobbyn }	550	88.2	20.2	16
,, (Ni)	Argylla }				
Elsie Siding (loc.)	Dobbyn	17	1.5		9
Emerald	Kuridala	14	4.2E		30
Emily	Cloncurry	9	2.6		30
Empire	Marraba	7(8)	1.7		24
Emu	Argylla	10	1.3	0.3	13
Erin-go-Bragh (or Alma)	Malbon	20(42)	8.0E		40
Eureka	Quamby	46	6.4	25.7	14
Eva (and Eva East)	Marraba	28(48)	9.3E		33
Extended	,,	6	1.3		21
Fairfield	Cloncurry	216	18.9	1.2	9
Fanny	see Lady Fanny	North			
,, North	,, ,, ,,				
Federal	Cloncurry	4,156	977.3	50.2+	24
Fighting Chance	Kajabbi	87	16.6	6.3	19
First Hiron	Paradise Valley	5	1.0		19
Fisher's Creek (loc.)	Pumpkin Gully	47	14.2E		30
Five to Nine	Mount Isa	21	1.5		7
Flat Top	Pumpkin Gully	121	5.3		4
Floodlights	Duchess	31	5.2	1.5	16
Floradora	Quamby	(40)			
Florence	Malbon	90(140)	20.9E	1.3	23
Flor Vale		19	5.7E		30
Flow Ann		24	2.4		10
Flying Dutchman	Pumpkin Gully	48	3.2	19.5	7
Foothills	Cloncurry	8	1.4		18
Fortyniner	Mount Isa	85	5.5		7
Four Brothers	Soldiers Cap	7	1.4	0.9	20
Frank's Creek (loc.)	Ballara	32	9.6E		30
Gabe Tepe	Duchess	13	1.2	0.7	9
Gem	Quamby	5	1.0	0.7	19
Gift	Marraba	30	12.0		40
Ginburra (loc.)	Quamby	75	4.6	2.9	6
Gorge, The (loc.)	Marraba	52(103)	15.5E		30
Great Australia	Cloncurry	33,965	2,693.3	29.6	8
Green Hole		6	2.1E		35
Green Rose	Kajabbi	7	1.1	0.9	16
Green's Creek†	Duchess	126	10.5		8
,, ,, (loc.)	,,	18(33)	5.3E		30
Guess	Selwyn	(31)			
Hamilton (Ni) (Paddock Lode)	Cloncurry	669	83.2	12.9	12

*Also produced approx. 6,000 tons of cupriferous silica flux
+ Also produced 2,979 oz. of silver.
† *Green's Creek* ore came from the *Binna Burra* and *Mt. Hope* leases.

Name of Mine or Locality	Location	Ore (tons)	Copper (tons)	Gold (oz.)	% Cu
Hampden	Kuridala	173,940	11,785.5	10,629.6‡	6.8
„ (Flue Dust)	„	10,165	811.1	306.6	8
„ (Slag)	„	64	5.0		8
„ Block 38	„	332	89.0	15.5	27
Hampden Consols (C.)	Kuridala	21,418	1,901.2	1,138.9	9
„ Queen	„	6	1.4	1.2	23
„ West (or Block 33)	„	61	18.3E		30
„ (loc.)	see Kuridala (loc.)				
Hampden and Mt. Cuthbert (Flue Dust)		1,133	92.8	25.5	8
Harriet Doris	Paradise Valley	see Lady Jean			
Helen	Kajabbi	14	1.2		8
Herbert	Selwyn	16	3.4		21
Hidden Treasure	Ballara	37	6.6	1.7	18
Hidden Treasure	Quamby	100	8.6		9
Hidden Treasure	Dobbyn	73	5.9		8
Highland Mary	Marraba	17	5.9		35
Hock		(19)			
Hopetown	Malbon	34	7.6	2.2	22
Horse Creek (loc.)	Kuridala	19	6.1		32
Horseshoe	Marraba	(19)			
Hugartie	Malbon	40	3.1		8
I Doubt*	Pumpkin Gully	33	4.3	8.5	13
Inherited	Duchess	771	93.8	64.2	12
Inkerman	Ballara	113	12.2		11
Inquiry	„	(31)			
Isabella	Kajabbi	9	2.7E		30
Italian	Duchess	124	31.7E	1.2	26
Ivena (Strike)	Mount Oxide	2,165	465.5	2.2 m	21
I.X.L.	Soldiers Cap	89	19.2	5.0	22
I.X.L.	Argylla	201	19.7	0.2	10
Jacky Jacky	Ballara	(36)			
Jessie	Marraba	238	57.7		24
Jessie	Argylla	27	2.0		7
John Bull	Ballara	6	1.8		30
John Egan	„	(33)			
John, The (Ni)	Mount Isa	46	3.3		7
Joker	Quamby	12	1.5	2.1	13
Joker (Old Joker)	Soldiers Cap	85	21.0	5.7	25
Jolly Roger (Ni)	Ballara	112	8.2		7
Jubilee (Ni)	Ballara	95	18.5		19
Juenburra Open-cut	Duchess	488	28.0		6
Just in Time	Malbon	595	131.1	6.3	22
Kaampa (loc.)	Pumpkin Gully	634(684)	99.6	45.4	16
Kajabbi (loc.)		1,783	297.4	113.2	17
„ (dumps)	see Dump, Kajabbi				
Kalkadoon (C)+	Kajabbi	45,887	3,494.8	38.5	8
Kalkadoon	Kuridala see Mt. Kalkadoon				
Kangaroo	Calton Hills	see Mammoth			
King Edward	Pumpkin Gully	315	23.9	84	7
Kingfisher	Soldiers Cap	5	1.1	0.2	20

‡ also produced 5,582 oz. of silver.

* See also table of individual gold mines.

m Also produced 2,505oz. of silver

\+ Also 313 tons of cupriferous limestone flux yielded 1.8 tons of copper.

Name of Mine or Locality	Location	Ore (tons)	Copper (tons)	Gold (oz.)	% Cu
Kingfisher	Thorntonia	123	11.6		9
King of the Range		7	1.0		14
King's Cross	Ballara	2,126 (2,175)	224.7	1.8	11
King's Crown	Argylla	11	1.1		10
*King Solomon** (King Solomons Mines)	,,	894	47.4		5
Kohinoor	Dobbyn	287(857)	39.0	6.0	14
Koolamarra (loc.)	Quamby	102	14.4	4.8	14
Kuridala (loc.)		7,999 (8,111)	1,621.6	136.9	20
,, (Dumps)	see Dumps, Hampden				
Labour Victory (Victory)	Selwyn	1,074 (1,303)	239.8	19.5	22
Lady Agnes	see Agnes				
Lady Amy	see Amy				
Lady Ann	Selwyn	12	1.1		9
Lady Annie	Paradise Valley	7,588	737.1	2.1	10
Lady Belle	Dobbyn	28	2.5		9
Lady Clayre	Quamby	21	2.4		11
Lady Ellen	Mount Isa	41	5.8		14
Lady Ethleen	Ballara	587	51.0	1.4	9
Lady Fanny (Fanny)	Duchess	2,592 (2,861)	211.2	17.0	8
Lady Fanny North (Ni)	Duchess	876	183.3	36.9	21
(North Fanny and North Lady Fanny assumed to be the same)					
Lady Franklin	Ballara	6	1.7E		30
Lady Jean (Harriet Doris)	Paradise Valley	49	12.7		26
Lady Jenny (Ni)	Ballara	515	37.2	2.1	7
Lady May	Kajabbi	977(1,008)	202.1	33.9	21
Lady Northcote	Ballara	6	1.8E		30
Lady Rose (Rose)	,,	58(82)	13.2	3.1	23
Last Chance	Cloncurry	75	10.8	4.1	14
Last Chance	Kajabbi	29	4.9		17
Last Out	Paradise Valley	6	1.0		16
Laurel	Malbon	28	7.3		27
Leach, The		13	1.1		9
Leichhardt (loc.)	Kajabbi	24(40)	7.2E		30
Lillian	Argylla	26	2.6		10
Lillimay (Royal)	Kajabbi	1,432	99.7		7
Limelight	Mount Isa	Produced 649 tons of cupriferous limestone flux.			
Limestone Ck. (loc.)	Cloncurry	56(292)	17.9	0.4	32
Little Beauty	Duchess	12(54)	1.5	0.5	13
Little Duchess	Cloncurry	26(33)	7.9E		30
Little Eva	Kajabbi	228	27.0	7.0	12
Little Hope	,,	15	1.2		8
Little Shamrock	Duchess	15	4.5E		30
Little Stranger		13	3.9E		30
Little Sunset (Ni)	Ballara	40	6.8		17
Little Windsor	Kajabbi	13	3.2	0.6	25
Little Wonder (see also Cosmopolitan)	,,	1,708	211.4	16.8	12
Lone Hand‡	Marraba	62(98)	3.6	31.9	6
Longara (loc.)	,,	145	56.6	17.0	39
Lookout	,,	29	8.4E	0.7	29
Lost Weekend		106	7.6		7

* Also 2,195 tons of cupriferous limestone flux yielded 49.3 tons of copper.

‡ See also Production of Miscellaneous Mines.

Name of Mine or Locality	Location	Ore (tons)	Copper (tons)	Gold (oz.)	% Cu
Lottery	Malbon	(22)			
Lucky Digger	Argylla	70	13.0		19
Lucky Knob	Produced 1,454 tons of cupriferous limestone flux.				
Lucky Spark		20	1.0		5
Mabel		(30)			
Magdaline	Argylla	7	1.1	0.5	16
Maggie's Ck. (loc.)	Selwyn	18	6.3E		35
Magnet (C)	Quamby	5,937 (6,784)	727.6	231.2	12
Magpie	Cloncurry	217	20.8	11.0	10
Magpie North	,,	9	1.1	0.2	12
Maiden	see St. Mungo				
Maitland		49	3.4		7
Majuba	Argylla	9	2.0		22
Malbon	Malbon	512(1,302)	108.5	18.1	21
Mammoth	Mount Oxide	725(733)	105.8	4.1	14
Manuel	Duchess	9	1.2	0.3	13
Manxman	Kajabbi	1,070	130.7	2.7	12
Marble Arch	,,	18	3.5	1.2	19
Margaret	Cloncurry	23	2.7		12
Margnor (or Toby Barton)	Marraba	99	7.6	6.6	8
Marraba (loc.)		596	84.8	20.5	14
Martin's Ck. (loc.)	Marraba	10(40)	3.0E		30
Mary Can	Malbon	33	7.0		21
Mary Ruth		19	0.9		5
Mascotte	see Mt. Mascotte				
Mata	see Little Duchess				
Matlock	see Mt. Maggie				
Maud A.	Duchess	15(23)	3.8E		25
Mavis	Quamby	25	3.9	1.3	16
Mavis	Mount Isa	27	2.3		9
May	Duchess	7	1.6		23
May Graham	Soldiers Cap	60	18.0		30
MacGregor (C) (Wee MacGregor)	Ballara	44,411	2,730.7	1,398.8	6
McDonald's Ck. (loc.)		4	1.2E		30
McLeod Hill	Calton Hills	250	34.3		14
McNamara (C) (or Mt. McNamara)	Marraba	4,849	609.3	137.0	13
McPhail	Malbon	18	3.4	1.0	19
Megaphone	Argylla	1,394	246.4	3.3	18
Mel		20	0.9		5
Melba (Melbar)	Ballara	77	17.4		23
Merry Monarch	Kajabbi	4	1.2E		30
Meteor	Argylla	2(25)	0.2		10
Meteorite		6	1.3	0.3	22
Midway	Kuridala	18	1.7	2.6	10
Mighty Atom	Kajabbi	9,503	1,163.4	33.6	12
Mighty Atom South	,,	29	4.6	0.8	16
Miner's Dream	,,	17	4.6		27
Minya		8	2.4	0.4	31
Mirage		Produced	121 tons of limestone	cupriferous flux	
Mocking Bird	Quamby	23	4.6	0.5	20
Mona	Ballara	23	6.9E		30
Monakoff	Pumpkin Gully	186	18.3	11.8	10
Monarch Senior	Duchess	5(13)	1.4		28

Name of Mine or Locality	Location	Ore (tons)	Copper (tons)	Gold (oz.)	% Cu
Monastery (Ni)	Duchess	12(40)	3.6E		30
Monitor	see Young Australian				
Monte Bello		765	9.8	(cupriferous limestone flux)	
Moon	Quamby	32	5.7	4.2	18
Moonlight	,,	11	2.2	1.6	19
,, ×	Chatsworth	7	1.5	1.3	21
Morris Ck. (loc.)	Cloncurry	48	14.4E		30
Moss		19	3.8	0.5	20
Mountaineer	Ballara	6	1.5	0.3	26
Mountain Home	(see Mount Norna)				
Mountain King	Argylla	35	3.5	2.2	10
Mount Beattie	Malbon	53	4.3		8
Mount Birnie (Ni)	Duchess	13	1.6	0.7	12
(Mount Burns)					
Mount Burns	Dobbyn	217	19.1		19
Mount Burns	Mount Isa	30	2.1		7
Mount Clark		30	2.3		8
Mount Clarke	Calton Hills	15	1.3		9
Mount Copper Top	Kajabbi	11	1.8	0.7	16
Mount Cuthbert (Ni)	,,	60,680	4,323.9	174.5*	7
,, ,, (Flue Dust)		1,259	86.4		7
see Hampden and Mt. Cuthbert Flue Dust					
Mount Cuthbert South (C)	Kajabbi	14	4.1E		30
Mount Doolan	Dobbyn	24	2.9	0.8	12
Mount Dore	Selwyn	16	5.9		37
Mount Douglas	Pumpkin Gully	4	1.2E		30
Mount Elliott (C)	Selwyn	263,741 (264,027)	24,435.4	33,894	9
Mount Elliott (slag)	,,	68	8.6		13
Mount Elliott (Reward Claim)	,,	155	24.8	15.4	16
Mount Federal	see Federal				
Mount Ferguson	Kajabbi	5	1.1	0.3	21
Mount Glory	Malbon	25	2.1	0.4	8
Mount Godkin	Quamby	(26)			
Mount Gordon	Mount Oxide	101	24.5	1.8	24
Mount Hope (Ni)	Duchess	1,373 (1,441)	103.4	3.5	8
Mount Hope North	,,	172	15.5	0.8	9
Mount Isa (loc.)‡		19	3.8	0.2	20
Mount Kalkadoon	Kuridala	140	29.6		21
Mount Kelly	Calton Hills	2,359	157.3		7
Mount Maggie	,, ,,	1,937	133.4		7
Mount Mascotte (C)	Duchess	4,824	866	248.4	18
Mount McCabe	Marraba	4(23)	1.2E		30
Mount McLeod	see MacLeod Hill				
Mount McNamara	see McNamara				
Mount Metallic	Kajabbi	91(112)	27.4	0.7	30
Mount Millicent	,,	11(32)	2.2	0.7	20
Mount Mindie	Marraba	103	39.1E		38
Mount Norna	Soldiers Cap	199	41.6	0.3B	21

× see also Production of Individual Gold Mines.

* Also produced 996 oz. of silver.

B also produced 1,912 oz. of silver.

‡ For Mt. Isa mine production see Table IV.

Name of Mine or Locality	Location	Ore (tons)	Copper (tons)	Gold (oz.)	% Cu
Mount Olive	Kajabbi	1,910	227.6	0.4	12
Mount Oxide		48,249 (50,450)	10,140.0	144.7+	21
Mount Remarkable	Kajabbi	68	20.3E		30
Mount Ritchie	Dobbyn	165	16.1	0.8	10
Mount Start	Marraba	15	5.1E		34
Mount Vaughan	Kajabbi	10	1.6	0.6	16
Mussolini	,,	707	140.0	6.9	20
My Luck	Argylla	185	13.1		7
Mystery	Ballara	12	1.2	0.2	10
Mystery Hill	Cloncurry	10	1.9		19
Naraku (loc.)	Quamby	767	93.8	27.3	12
Naraku Squibs	,,	26	1.0	4.6	4
Native Bee	Mount Isa	876	71.8	5.8	8
Native Companion	Quamby	502(554)	92.8	11.5	18
New Australian	,,	38	2.2		6
New Bluebird	Mount Isa	94	7.7		8
New Chum	Cloncurry	(15)			
New Crusader	Dobbyn	78	9.0		12
New Kalkadoon	Kuridala	5	1.6		30
New Longara	Marraba	6	1.6	0.3	27
New Moon	Cloncurry	18	0.6		3
New Year	Dobbyn	18	2.7E		15
New Year Gift	Cloncurry	11	1.3		11
Night March	Duchess	4	1.1	0.2	28
Nil Desperandum	Dobbyn	83(98)	13.3E	3.8	16
Nil Desperandum	Duchess	408	27.5	0.3	7
Non-Pariel	Ballara	28	5.7		20
Noontide	Marraba	61	11.3E		18
Norma		15	1.1		7
North Bedford	Quamby	15	1.8		12
North Blockade	see Blockade North				
North Volga	Quamby	60	6.5	4.0	11
Okay (The Okay)	Argylla	78	6.1		8
Old Joker	see Joker				
Old Sydney	see Sydney				
Oliver Twist	Quamby	(29)			
Oona (loc.)	Kajabbi	250	28.1	7.9	11
Oorindimindi	Pumpkin Gully	7	2.0E		30
O.P. (Croxham Park?)	Thorntonia	76	5.9		8
Orphan	Dobbyn	23,764	2,740.0	601.7*	12
O'Toole Ck. (loc.)	Soldiers Cap	12	3.6E		30
Over the Hill	Calton Hills	57	4.2		7
Oxford		17	1.6		9
Oxide Creek (or Big Oxide)	see Mount Gordon				
P.A.	Calton Hills	102	7.7		8
Paddock Lode	see Hamilton				
Painter	Quamby	87	16.6	8.2	19
Palm Tree (Loc.)	,,	40	11.9E		30
Parting Gift		12	2.9	2.0	24
Patrick	Duchess	23	2.5	1.0	11
Paul Freeman (or Freeman)	Dobbyn	11	1.7	0.2	15
Peach Pie	Ballara	92	8.3		9
Pearl	,,	76 (136)	24.4		32
Perseverence	Marraba	13	2.2	0.7	17

+ Also produced 28,723 oz. of silver.
* Also produced 1,643 oz. of silver.

Name of Mine or Locality	Location	Ore (tons)	Copper (tons)	Gold (oz.)	% Cu
Perseverence	Duchess	660	98.5	31.2	15
Philice	Mount Isa	7	1.1		15
Pegeon		42	4.7	3.0	11
Pindora	Malbon	115(2,968)	19.7	5.6	17
Pinnacles (loc.)	Pumpkin Gully	14	3.4		25
Pioneer	Marraba	352	92.3	20.9	26
Pioneer Chief	,,	30(56)	8.2		27
P.K.	Quamby	19	2.0		11
Playanus		24	4.6		19
Pokara (loc.)	Malbon	12	1.0	0.5	9
Possible		8	2.4E		30
Premier		6	1.8E		30
Prince of Wales (Ni)	Ballara	116	18.9	1.0	16
Prodigal	Duchess	54(76)	13.2E		25
Prospector	Marraba	30	10.0E		33
Prospector Ck. (loc.)	Kajabbi	66(138)	19.7E		30
Proxham Park (Croxham Park)	see O.P.				
Pumpkin Gully (loc.)		92	28.7E		31
Pymurra (loc.)	Pumpkin Gully	266	41.2	5.2	16
Python	Dobbyn	16	2.6		16
Python	Soldiers Cap	24	3.6	1.5	15
Python Extended	Argylla	47	5.0		11
Quamby (loc.)		510	54.7	38.3	11
Queenslander	Kajabbi	10(17)	2.8		28
Ready Rhino (Rady Rino)	Marraba	43	7.2E	1.3	17
Red Cross	Dobbyn	13	1.1		9
Red Wings	Mount Isa	29	1.4		5
Referee	Kajabbi	2,236 (2,436)	376.5	48.6	17
Revenue	Duchess	163	20.7	8.9	13
Revenue North	,,	16	1.6	1.1	10
Reward Claim	see Mt. Elliott	Reward	Claim		
Reyphie		8	1.4	0.6	17
Ridgepole (Ni)	Lawn Hill	23	2.7		12
Rifle Range		5	1.8E		35
Robert's Ck. (loc.)	Soldiers Cap	6	1.8E		30
Rocklands	Cloncurry	8	2.3E		30
Rocky Home (Ni)	Argylla	175	17.9		10
Rocky Range	Argylla	68	5.0		8
Rolling Stone (Ni)	,,	10	0.9		9
Rose	see Lady Rose				
Rosebud	Ballara	7,921 (21,030)	519.0		7
Rosina	Mount Isa	7	2.1	0.3	30
Ruby	Kajabbi	10	2.6	0.6	26
Ruth	see Referee				
Sandy Ck. (loc.)	Soldiers Cap	11	3.2E	0.1	30
Scotia	Kajabbi	7	1.0		14
Scots & The Mark	Duchess	27	2.1		8
Second Chance	Malbon	509	105.5	41.5	21
Second Try	,,	6	1.0	0.1	17
Secret	Ballara	47(1,387)	9.4	1.6	20
Selwyn		2,367	494.9	94.6	21
Shamrock	Soldiers Cap	54	10.3	3.3	19
Singer	Kajabbi	39	4.3	1.0	11
Slaty Ck. (loc.)	Marraba	208	65.1E		32
Snowball	Dobbyn	20	4.6	1.3	23
Snowdrop	Dobbyn	8	1.0		12
Snow Queen	Ballara	90	6.9		8
Snowstorm	Ballara	56	4.7		8
Soldiers Cap (loc.)		66(83)	19.7E		30

Name of Mine or Locality	Location	Ore (tons)	Copper (tons)	Gold (oz.)	% Cu
Solomon	see King	Solomon			
South Atom	Kajabbi	139	21.4	2.0	15
South Blockade	see Blockade	South			
South Bonza	see Bonza South				
South Dobbyn	see Dobbyn	South			
South Clare	Quamby	67	6.2	7.4	9
Southern Cross	Marraba	279	52.6	11.6	19
Spirit of Progress	Mount Isa	35	1.2		4
Splinter	Ballara	9	1.3	0.6	14
Spray		(21)			
Springs	Ballara	49(74)	14.8E		30
Springs Extended	,,	52	16.7E		32
Squib	Quamby	122	11.3		9
Squibs (Cloncurry)		8	1.4	0.3	17
,, (Dobbyn)		19	2.0		10
,, (Duchess)		10	1.3		13
,, (Malbon)		4	1.0	0.1	25
,, (Naraku)	see Naraku	Squibs			
Standawi		11	1.0		9
Star	Quamby	56	6.4	10.2	11
St. Andrews	Duchess	51(298)	5.1	0.8	10
St. George	,,	157	48.4	4.3	31
St. Mungo (Maiden)	,,	6,596(7,017)	1,537.0		23
St. Paul's Ck. (loc.)	Dobbyn	9(25)	2.6E		30
Strike	see Ivena				
Success* (Varie's Success)	Marraba	303	107.3	5.8	36
Sulphides	Dobbyn	17	3.4		20
Sunflower	Ballara	11	3.3E		30
Sunrise	Soldiers Cap	59	2.8	19.6	5
Sunset+	Ballara	543	104.1	0.6	19
Surprise	Kajabbi	587(594)	105.9	41.6	19
Surprise North	,,	30	3.2	2.3	11
Surprise		20	1.7		8
Sweet William	Marraba	106	17.5	6.5	16
Sydney	Dobbyn	12	2.0		17
Sylvia May	Mount Isa	24	4.1		17
Tambourine	Marraba	6	1.8E		30
Tartan		38	11.4E		30
T.C.	Kajabbi	231(281)	38.7	12.7	17
Telegraph	Malbon	27(45)	8.0E		30
Tharsis	Marraba	90	10.8E		12
The Chance	Duchess	17	3.5	1.3	21
The Dawn		10	1.1		11
The Leach	see Leach, The				
The John	see John, The				
The Scots & The Mark	see Scots and	the Mark			
The Western	see Western				
Three As	Calton Hills	10	0.5		5
Three Stars	Ballara	22	1.8		8
Tile	Soldiers Cap	51	5.8	3.5	11
Timberoo	Marraba	386	132.4	0.1	34
Tin Lizzie	Mount Isa	79	9.3	7.8	12
Tin Lizzie	Quamby	41	5.7	1.0	14
Tip Top	Kuridala	44	13.5E		31
Toby Barton	see Margnor				
Tokio Rose		67	3.3		5
Tolrah	Argylla	10	0.4		4

* See also Production of Individual Cobalt Mines.

\+ Also 208 tons of cupriferous limestone flux yielded 7.2 tons of copper.

Name of Mine or Locality		Location	Ore (tons)	Copper (tons)	Gold (oz.)	% Cu
Toole Creek		see O'Toole Creek				
Top of the World		Mount Isa	41	3.8		9
Trafalgar	(Ni)	Ballara	485	64.9	27.8	13
Tramp Hill			14	1.1		8
Transylannia		Ballara	16	2.0		12
Trekelano (C)	(Ni)	Duchess	184,811	20,140.7	13,606.0*	10.9
Trekelano North		,,	20	3.0	1.4	15
Trey Bit		Argylla	218	19.9		9
True Blue		Duchess	90(120)	7.5	1.0	8
True Scott			11	1.0		9
Trump, The		Malbon	3(4)	1.2		39
Trump		Kajabbi	54	10.5	1.6	20
Turp Ck. (loc.)			10	3.2E		32
Two A			13	0.5		4
Two Macs		Kajabbi	263	49.8	28.4	19
Two Reds		Argylla	115	5.1		4
Two Sports		Quamby	15	6.0E		40
Una		,,	173(222)	32.4	33.4	19
United States	(Ni)	Thorntonia	12	2.0		17
Varie's Success		See Success				
Victoria		Mount Isa	19	0.7		4
Victoria		Duchess	6	1.3		22
Victory		see Labour Victory				
Victory (Victor)		Quamby	43	3.8	1.4	9
Volga	(Ni)	,,	199	27.6	16.8	14
Vulcan		Marraba	280	11.7	0.6	4
Waimate		Mount Isa	11	1.7		15
Wallace		Cloncurry	155	27.6	66.0	18
Wallaroo†		Ballara	248	43.5	17.3	18
Wallaroo Flat		Quamby	61	7.5	4.5	12
Wallat		Duchess	38	5.3	4.0	14
Wanyee		Lawn Hill		84.5		28
Waratah		Marraba	20	7.0E		35
Warwick Castle		Kajabbi	1,580	174.2	11.4	11
Wee MacGregor		see MacGregor				
Western		Kajabbi	154	25.0	0.2	16
Western Ec.		,,	8	1.3	0.5	16
Western Star		Malbon	8	1.3	0.2	16
Wharspurwhar		Kajabbi	184	21.6		12
White Cat		Kajabbi	15	1.2	1.1	8
White Christmas		Cloncurry	14	0.8		6
Willandungur (Woolondonga)		Ballara	1,362(1,574)	175.0	4.5	13
Willcocks			(307)			
Wills, The			18(35)	5.4E		30
Willsburgh		see Edna May				
Witch		Argylla	(12)			
Wonder Valley		Cloncurry	138	18.2		13
Wonga		Argylla	8	2.4E		30
Woobera (loc.)		Duchess	79	9.0	3.4	11
Woolloodah		Ballara	14	1.1		8
Yammamilla (Yamamiller)		Kajabbi	353	33.2	7.0	9
Yellow Bird			10	1.6		16
Yeronga		Cloncurry	35	11.6E		33
Yoomoo (loc.)		Marraba	1,106	166.1	41.3	15
Young Australian		Kuridala	270(335)	18.0		6
Zingara		Marraba	19	4.2	1.8	22
4 Mile (loc.)			18	5.7E		32
5 Mile (loc.)			5	1.5E		30
18 Mile Well (loc.)			26	8.5		33
88		Malbon	28(74)	10.1E		36

* Also produced 10,885 oz. of silver.

† Some production from the Wallaroo was included with the figures for the Wee MacGregor.

TABLE II B

Production of Silver-Lead Mines in the Mt Isa area.

(For Mt Isa Mine production see Table IV.)

Name of Mine	Ore (tons)	Silver (oz.)	Lead (tons)	Years of Production
Bernborough	6,531	38,740	1,718.4	1947-51
Copalot	319	1,090	52.8	1955-57
Doolan's Hope	7	18	1.2	1950
Dumps (Mt Isa)	24	69	5.9	1949
New Silver Valley	7	99	2.6	1948
North Star	199	1,200	47.0	1950-51
South Crystal	178	248	31.4	1949-51
Spider Ant and Reject	15 39	783	29	1930
	7,319	42,247	1,888	

These ores were treated by Mt Isa Mines Ltd. with the exception of the production from the Spider Ant and Reject which was treated at the Chillagoe State Smelters. Production of silver-lead on a small scale is reported for the period 1923-27 from the Mt Isa area but records of individual mine production are not available. The Bernborough mine which is the largest producer in the Mt Isa area apart from Mt Isa Mine was acquired by Mount Isa Mines Ltd in 1951.

TABLE II C

Production of Cobalt Mines.

Name of Mine	Locality	Ore (tons)	Cobalt (tons)	Value £	Years of Production
Mt Cobalt	Selwyn	3,235*	766.4	157,096	1920-1934
Success† (Varie's Success)	Marraba	25	5.4	1,304	1929-1931
Queen Sally	Kajabbi	26	2.6	820	1926 and 1930
			774.4	159,220	

* Hand-picked ore and concentrates. Figures for ore production incomplete.

† See also production of individual copper mines.

TABLE II D

Production of Gold Mines

Name of Mine	Locality	Ore Tons	Gold Oz.	Years of Production	Authority
Boomerang	Gilded Rose	134.5	214.2	1933-41	Mining Warden's Reports
Bower Bird and Soldiers Cap Batteries			36.5	1909	" " "
Brilliant	Bull Ck.	see Table IIA			
British Lion	Soldiers Cap	34.0	16.5	1905	" " "
Caledonia	Pumpkin Gully		117	1872-75	Hodgkinson (1876)
Comet	Gilded Rose	27.4	19.9	1931-36	Mining Warden's Report
(Some production from the adjacent "Boomerang" and "Comet" was not differentiated.)					
Comstock (Australian)	Soldiers Cap	109.1	194.6	1905, 1933-37	Mining Warden's Report
Crescent No. 1	May Downs	242.2	100.3	1927-35	" " "
Dough	Florence Ck.	21.9	10.5	1921	" " "
Falcon	Soldiers Cap	168.9	255.3	1932-39	" " "
(Rose & Thistle)	(Early production around 1880 not recorded.)				
Florence Ck.		11	11.0		
Flying Dutchman	Pumpkin Gully	see Table II A.			
Gertrude	Doughboy Ck.		1,300	before 1895	Rands (1895)
Gilded Rose			1,324	1872-75	Hodgkinson (1876)
" "		3,408	4,713	1875-83	Rands (1895)
" "	tailings dumps	649.5	58.7	1905, 09, 41	Mining Warden's Report
" "	concentrates from dumps	0.1	39.5	1939-47	" " "
" "	see also ZAP claim				
" "	locality	52.4	104.1	1942	" " "
Gilt Edge	Gilded Rose	150.3	246.1	1931-41	" " "
Homeward Bound	Pumpkin Gully		64	1872-75	Hodgkinson (1876)
Homewards	" "	34.5	10.4	1934	Mining Warden's Reports
I Doubt	" "	27.3	18.4	1934	" " "
Iron Blow	Gilded Rose	45.7	44.8	1934-36	" " "
John O'Groat	Pumpkin Gully	50	51.5	Before 1895	Rands (1895)
Jones' Favourite (I Own It)	Gilded Rose	26.3	42.6	1931-33	Mining Warden's Reports
King Edward	Pumpkin Gully	139.5	20.7	1936-41	Mining Warden's Reports
Lady Florence	Florence Creek	5.9	17.2	1934-35	" " "
La France	Gilded Rose	90.4	62.6	1935-37	" " "
Last Call	Martin Creek	128	143.3	1891-94	" " "
Lone Hand	see Table IIA				
Mary Ann	Pumpkin Gully	52.8	23.1	1937-41	" " "
Moonlight	Chatsworth see also Table IIA	49	12.8	1937	" " "
Mount Freda (Saracenesca)	Soldiers Cap	880.3	172.9	1934-40 & before 1895	" " " and Rands (1895)
Mount Quamby	Quamby	54	28	1921	Mining Warden's Reports
			166.8	1931-35	" " "
New Year's Gift	Soldiers Cap	47.2	27.6	1941	" " "
Pak-A-Pu	" "	27.9	27.7	1937	" " "
Princess	Pumpkin Gully	17.0	18.4	1905	" " "
Rose & Thistle South	Soldiers Cap	114	28.5		" " "
Sauce Bottle	Gilded Rose	264.1	262.8	1933-40	" " "
Silver Lining	" "	98.9	60.9	1934-39	" " "
Silver Lining & Iron Blow	" "	192.1	140.9	1937-38	" " "

TABLE II D. *Production of Gold Mines*—cont.

Name of Mine	Locality	Ore Tons	Gold Oz.	Years of Production	Authority
Sing's Reward	Borah Creek		15.5	1934-35	Mining Warden's Reports
Soldiers Cap loc.		126.4	76.7	1905, 34	,, ,, ,,
Sunnymount	Gilded Rose	26.1	13.6	1937	,, ,, ,,
Surprise	Pumpkin Gully		170	1872-75	Hodgkinson (1876)
Sweat Box (New Moon)	Gilded Rose	92.3	60.6	1932-40	Mining Warden's Reports
The Chance (Chance)	Soldiers Cap	27.5	26.5	1905, 33-40	" " "
The Chief	Pumpkin Gully		29	1872-75	Hodgkinson (1876)
Tip Top Camp	Agate Downs		<300	before 1895	Rands (1895)
Uncle Sam	Pumpkin Gully		17	1872-75	Hodgkinson (1876)
Uncle Tom	" "	181.3	81 111.4	" " 1911, 36-41	" " Mining Warden's Report
Urandula	Soldiers Cap	80	140E.		Rands (1895)
Victoria	Bower Bird	932	895.5	1895-97, 1909	Rands (1895) and Warden's Reports
Victory	Gilded Rose	184.3	281.5	1933-41	Mining Warden's Reports
Victory Consol.	,, ,,	239.1	495.7	1935-40	" " "
Victory Amal.	,, ,,	50.2	81.7	1940	" " "
Wanderer	Pumpkin Gully		80	1872-75	Hodgkinson (1876)
Zap	Gilded Rose	125.7	104.7	1931-33	Mining Warden's Reports

(The "Zap" claim was over the "Gilded Rose" tailings dump)

Locality Index

Agate Downs—40 miles south of Cloncurry.
Borah Creek—20 miles S.W. of Kajabbi.
Bower Bird—23 miles W.S.W. of Kajabbi.
Bull Creek—11 miles S.E. of Cloncurry.
Chatsworth—33 miles S.S.W. of Selwyn.
Doughboy Creek—28 miles S.W. of Kajabbi.
Florence Creek—32 miles south of Cloncurry.
Gilded Rose—9 miles E.S.E. of Cloncurry.
May Downs—28 miles N.W. of Mt. Isa.
Pumpkin Gully—8 miles E. of Cloncurry.
Quamby—28 miles N.W. of Cloncurry.
Soldiers Cap—25 miles S.E. of Cloncurry.

The production figures have been compiled from official reports of the Cloncurry Mining Warden and by W. O. Hodgkinson (1876) and W. H. Rands (1895). The greatest period of production took place from 1867-1900, but production figures for individual mines are incomplete, and no attempt has been made to list production from alluvial workings.

TABLE II E

Miscellaneous Mines Production

Name of Mine	Locality	Type of Ore	Ore (tons)	Metal or Mineral	Value £	Period of Production
Big Beryl	Mica Ck.	Beryl		71.8 tons	4,878	Intermittent 1943-58
Hexagon, Beryl Queen, Beryl King	" "	"		7.7 „	1,302	1958
Lone Hand*	Marraba	Bismuth	86.3	0.51 tons	149	1931-36
Mica Creek loc.	Mt. Isa	Mica		12.5 cwt.	805	1922, 1925, 1927
McLennan's Claim	Kajabbi	Scheelite	—	12.7 tons	10,637	Intermittent 1931-52
Tunny's show	Kuridala	"	2.2	0.15 "	158	1953
Trekelano loc.	Duchess	"		0.1 „	11	1938
Silver Phantom	Kuridala	Silver	84.9	129,138 oz	43,343	1954-58
O'Brian's Soak Loc.	Duchess	"	8.7	10,124 "	2,053	1918

* See production table of individual copper mines.

TABLE II F

"Limestone" Flux Production: Cloncurry-Mount Isa Gold and Mineral Fields.

Quarry or Lease	Location	Production (tons)	Remarks
Salmon Dingo Dolomite	Dolomite siding 6 miles south-west of Cloncurry	208,867	150,943 tons cupriferous flux for Hampden smelters, 1911-20. 57,924 tons for Mt Isa smelter 1949-53. 16,824 tons consumed by Mt Isa smelter in 1948 probably mainly from Dolomite quarries. 1958 production not recorded.
Wilgar (New Years Gift)	11 miles west of Cloncurry	105,559	1950-51, 1953-56 & 1958, for Mt Isa Mines Ltd.
Marimo	10 miles south of Cloncurry	50,986	1940-43 & 1946, for Mt Isa Mines Ltd. Figures for 1947 not recorded. Cupriferous in part.
First Hope	2 miles E.N.E. of Cloncurry	10,691	1953, for Mt Isa Mines Ltd.
Quamby Queen	2 miles N.N.E. of Quamby	2,074	1948-53, ,, ,, ,,
Jackpot	Cloncurry	426	1950-51, ,, ,, ,,
McConachie (Juenburra)	4 miles south of Duchess	122,200	1931-40 & 1950-53, for Mt Isa Mines Ltd. 1946-47 and 1958 production not recorded. Cupriferous in part, with a little molybdenite.
Myubee Siding (Lucky Chance)	8 miles N.W. of Duchess	1,145	1952 and 1957, for Mt Isa Mines Ltd.
Snowball Bobby Dazzler	Kajabbi	3,823	1950-53, ,, ,, ,,
Oona Siding	N.N.W. of Kajabbi	1,050	1950-52, ,, ,, ,,
Elsie Siding	2 miles south of Dobbyn	1,033	1950-53, ,, ,, ,,
Kalkadoon	9 miles W.N.W. of Kajabbi	313	1956, cupriferous flux for Mt Isa Mines Ltd.
Sunset	1 mile N.N.W. of Mary Kathleen	208	1956-57, ,, ,, ,,
Copper Blonde	14 miles N.N.E. of Mary Kathleen	7,531	1957-58, ,, ,, ,,
King Solomon	22 miles east of Mt Isa	2,195	1956-58, ,, ,, ,,
Limelight	15 miles E.N.E. of Mt Isa	649	1957, ,, ,, ,,
Lucky Knob	?	1,454	1956-57, ,, ,, ,,
Mirage	36 miles W. of Cloncurry	121	1957, ,, ,, ,,
Monte Bello	3 miles N.E. of Ballara	765	1956-57, ,, ,, ,,

TOTAL 521,090

TABLE III

Treatment of Copper Ores from the Cloncurry-Mount Isa Gold and Mineral Fields

A. *Mount Elliott Smelter*

Year	Tons Ore	Tons Copper	Oz. Gold	Oz. Silver	Fluxes	
					Ironstone	Limestone
1909	6,631	958	1,496	N.A.*	N.A.	N.A.
1910	16,585	2,041	3,617	2,206	"	"
1911	41,922	5,447	10,493	5,170	3,966	1,278
1912	54,531	6,690	11,776	12,013	1,466	885
1913	30,369	3,205	5,211	6,857	N.A.	N.A.
1914	18,757	1,840	2,856	3,658	6,305	2,184
1915	16,521	1,734	2,145	3,836	3,181	1,863
1916	16,648	1,565	657	3,274	4,993	2,641
1917	16,679	773	106	425	16	804
1918	77,452	3,581	N.A.	N.A.	8,440	168
1919	19,796	899	"	"	1,345	—
	Smelter closed down during 1919.					
	315,891	28,733	38,357	37,439	29,712	9,823

In addition to ore from the Mt Elliott mine, ore was treated from the Hampden Consols, Great Australia, Mt Cuthbert, Mt Oxide, Kalkadoon, Chinaman, Mighty Atom, Dobbyn, Lady Ethleen, and Lady Jenny mines. The ironstone flux was obtained from Hematite siding.
* Not available.

B. *Hampden Smelter*

Year	Tons Ore	Tons Copper	Oz. Gold.	Oz. Silver	Fluxes		
					Limestone	Ironstone	Quartz
1911	17,211	1,579	1,535	20,776	1,992	5,907	—
1912	22,465	2,392	850	24,930	1,089	6,308	—
1913	55,590	5,678	1,844	51,756	N.A.	N.A.	—
1914	60,836	6,079	1,971	51,950	11,437	477	—
1915	69,708	7,989	2,193	65,699	20,446	1,033	—
1916	72,372	7,052	2,245	55,965	30,948	1,123	—
1917	76,135	6,636	2,459	45,821	28,230	1,611	—
1918	75,301	5,915	3,851	19,362	27,976	585	779
1919	23,250	2,140	968	14,833	6,573	—	
1920	69,598	5,154	2,787	28,032	22,252	9	976
	Smelter closed at end of 1920.						
	542,466	50,614	20,703	379,124	150,943	17,053	1,755

In addition to ore from the Hampden Mines, ore was treated from the Duchess, Trekelano, Wee MacGregor, Mt McNamara, Answer, Mt Mascotte, St Mungo, Magnet, and Pindora mines. The limestone flux was obtained from the Salmon and Dingo mines and open-cuts near Dolomite siding. The ironstone was obtained mainly from the Iron Duke mine. These fluxes contained a small percentage of copper.

C. *Mount Cuthbert Smelter.*

Year	Tons Ore	Tons Copper	Fluxes	
			Limestone	Ironstone
1917	25,562	1,805	11,159	N.A.
1918	36,466	2,129	3,226	1,610
1919	11,287	840	N.A.	N.A.
1920	33,096	2,012	„	„
	Smelter closed at end of 1920.			
	106,411	6,786	14,385	1,610

In addition to ore from the Mt Cuthbert mine, ore was also treated from the Kalkadoon, Mighty Atom, Little Wonder, Orphan, Warwick Castle, Australian Margaret, and Surprise mines.

D. *Ore treated at small smelters on the Field.*

	Smelter	Tons Ore	Tons Matte	Copper Tons	Gold Oz.	Silver Oz.
1908	Q'ld Exploration Co. Willcocks Cloncurry Copper Mines	12,446	1,612	916	187	595
	Gorge Smelting Works (A. Allis)	213	60	47	N.A.	N.A.
1909	do.	96	32	24	„	„
	Great Australia	180	42	N.A.	„	„
1915	Corella	7,893	—	534	229	652
1916	„	8,165	1,100	514	313	7
1917	„	13,743	—	767	487	—
		1,800	—	96	83	—
		44,536		2,898	1,299	1,254

The Corella Smelter treated ore from the Rosebud, Secret, Galah, and other mines in the Ballara area. In most cases the copper matte produced at these small smelters was sent elsewhere for further treatment.

E. *Copper Ores treated at Smelters off the Field.*

Year	Where Treated	Tons Ore	Copper Tons	Gold oz.	Silver Oz.	Value £
1907	Wallaroo and Waratah	2,343	637	N.A.	N.A.	N.A.
	Great Britain	384	N.A.	..	,,	,,
1908	Wallaroo, Waratah, Melbourne and Great Northern	1,225	334	..	,,	18,789
	Great Britain	1,062	N.A.	..	,,	N.A.
1909	Electrolytic Smelting and Refining Co. (Port Kembla)	1,131	335	27	143	19,824
	Other smelters in Southern States	281	89	N.A.	N.A.	5,160
	Great Britain	683	191	,,	,,	11,294
1910	Electrolytic Smelting and Refining Co.	3,040	806	230	2,220	44,671
	English And Australian Copper Co.	657	228	N.A.	N.A.	12,306
	Great Britain	1,266	354	,,	,,	19,140
1911	N.A.	5,709	N.A.	,,	,,	N.A.
1912	,,	4,800	,,	,,	,,	97,499
1913	,,	3,174	,,	,,	,,	61,904
1914	,,	982	296	37	942	18,131
1915	Port Kembla and Waratah N.S.W.	616	157	181	697	12,233
1916	ditto	281	59	—	62	6,841
	N.A.	1,949	465	N.A.	N.A.	53,918
1917	,,	4,140	879	,,	,,	101,945
1918	,,	1,650	378	,,	,,	41,567
1919	,,	2,130	496	1	451	47,246
1920	,,	2,050	474	18	371	46,415
	Port Kembla	119	31	10	49	3,132
1921	Chillagoe State Smelters	N.A.	89	N.A.	N.A.	6,171
1922	N.A.	,,	325	,,	,,	20,475
1923	Chillagoe State Smelters	735	184	,,	,,	N.A.
	Overseas	1,470	338	,,	,,	,,
1924	Overseas	1,093	266	,,	,,	,,
1925	Chillagoe State Smelters	7,923	880	,,	,,	,,
	Port Kembla	201	67	,,	,,	,,
	Overseas	120	33	,,	,,	,,

Year	Where Treated	Tons Ore	Copper Tons	Gold oz.	Silver oz.	Value £
1926	Port Kembla	1,032	239	N.A.	N.A.	N.A.
	Mt Morgan	4,951	842	,,	,,	,,
1927	Port Kembla	8,834	1,653	,,	,,	,,
	Mt Morgan	11,261	1,277	,,	,,	,,
1928	Port Kembla	11,132	1,998	641	8,000	130,483
	Overseas	733	341	33	1,418	21,957
1929	Port Kembla	16,974	2,673	1,205	10,245	216,049
	Overseas	1,726	704	96	3,486	56,093
1930	Chillagoe State Smelters					
	Ore	8,279	1,704	427	7,387	103,631
	Fluxing Copper Ore	1,268	—	—	—	1,238
	Port Kembla	2,612	459	198	1,696	28,222
	Overseas	20	6	1	43	365
1931	Chillagoe State Smelters	13,475	2,233	499	7,164	89,137
	Port Kembla	294	83	21	254	3,463
1932	Chillagoe State Smelters	16,579	2,598	327	6,548	92,077
1933	do.	13,437	2,088	632	7,644	77,401
1934	do.	14,169	1,878	766	7,095	65,874
1935	do.	9,946	1,417	572	5,615	52,764
1936	do.	13,008	1,862	1,030	6,145	83,562
1937	do.	20,544	2,720	1,088	8,104	168,536
1938	do.	12,382	1,562	733	4,290	75,119
1939	do.	13,470	1,740	856	6,262	91,222
1940	do.	12,342	1,688	831	3,889	108,555
1941	do.	10,576	1,293	458	3,291	114,641
1942	do.	10,164	1,283	594	2,904	150,757
1943	do.	2,734	330	162	757	N.A.
	Chillagoe State Smelters closed down July 1943					
	Copper Ores smelted at Mt Isa April 1943—May 1946					
1946	Mt Morgan	574	N.A.	N.A.	N.A.	N.A.
1947	do.	261	35	,,	,,	1,685
1948	do.	108	16	10	—	2,717
1949	do.	276	32	7	—	5,659
1950	do.	294	33	9	31	6,380
1951	do.	225	27	13	1	6,585
1952	do.	53	8	6	—	2,347

Mt Isa Mines Ltd copper smelter commenced production early in 1953.

Total Ore Treated at Smelters off the Field	Tons Ore	Copper Tons	Gold oz.	Silver oz.	Value £
Chillagoe State Smelters	168,371 *11,392	24,067 1,482	8,853 162	76,338 757	1,273,276 6,171
Total	179,763	25,549	9,015	77,095	1,279,447
Port Kembla and elsewhere in Southern States	36,119 *14,573	6,600 3,248	2,513 N.A.	23,266 N.A.	464,918 36,255
Total	50,692	9,848	2,513	23,226	501,173
Mt Morgan	956 *17,047	117 2,154	45 N.A.	32 N.A.	23,662 1,685
Total	18,003	2,271	45	32	25,347
Overseas or unspecified	7,641 *27,499	2,317 3,229	186 N.A.	6,711 N.A.	190,207 407,742
Total	35,140	5,546	186	6,711	507,949
Total ore treated off the Field	283,598	43,214	11,759	107,064	2,403,916

"N.A." Information is not available.

* Miscellaneous incomplete returns.

The small production of copper ore prior to 1908 was all treated at smelting works off the field with the exception of ore mined at the Great Australia between 1885 and 1887. This was treated at a locally erected smelter and 3,650 tons of copper ore were treated.

F. *Ores Purchased by Mount Isa Mines Ltd for Treatment.*

Year	Tons Ore	Tons Copper
1943	7,523	681
1944	7,645	696
1945	1,956	253
1946	39	5
1953	7,675	532
1954	6,146	539
1955	12,414	1,231
1956	16,345	1,526
1957	9,213	986
1958	5,209	591
	74,165	7,040

TABLE IV.

MOUNT ISA MINES LIMITED PRODUCTION.

A.—*Production of Metals.*

Year	Silver (oz.)	Value £	Lead (Tons)	Value £	Zinc (Tons)	Value £	Copper (Tons)	Value £	Total Value £
1931	1,020,489	71,406	17,128	230,003					301,409
1932	2,230,795	177,041	47,633	572,829					749,870
1933	2,159,108	173,879	45,038	526,385					700,264
1934	2,192,495	201,853	42,437	462,980					664,833
1935	2,351,135	277,184	32,900	470,480	4,411	68,863			816,527
1936	3,013,743	263,702	35,728	628,630	30,443	453,356			1,345,688
1937	3,177,878	276,798	38,121	879,723	27,598	606,150			1,762,671
1938	3,461,538	292,294	41,147	627,280	23,735	329,464			1,249,038
1939	3,812,186	318,239	45,266	685,448	29,092	415,571	343	17,172	1,436,430
1940	4,304,126	430,802	48,118	905,968	29,584	554,703	196	11,760	1,903,233
1941	3,799,091	497,894	43,273	814,795	27,437	514,437	351	31,624	1,858,750
1942	2,998,771	396,008	33,512	630,977	21,035	394,412	462	48,510	1,469,907
1943	756,908	99,344	8,579	129,109	5,077	76,158	6,233	662,130	966,741
1944	86,927	11,409					12,421	1,304,170	1,315,579
1945	88,611	14,030					11,763	1,176,270	1,190,300
1946	949,626	201,490	12,737	626,736	11,361	519,124	3,525	352,498	1,699,848
1947	2,152,532	391,592	30,740	2,596,253	25,216	1,738,600	459	56,239	4,782,684
1948	2,398,405	440,337	32,397	3,164,664	21,593	1,687,325	623	63,593	5,355,919
1949	2,615,724	528,888	34,291	3,800,377	21,241	1,954,199	506	54,773	6,338,237
1950	2,911,425	972,632	39,115	5,024,900	25,800	3,757,368	702	100,581	9,855,481
1951	2,731,771	1,082,739	32,883	6,485,166	21,743	4,550,686	335	62,929	12,189,274
1952	3,383,515	1,304,062	39,016	6,505,815	23,683	4,471,637	520	118,753	12,402,215
1953	2,859,317	1,090,532	35,787	3,476,116	19,944	1,817,123	16,185	4,840,938	11,227,373
1954	3,335,505	1,269,019	40,561	4,902,207	19,615	1,912,208	20,623	6,465,450	14,550,983
1955	3,703,139	1,485,270	40,309	5,340,710	17,151	1,940,315	22,472	9,650,272	18,416,567
1956	3,882,518	1,597,407	43,220	6,299,661	16,331	2,005,243	29,694	12,758,999	22,661,310
1957	4,220,996	1,705,065	50,251	6,070,883	19,445	1,984,568	29,627	8,137,446	17,897,962
1958	5,175,117	1,978,900	59,559	5,478,716	17,484	1,436,921	39,321	10,186,278	19,080,815
Totals	75,773,391	17,549,816	969,746	67,336,811	459,019	33,188,431	196,361	56,100,385	174,189,908

TABLE IV

B.—*Production of the Mt Isa Mine and the Mount Isa Mines Ltd Mill and Smelters.*

Year ended 30th June	Ore Treated (tons)			Lead (Bullion)	Zinc Concentrates	Blister Copper	Copper Concentrates
	Silver-lead-zinc	Copper	Total				
1932	455,574		455,574	38,008			
1933	721,200		721,200	54,454			
1934	490,977		490,977	37,128			
1935	547,349		547,349	38,339			
1936	630,175		630,175	34,578			
1937	591,343		591,343	37,084	52,204		
1938	617,485		617,485	41,102	55,185		
1939	586,932		586,932	41,745	44,656		
1940	742,755		742,755	47,140	55,745		
1941	708,701		708,701	46,410	55,788		
1942	604,171		604,171	37,945	45,397		
1943	165,884	73,994	239,878	24,880	29,059	3,671	
1944		268,423	268,423			18,098	
1945		288,426	288,426			13,231	
1946	52,852	202,360	255,212	1,560	3,868	5,745	
1947	455,314		455,314	24,280	42,375		
1948	568,788		568,788	28,720	45,702		
1949	625,261		625,261	37,155	46,529		
1950	542,031		542,031	32,061	41,743		
1951	567,957		567,957	33,495	45,096		
1952	626,014		626,014	36,860	46,881		
1953	641,520	206,380	847,900	36,970	41,828	5,477	
1954	645,083	565,897	1,210,980	35,725	40,198	19,869	
1955	670,514	573,678	1,244,192	39,730	36,415	21,585	
1956	656,738	725,738	1,382,476	36,545	30,684	24,408	
1957	671,465	733,348	1,404,813	45,190	35,404	28,875	
1958	811,508	843,562	1,655,070	50,960	36,128	31,165	
1959	922,416	1,356,163	2,278,579	57,035	27,280	41,945	38,685
Totals	15,320,017	5,837,969	21,157,986	975,399	858,165	207,964	38,685

The production figures were obtained from the Annual Reports of the Directors of Mount Isa Mines Ltd. The figures for ore treated include lead ore purchased from small producers in the Lawn Hill and Mt Isa areas, and copper ore purchased from small producers in the Cloncurry-Mt Isa Mineral Fields. To the end of 1958 purchases of copper ores totalled 74,165 tons containing 7,040 tons of copper, and of silver-lead ore, 12,292 tons containing 4,577 tons of lead and 114,656 oz. of silver. In addition to ores from the Cloncurry and Burketown Fields small parcels of ore have been treated from the Northern Territory and from other fields in Northern Queensland in recent years.

The use of limestone and ironstone from the Cloncurry and Mount Isa Mineral Fields as flux at the Mount Isa smelters can be obtained from the annual production figures from 1930 onwards in Table 1 as the entire production was used by Mount Isa Mines Ltd.

C.—*Production of Copper Dross.*

Year Ending 30th June	Dross (Tons)	Copper (Tons)	Lead (Tons)	Silver oz.
1936	1,050	210		
1937	1,523	274		
1938	2,129	349	1,413	127,308
1939	2,227	354	1,422	119,216
1940	1,714	293	1,096	91,025
1941	No shipments of dross. Returns from production carried forward.			
1942	2,004	351	1,246	104,066
1943	1,967	354	1,464	103,031
1944				
1945				
1946				
1947	1,575	332	985	66,027
1948	2,188	409	1,400	93,428
1949	2,673	497	1,652	119,750
1950	2,848	582	1,770	133,731
1951	2,226	437	1,390	99,820
1952	2,789	616	1,717	145,865
1953	2,991	576	1,825	153,588
1954	3,778	682	2,451	218,443
1955	4,866	896	3,167	277,114
1956	4,389	906	2,763	272,327
1957	4,536	898	2,882	243,919
1958	4,477	805	2,958	241,623
1959	4,791	857	3,229	298,793
Totals	56,741	10,678	34,830	2,909,074

This dross is produced during the lead smelting process and has been exported to U.S.A. for the extraction of the metallic contents. The figures were obtained from the Annual Reports of the Manager of Mt Isa Mines Ltd. Complete returns are obtainable only from 1938 onwards. Smelting of silver-lead ore was discontinued in the 1943-46 period when the smelter was used for the production of blister copper.

TABLE V

THE LAWN HILL AREA (BURKETOWN MINERAL FIELD)

A.—Metal Production.

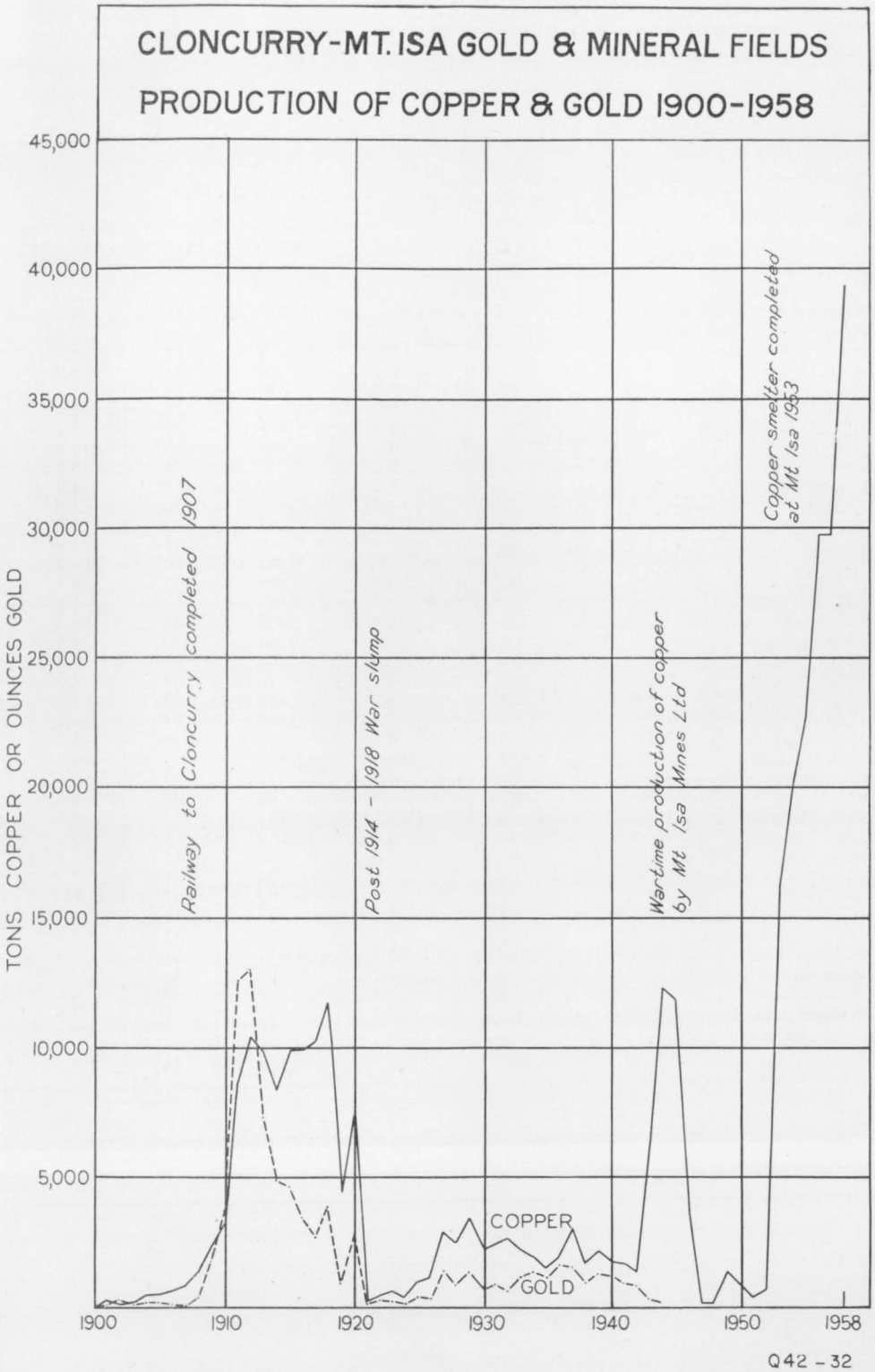
YEAR	Pb (tons)	Value £	Ag (oz.)	Value £	Cu (tons)	Value £	Annual Value
1888	10	175	N.A.	N.A.			175
1897	58	696	3,181	345			1,041
1898	154	1,540	6,206	621	10	150	2,311
1899	13	105	359	40	36	432	577
1900	59	1,003	1,556	176	4	240	1,419
1901	117	1,521	2,646	296			1,817
1902	44	476	2,309	250			726
1903					1	58	58
1905	7	96	667	77			173
1906	2	36	204	26	32	2,911	2,973
1907	4	60	360	45			105
1912	21	365	930	108			473
1913	6	99	3,780	425			524
1914	156	2,808	7,600	792			3,600
1915	182	4,186	9,600	960			5,146
1916	314	9,805	8,017	1,035			10,840
1917	231	6,937	7,556	1,275			8,212
1920	75	2,849	2,300	592			3,441
1924	136	4,579	4,081	620			5,199
1925	179	6,417	2,712	373			6,790
1926	170	5,287	3,978	497			5,784
1927	235	5,734	7,860	917			6,651
	1928 - 1947. No production.						
1948	91	8,304	3,385	635			8,939
1949	95	10,057	6,241	1,176			11,233
1950	47	6,457	1,697	571			7,028
1951	135	27,658	3,505	1,731			29,389
1952	239	39,980	5,344	2,078			42,058
1953	244	23,661	3,670	1,413			25,074
1954	89	10,809	1,770	664	1	317	11,790
1955*	274	34,960	7,851	2,940	3	1,501	39,401
1956*	586	80,698	17,233	7,074			87,773
1957	524	63,808	15,338	6,308			70,116
1958	455	44,729	10,309	4,069			48,798
	4,953	£405,895	152,245	£38,129	87	£5,609	£449,633

* Production from the *Copalot* mine, 11 miles south of Mt Isa, and the *New Queen* mine, Charters Towers, for the years 1955-56 has been included in the returns for the Burketown Mineral Field in the Mining Warden's reports. This production amounted to 61 tons of lead and 1,273 oz. of silver.

B.—*Individual Mine Production for the Period 1948-1958.*

Name of Mine	Ore (tons)	Lead (tons)	Silver (oz.)	Percent Pb.	Oz. Ag per ton
Anglo American	127	57.0	833	45	6.6
Anglo Australian and Little Wonder	2	0.9	9	39	3.7
Aqua Regis	12	6.1	45	53	3.9
Axis (Axis Ridge)	89	52.8	636	59	7.1
Bald Hill	10	2.3	16	23	1.6
Bell's Lode	36	18.8	328	52	9.1
Blue Star	11	4.1	126	38	11.8
Brown's Prospect	8	2.8	76	35	9.5
Cassowary	8	5.8	339	75	44.0
Chance	1	0.7	2	70	2.0
Dodge	3	1.4	12	47	4.0
Double M	16	7.4	64	45	3.9
East Star	717	433.0	3,384	60	4.7
Glencoe	46	19.6	299	43	6.5
Greater Britain	68	35.3	342	52	5.0
Lilydale	175	74.8	769	43	4.4
Little Banner	7	2.1	34	30	4.9
Little Duck	14	8.4	68	58	4.7
Little Wonder	15	6.7	70	45	4.7
Lucky Dollar	143	75.0	458	52	3.2
Lucky Dollar No. 2	11	8.3	67	75	6.1
Macarthur	3	0.7	7	25	2.5
Mended Hill	673	413.5	15,557	61	23.1
New Duck	8	4.9	52	63	6.6
Shepherd's Prospect	16	7.9	86	49	5.4
Silver Jackpot	39	29.1	231	75	5.9
Silver King	2,599	1,356.4	47,152	52	18.1
Silver Queen	34	15.0	168	44	4.9
Silver Valley	4	1.9	24	45	5.7
Star Dust	10	6.1	66	63	6.9
Star of the East	3	1.5	13	54	4.7
The Queenslander	7	3.2	39	44	5.4
Western King	97	49.2	1,650	51	17.1
Westward Ho	3	1.2	87	38	27.2
White Rock	3	1.2	12	40	4.0
Worner and Tunnys Prospect	9	2.4	71	27	7.9
TOTALS	5,027	2,717.5	73,192	54	14.6

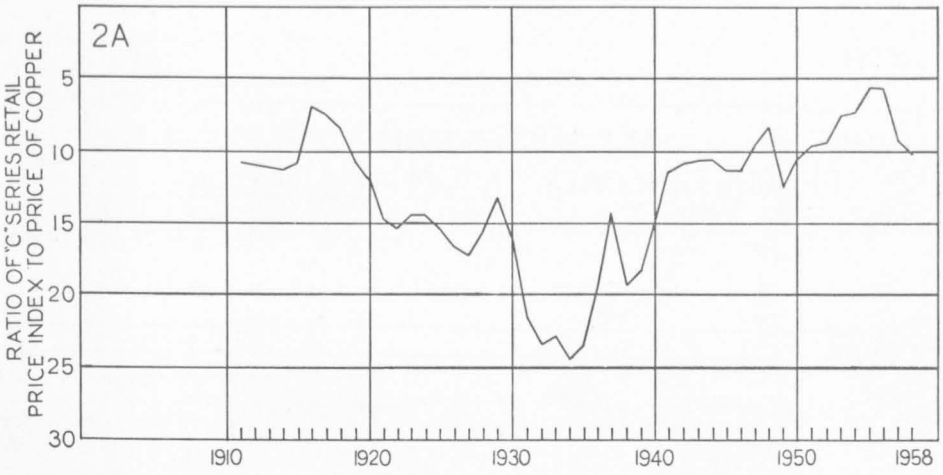
GRAPH I

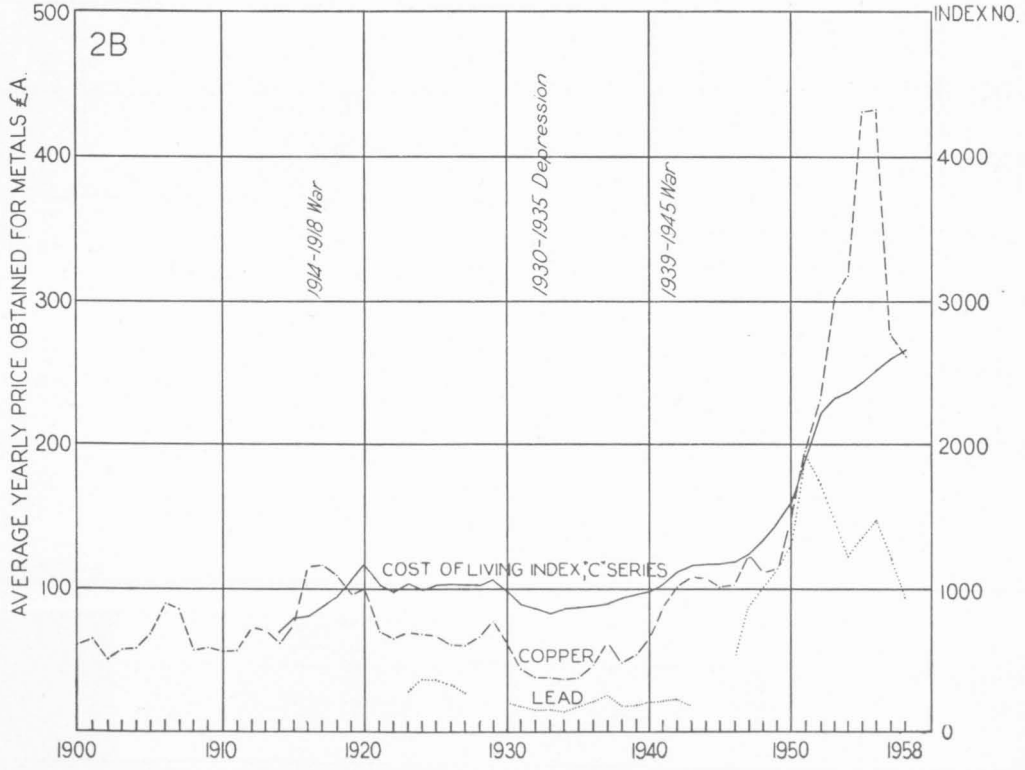


Q42 - 32

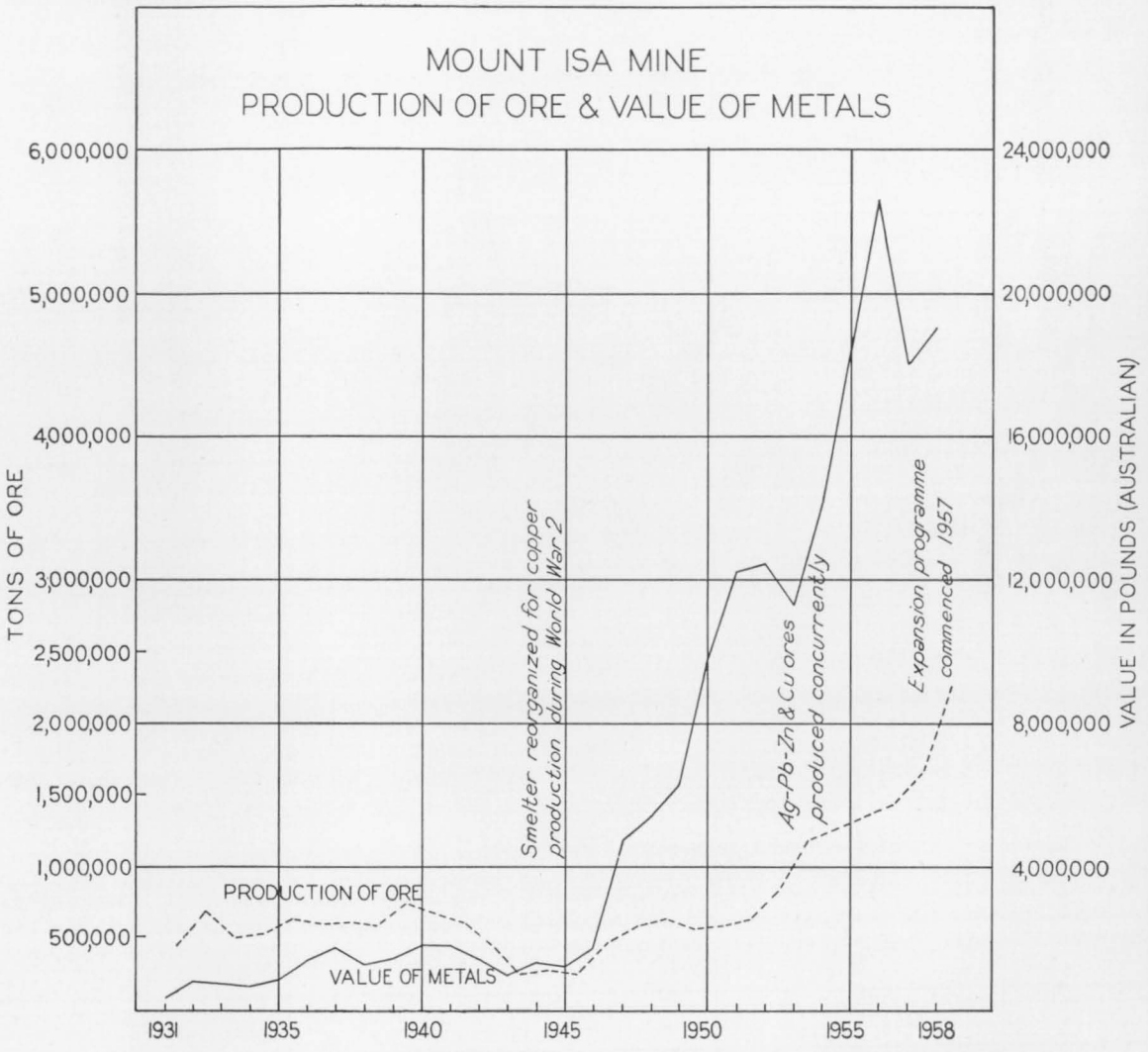
GRAPHS 2A & 2B

RELATION OF COPPER & LEAD METAL PRICES TO THE "C" SERIES RETAIL PRICE INDEX

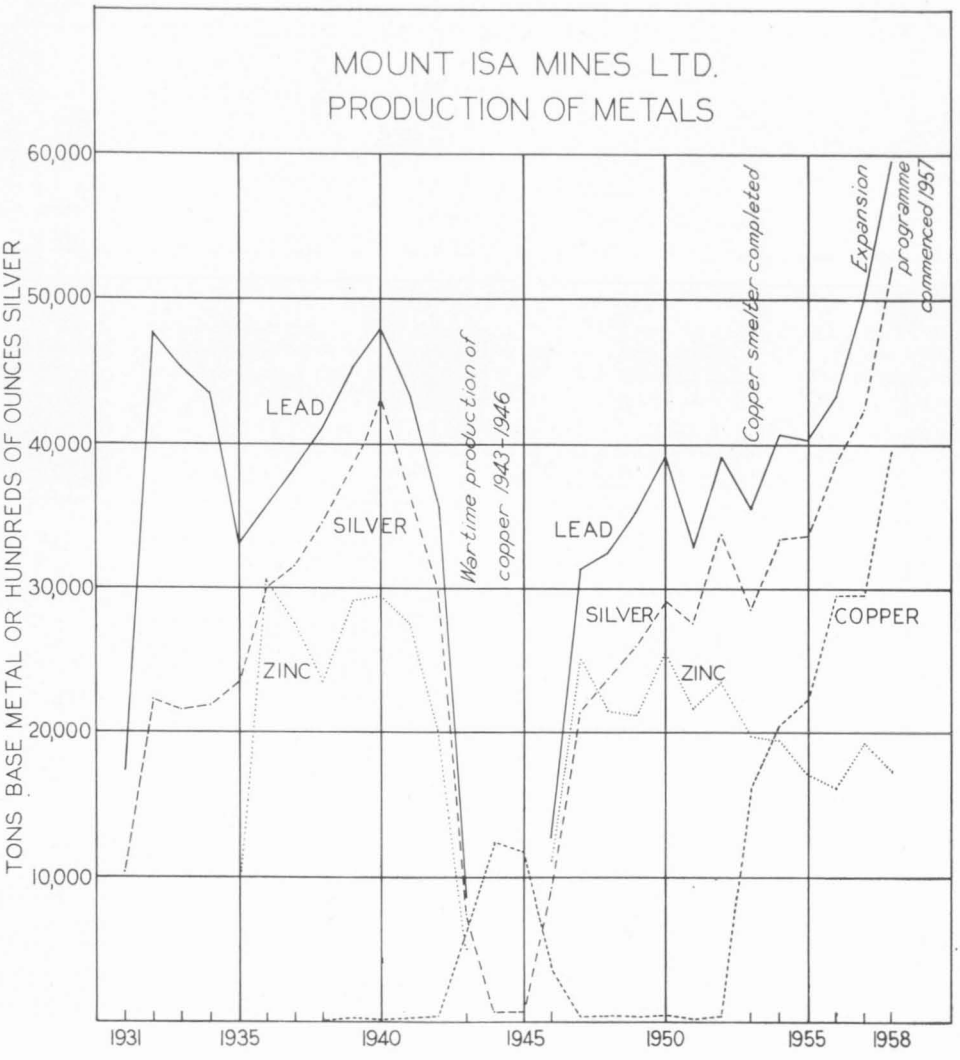




GRAPH 3


MOUNT ISA MINE
PRODUCTION OF ORE & VALUE OF METALS
TONS OF ORE
VALUE IN POUNDS (AUSTRALIAN)
6,000,000
5,000,000
4,000,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
24,000,000
20,000,000
16,000,000
12,000,000
8,000,000
4,000,000
1931
1935
1940
1945
1950
1955
1958
PRODUCTION OF ORE
VALUE OF METALS
Smelter reorganized for copper production during World War 2
Ag-Pb-Zn & Cu ores produced concurrently
Expansion programme commenced 1957

GRAPH 4


MOUNT ISA MINES LTD.
PRODUCTION OF METALS
TONS BASE METAL OR HUNDREDS OF OUNCES SILVER
60,000
50,000
40,000
30,000
20,000
10,000
1931
1935
1940
1945
1950
1955
1958
LEAD
SILVER
ZINC
LEAD
SILVER
ZINC
COPPER
Wartime production of copper 1943-1946
Copper smelter completed
Expansion programme commenced 1957

GEOGRAPHICAL INDEX

Geographical names used in the text of the Bulletin are indexed below. The index includes the names of mines, mineral deposits, and leases, except as they appear in the Production Tables in Appendix II, and also includes the names of geological faults, but does not include geological formation names nor the names of granite bodies, as the principal reference to each of these may be found from the "Contents." Names that appear on the map Sheets, but not the text, are not indexed.

The principal references to the main mineral deposits appear in bold type.

Co-ordinates were measured from 4-mile map Sheets and are not instrumental determinations.

Abbreviations: P - Plate; F - Figure; Ag - silver; Au - gold; Be - beryl; Bi - bismuth; Co - cobalt; Cu - copper; Fe - iron; Ls - "limestone" (calcite); Mn - manganese; Ni - nickel; R - rare earth metals; Se - Selenium; Th - thorium; Ur - uranium; W - wolfram; Zn - zinc.

Name	Atlas Plate No.	Co-ordinates		Reference
		S	E	
		Lat.	Long.	
Accident Creek	3	18°05′	138°20′	110, 119.
Agate Downs Outstation	9	21°21′35″	140°25′00″	83, 234, 242.
Amy Lease (Ur)	8			246.
Anglo-American Mine (Ag, Pb)	3	18°36′20″	138°32′20″	226.
Answer Downs Homestead	9	21°40′20″	140°59′30″	88.
Answer Mine (Cu)	9	21°40′00″	140°21′35″	82, 204, 205, **216.**
Apple Pie Mine (Cu)	8	20°43′	140°01′	237, 251.
Archie Creek	3	18°35′	138°46′40″	41, 187.
Ardmore Homestead	6	21°39′00″	139°13′05″	74, 76, 125, 151, 228.
Argylla Creek	8	20°36′30″	139°49′30″	62.
Argylla Mine (Cu) (See Blockade Mine)				
Argylla Ranges	8	20°39′	139°52′	16, P3, P4, P12, P33.
Axis Mine (Ag, Pb)	3	18°41′	138°34′	226.
Ballara	8	20°56′50″	139°57′50″	24. 50, 62, 67, 86, 90, 91, 152, 193, 231, 245, 246.
Ballara Deposit (Ur)	8	20°46′50″	139°57′50″	204, 214, 245.
Barkly Tableland				20, 25, 27, P8.
Barney's Well	5	20°03′20″	139°20′35″	100, 112.
Bernborough Orebodies	5	20°45′25″	139°28′45″	218.
Big Beryl Mine (Be)	5	20°47′	139°26′	178, **249,** 251.
Blackeye Creek (Ti)	9	21°41′	140°51′	246.
Black Mountain (See Mount Leviathan)				
Black Mountain (Mount Unbunmaroo)	9	22°32′	140°17′	189.
Black Rock (See Mount Isa Orebody)				
Black Rock Creek	4	19°29′	139°05′	105.
Black Star (See Mount Isa Orebody)				
Blockade (Argylla) Mine (Cu)	8	20°37′10″	139°52′25″	23, 60, 192, 193, 195, 203, **217,** 244, 248.

Name	Atlas Plate No.	Co-ordinates		Reference
		S	E	
		Lat.	Long.	
Blue Bell Mine (Cu)	3	19°0′	138°42′	226.
Boomarra Station	7	19°34′	140°21′40″	243, 244.
Boulia		22°54′53″	139°54′25″	27, 189, F12.
Bower Bird Area	8	20°04′	139°42′	75, 192, 234, 235.
Brilliant Ext'd (Au, W, Bi)	8	20°50′	140°37′30″	235, 241, 242.
Broadhurst Bore	9	21°24′50″	139°34′10″	145.
Buckingham Downs Homestead	1	22°05′	139°46′	23, 62, 122, 128, 256.
Burke Plain	9			33.
Buckley River	5	20°13′	139°13′	121.
Bungalien Rly Siding	9	21°18′20″	139°58′40″	22, 42.
Burketown		17°44′	139°32′	15, 18, 23, 199, F2.
Burketown Mineral Field	3	18°44′	138°34′	15, 27, 198, 204, 206, 218, 226, 227.
Bushy Park Homestead	9	21°15′50″	139°43′20″	23, 96, 135, 143.
Bustard Creek	9	21°42′	140°47′	16, 148.
Butru Railway Siding	9	21°29′20″	139°43′45″	143, 283.
Cairns (Toko) Range (See Toko Range)				
Calton Hills Station	5	20°8′45″	139°24′05″	23, 27, P4.
Cameron Fault	8	20°46′40″	139°58′45″	184.
Cameron River	8	20°33′10″	140°08′30″	231, 245.
Camooweal	4	19°55′15″	138°07′10″	15, F2, P8.
Carioca Mine (Cu)	8	20°35′15″	139°53′30″	140, 166.
Carl Creek	4	19°01′30″	138°44′	127.
Caroline Range	3	18°26′15″	138°42′50″	101, 102, 110, 111, 187.
Carpentaria, Gulf of	2	17°13′	139°21′	15, 18, 33, 36.
Carter's Bore	5	20°56′00″	139°18′25″	107.
Cattle Creek	8	20°54′	139°55′	27, 86, 87, 88, 164, 165, 168, P24, P29, P32.
Centipede Deposit (Co)	8	20°05′	140°01′	238, 243.
Charley Creek	8	20°40′40″	139°47′20″	92.
Chatsworth Station	9	21°58′30″	140°17′40″	36, 219, 222, 251.
Chinaman's Flat (Au)	9	21°03′30″	140°26′	192.
Chumvale Station	8	20°40′50″	140°23′35″	87, 95, 174.
Cleanskin Creek	8	20°23′55″	140°03′10″	88, 164, 165, 168, 170, 172, P10, P20.
Cliffdale Creek	2	17°37′	138°18′	113, 114, 115.
Cloncurry	8	20°42′30″	140°30′25″	15, 16, 18, 19, 21, 23, 24, 26, 27, 80, 81, 93, 148, 192, 193, 194, 203, 204, 209, 214, 234, 235, 236, 242, 250, F2, F11.
Cloncurry 'Overthrust'	8 & 9	21°06′45″	140°41′35″	41, 54, 71, 168, 184, 185, 188.
Cloncurry Plain	8			33.
Cloncurry River	7, 8, and 9			21, 22, 23, 26, 35, 81, 242.
Cloncurry Shire				24.
Colless Creek	3	18°41′20″	138°24′05″	119, 124, 243, 298.
Comfort Lease (Ur)	8	20°34′30″	140°4′20″	246.
Comstock Lode (Au, Co, W)	8	20°58′	140°45′	235, 238, 241, 243.
Constance Range (Fe)	3	18°25′	138°21′	3, 14, 27, 28, 29, 33, 35, 36, 58, 110, 112, 117, 118, 119, 120, 124, 126, 188, 189, 191, 199, 200, 239, **240**, 252, P6, P7, P17.
Coocerina Lode (Co)	8	20°18′	140°09′	243.
Coolullah Hstd.		19°49′59″	40°09′40″	148.

Name	Atlas Plate No.	Co-ordinates		Reference
		S	E	
		Lat.	Long.	
Copper Blonde Deposit (Ls, Cu)	8	20°33′	140°03′	246, 247.
Corella Creek	8	20°51′30″	138°53′20″	67, P11.
Corella River	8	20°47′00″	140°06′40″	20, 21, 35, 86, 186, 216, 248.
Counter Lease (Ur)	8	20°40′	139°37′	198, 229, 230, 231, **233,** 255.
Crusader Mine (Cu)	7	19°48′40″	140°02′25″	32, 63, 143, 145, 173, 192, 193, 204, 206, 208.
Dajarra	9	21°41′50″	139°31′15″	15, 25, 33, 63, 135, 139, 140, 143, 166, 167, 170, 242, F4.
Deighton Pass	8	20°43′10″	139°54′00″	16, 86, 96.
Dentalium Plateau	3	18°41′	138°38′	27, 28, 117.
Devils' Hill	8	20°55′55″	140°37′05″	P2.
Devoncourt Station	9	21°09′25″	140°11′55″	23, 91, 214.
Diamantina River				26.
Diane Deposit (Ur, Ti)	8	20°39′	140°04′	246.
Digby Denham Mine (Cu, Ls)	7	19°52′30″	139°59′30″	247.
Dingo Mine (Ls, Cu)	8	20°45′	140°27′	193, 246, 247.
Dobbyn	7	19°47′55″	139°59′50″	15, 112, 135, 143, 145, 166, 167, 214, 246, F2.
Dobbyn Mine (Cu)	7	19°48′	139°59′	192, 193, 204, 208, **214.**
Dodge-Loane Lease (Ur)	8	20°35′	140°12′	246.
Dolomite Quarry (Ls, Cu)	8	20°45′	140°30′	193, 197, 206, 246, 247.
Doughboy Creek	8	20°19′00″	139°46′00″	61, 103, 218, 234, 235.
Dronfield Railway Siding	9	21°13′30″	140°02′20″	147.
Duchess	9	21°21′30″	139°51′50″	15, 24, 25, 87, 138, 139, 140, 147, 153, 158, 167, 168, 170, 172, 173, 174, 175, 176, 177, 199, 211, 212, 241, 244, 246, 250, 253, 256, 293, F2, P30.
Duchess Mine (Cu)	9	21°22′	139°52′	193, 194, 195, 203, 204, 206, 208, **211,** 235, 237, 243, 247, 252.
Duchess-Juenburra Shear	9	21°23′40″	139°51′00″	211, 247.
Duck Creek	8	20°56′20″	140°14′15″	45, 62, 64.
Dugald River	8	20°12′00″	140°13′35″	35, 62, 152, 170, 172, 176, 238, 243, 250, 251.
Dugald River Prospect (Ag, Pb, Zn)	8	20°15′10″	140°10′30″	14, 32, 86, 88, 89, 94, 192, 196, 204, 217, 218, 219, 220, 221, 222, 223, **226,** 236, 239, 251, P24.
Dynamite Creek	7	19°28′10″	139°41′25″	47, 75, 103, P13.
East Branch Leichhardt River (See Leichhardt River, East Branch)				
Eastern Creek	4	19°52′00″	139°25′20″	73.
Edna May Mine (Cu)	8	20°48′45″	139°49′50″	63, 136, 173, 248.
Elaine Dorothy Lease (Ur, R)	8	20°47′10″	140°00′30″	244.
Elizabeth Creek	3	18°13′	138°22′	110, 118, 126, 218.
Elizabeth Creek Area	4	18°18′15″	138°06′55″	120, P7, P17.
Embla Ridge Lease (Ur)	8	20°51′	140°23′40″	229.
Ewen Creek	7	19°56′30″	139°45′05″	145.

Name	Atlas Plate No.	Co-ordinates S Lat.	Co-ordinates E Long.	Reference
Falcon (Rose and Thistle) Mine (Au, W)	8	20°49′20″	140°47′40″	89, 235, 241.
Federal Mine (Cu)	8	20°36′00″	140°11′50″	16, 87, 123, 208, **215,** 237, 238.
Fiery Creek	4	19°05′10″	139°12′30″	31, 102, 142, 154, 296, P23.
Fishers Creek	8	20°41′	140°43′40″	235.
Flat Tyre Lease (Ur)	5	20°39′40″	139°25′40″	229.
Florence Creek	9	21°10′45″	140°27′25″	77, 251.
Florence Rly. Siding	9	21°10′15″	140°22′00″	218, 242.
Flying Dutchman Mine (Au, Cu)	8	20°42′	140°41′	235.
Fort Constantine Station	8	20°28′20″	140°34′55″	23.
Fountain Range Fault	8	20°58′10″	139°56′10″	34, 67, 177, 248, P25.
Fullarton River	9	21°05′00″	140°53′00″	16, 158, 163.
Gap Bore	5	20°50′00″	139°12′45″	58, 59, 107, P21.
The General Mine (W)	8	20°13′	140°01′	241.
Georgetown				128.
Georgina Basin				33, 34.
Georgina River	4, 5 & 6	20°10′	138°02′	27, 36.
Gereta Homestead	8	20°01′30″	139°50′40″	75.
Gertrude Mine (Au)	8	20°18′	139°45′	235.
Gidyea Creek	4 & 5	20°00′	139°20′40″	75, 112.
Gilded Rose Mine (Au)	8	20°46′50″	140°37′20″	163, 176, 192, 194, 234, 235, **236.**
Glenormiston				26.
Glenroy Homestead	8	20°18′50″	139°44′40″	61, 103.
Godkin Lode (Co)	8	20°16′40″	140°09′20″	243.
Gold Creek		17°04′30″	137°44′30″	120.
Gorge Creek	2	17°53′30″	130°04′30″	50, 117, 167, 218.
Gorge Creek Fault	8	20°35′20″	139°41′	52, 187, 188.
Great Australia Mine (Cu)	8	20°44′	140°30′	23, 192, 193, 203, 204, 206, 208, **214,** 243, 247.
Green Creek	9	21°13′25″	139°50′55″	168.
Gregory Downs	3	18°38′25″	139°14′15″	23, 26.
Gregory River	3, 4	19°06′	138°25′	18, 20, 23, 26, 41, 101, 127, 128, 154, 166, 187, 252, 253.
Gumbardo Lease (Ur, Th)	8	20°40′30″	140°12′	245, 246.
Gunpowder Creek	4, 5 & 7	19°45′00″	139°18′10″	27, 31, 73, 75, 100, 103, 104, 105, 106, 112, 133, 217, P5, P13, P15.
Hampden Mines (Cu, Au)	9	21°17′05″	140°30′30″	24, 32, 85, 89, 193, 195, 196, 203, 204, 206, 207, 208, **212,** 235, 237, 241, 246, 251.
Handlebar Hill See Northern Leases)				
Hann's Ridge	3	18°41′	138°33′	111.
Hematita Range	7	19°54′20″	139°38′35″	240.
Hematite Siding (Fe)	9	21°25′	140°31′	240.
Hexagon Group (Bc)	5	20°48′50″	139°25′45″	249.
Hidden Valley Deposit (Ur)	8	20°40′	140°04′	244, 248,
Hobby No. 2 Lease (Ur)	8	20°33′20″	140°06′50″	246.
Ivena Mine (Cu)	4	19°28′	139°24′	208, 237.
Jayah Creek	6	21°34′30″	139°14′	108, 151.
Judenan Creek	4 & 5	19°53′35″	139°15′20″	100.
Juenburra Railway Siding	9	21°25′	139°50′	197, 244, 246, 247.

Name	Atlas Plate No.	Co-ordinates		Reference
		S	E	
		Lat.	Long.	
Kajabbi	8	20°02′00″	140°02′10″	15, 25, 152, 193, 204, 213, 219, 237, 238, 243, 247.
Kalkadoon Mine (Cu)	7	19°59′20″	139°55′	143, 193, 204, 208, **213,** 247.
Kamileroi Homestead	7	19°21′50″	140°03′00″	88.
King Edward Mine (Au, Cu)	8	20°43′30″	140°39′30″	235.
King Solomon Mine (Cu)	8	20°42′45″	139°49′10″	247.
Kings Cross Mine (Cu)	8	20°44′30″	139°54′30″	145, 206, 207.
Knapdale, Parish of	8			94.
Kurbayia Railway Siding	9	21°03′50″	139°37′45″	143.
Kuridala	9	21°17′00″	140°30′00″	15, 24, 32, 51, 80, 81, 82, 83, 84, 85, 138, 140, 141, 147, 149, 158, 168, 174, 176, 185, 204, 212, 218, 237, 241, 251, 256, 257, 258.
Kuta Lease (Ls)	8	20°48′00″	140°6′10″	247.
Labour Victory Mine (Cu)	9	21°26′55″	140°27′55″	83, 204.
Lady Annie Mine (Cu)	4	19°46′25″	139°02′30″	106, 195, 204, 206, 207, 208, 209, **217,** P29.
Lady Fanny Mine (Cu)	9	21°15′	139°47′	153, 173, 174, 175, 208, P9, P21.
Lady Rachel Mine (Cu)	9	21°01′20″	139°54′40″	245, 246.
Lagoon Creek	2	17°25′30″	138°07′	114, 115, 117, P8.
Lawn Hill Airstrip	3	18°32′20″	138°40′50″	111.
Lawn Hill Creek	3	18°40′25″	138°32′40″	18, 20, 110, 111, 117, **252.**
Lawn Hill Silver-lead Mining Area	3	18°44′	138°34′	14, 26, 27, 101, 110, 117, 198, 200, 218, 219, 220, 222, 223, **226,** 236, 241, 247, 257.
Lawn Hill Station	3	18°35′	138°34′40″	198, P7.
Leander Range	5	20°11′	139°28′	64, 65, 74, 76, 112, P4, P14.
Leichhardt Fault	5	20°35′40″	139°29′10″	52, 53, 108, 109, 188, 257.
Leichhardt-Gilbert Area				19.
Leichhardt River	5, 7 & 8	20°04′	139°55′	21, 24, 60, 97, 102, 103, 109, 173, 248, 253.
Leichhardt River (East Branch)	8	20°53′	139°47′	21, 26, 92.
Leichhardt River (West Branch)	5 & 8	20°36′	139°32′	21, 35.
Letter Box Creek	5	20°21′	139°23′	112.
Lilly May Mine (Cu)	8	20°26′	139°49′	207.
Lilydale Mine (Pb, Ag)	3	18°51′	138°35′30″	226.
Lilydale Springs	3	18°52′40″	138°36′40″	111, 118.
Limestone Creek	9	21°32′50″	140°15′30″	45, 62, 64, 82, 83.
Little Sunset Mine (Cu)	8	20°44′30″	139°55′50″	250.
Little Templeton River (See Yaringa Creek)				
Little Totts Creek (Pb)	4	19°35′50″	138°03′00″	219.
Little's Range (Fe)	3	18°37′	138°06′	200, **240.**
Livingstone's (Red tree) Deposit (Ur)	2	17°30′50″	138°06′20″	229, 230, P15.
Lochness Deposit (Fe)	7	19°54′10″	139°38′20″	75, 219, 239, **240,** 257.
Lone Hand Mine (Cu, W, Bi)	8	20°59′	140°16′	235, 241, 247.

Name	Atlas Plate No.	Co-ordinates		Reference
		S	E	
		Lat.	Long.	
Louie Creek	3	18°44′	138°31′40″	220.
Lucky Dollar Mine (Pb, Ag)	3	18°49′	138°36′20″	226.
McConachie Quarry (Ls)	9	21°25′	139°50′30″	247.
McKellars Well	5	20°57′25″	139°24′10″	59, P20.
McKinlay River	9	21°39′50″	140°55′30″	16, 68, 250.
Magazine Hill Deposit (Pb)	3	18°44′40″	138°36′30″	202.
Magnet Mine (Cu)	8	20°16′	140°12′	**217**, 244.
Makbat Creek	9	22°00′00″	139°48′05″	122.
Malbon	9	21°04′40″	140°18′05″	15, 71.
Malbon River	9	21°05′	140°14′	45, 62, 64.
Mammoth Mine (Cu)	4	19°41′30″	139°22′00″	101, 105.
Mangaminny Lease (Mn)				242.
Marimo Quarry (Ls)	8	20°50′	140°30′	246, 247.
Marimo Railway Siding	8	20°46′55″	140°25′00″	80.
Marraba Mines	8	20°59′	140°16′	204, 206, 207, 235, 237, 241.
Marraba Railway Siding	8	20°59′30″	140°18′00″	71, 78, 241, 242, 248, F10.
Mary Douglas Deposit (Au, Bi)	9	21°03′	140°26′30″	242.
Mary Kathleen (Ore Body and Plant) (Ur, R)	8	20°42′40″	140°01′00″	3, 13, 14, 25, 77, 88, 89, 129, 132, 141, 142, 167, 168, 178, 185, 191, 198, 201, 219, 228, 229, 230, 231, **232, 244**, 245, 247, 255, 256, 257, 291, P1.
Mary Kathleen (Township)	8	20°46′40″	139°58′45″	15, 16, 21, 77, 152, 216, 244, 248, 251, P33.
May Downs Homestead	5	20°26′15″	139°03′45″	107, 108, 127, 150, 157, 234, 235.
Megaphone Mine (Cu)	8	20°39′	139°54′	208.
Melba Mine (Cu)	8	20°51′05″	139°55′05″	67.
Mended Hill Mine (Pb, Ag)	3	18°45′10″	138°36′10″	110, 226, 227.
Mica Creek Area	5	20°49′20″	139°26′20″	129, 135, 141, 143, 165, 178, 223, 231, **245**, 246, 249, **250**, 251.
Mighty Atom Mine (Cu)	7	19°57′	139°59′	193, 204, 208, **215**, 247.
Milo Deposit (Ur)	8	20°46′	140°14′	218, 229, 230, **233**, 251.
Mingera Creek	5	20°26′05″	139°08′40″	105, 107, 150.
Mistake Creek	7	19°23′	139°55′	83, 99.
Mitakoodi Railway Siding	8	20°56′45″	140°18′35″	76, 77.
Monaghan's Bore	5	20°39′45″	139°10′30″	107.
Monakoff Deposit (Cu, Ur)	8	20°37′	140°42′	228, 229, 251.
Mort River	9	21°50′	140°24′	71, 83.
Mosquito Creek	7	19°19′05″	139°43′20″	146.
Mothers Day Mine (Ur)	5	20°40′10″	139°26′00″	165, 229.
Mountain Home (Cu)	8	20°55′	140°42′	237, 243.
Mount Brown	1	19°47′	141°27′	36, 128, 129.
Mount Burstall	8	20°48′45″	140°03′30″	141, 142, 170, 172.
Mount Colbalt Mine (Co, W)	9	21°44′00″	139°29′40″	32, 80, 167, 194, 196, 200, 228, 237, **238**, 241, 243, 256, 257, 258, P6.
Mount Cuthbert (Cu)	7	19°59′05″	139°55′05″	24, 145, 173, 193, 203, 204, 208, **213**, 243, 246, 247, 278.
Mount Dore Mine (Cu)	9	21°40′	140°29′	149, 228.

Name	Atlas Plate No.	Co-ordinates		Reference
		S	E	
		Lat.	Long.	
Mount Dromedary	7	19°36′10″	140°13′10″	244.
Mount Elliott Mine (Cu, Au)	9	21°32′20″	140°30′00″	32, 84, 89, 165, 193, 194, 196, 203, 204, 206, 207, 208, **211**, 235, 246, 247, 252.
Mount Fort Bowen	1	19°37′	141°19′	36, 124, 128, 129.
Mount Freda Mine (Au)	8	20°48′40″	140°44′30″	235.
Mount Gordon Fault	4	19°29′	139°24′20″	13, 41, 52, 53, 54, 105, 131, 178, 186, 187, 207, P26.
Mount Guide	9	21°02′20″	139°30′50″	20, 65, 66, 108.
Mount Guide Homestead	6	21°03′10″	139°26′30″	66, 101.
Mount Hope Mine (Cu)	9	21°10′20″	139°48′50″	248.
Mount Isa Fault	5	20°40′	139°28′	41, 42, 52, 53, 54, 76, 100, 101, 109, 110, 150, 188, 207, 221, 223.
Mount Isa (Orebody and Plant)	5	20°43′30″	139°28′35″	13, 14, 22, 27, 28, 29, 108, 109, 110, 129, 140, 177, 191, 194, 195, 196-8, 199, 200, 201, 203, 204, 205, 206, 207, 208, **210-11**, 218, 219, 220, 221, 222, **223-5,** 226, 235, 236, 237, 241, 243, 244, 246, 247, 248, 252, F20, P1, P16.
Mount Isa (Township)	5	20°44′	139°29′	15, 16, 20, 21, 24, 66, 73, 98, 99, 103, 108, 109, 129, 139, 141, 142, 162, 165, 167, 177, 187, 218, 229, 233, 248, 249, 250, 253, F2.
Mount Leviathan Deposit (Black Mountain) (Fe)	8	20°43′00″	140°28′50″	177, 239.
Mount McLeod Mine (Cu)	4	19°57′40″	139°09′20″	98, 295.
Mount McNamara Mine (Cu, Mn)	8	20°55′30″	140°25′30″	80, 204, 243.
Mount Malakoff	8	20°21′30″	140°28′50″	P11.
Mount Mascotte Mine (Cu)	9	21°12′	139°52′	216.
Mount Norna	8	20°54′55″	140°42′05″	P28.
Mount Norna Mine (Cu) See Mountain Home)				
Mount Olive Mine (Cu)	8	20°27′	139°49′	207.
Mount Oxide Fault	4	19°28′30″	139°23′	207.
Mount Oxide Mine (Cu, Fe)	4	19°28′35″	139°23′00″	23, 98, 99, 103, 104, 105, 106, 133, 187, 192, 193, 195, 196, 203, 204, 206, 207, 208, 209, **213**, 237, 239, 251.
Mount Philp	8	20°58′55″	139°56′20″	67, 84, 90, 164, 165, 167, 168, 176. P25.
Mount Philp Deposit (Fe)	8	20°58′55″	139°56′20″	32, 177, **239,** P25.
Mount Quamby	8	20°22′20″	140°10′40″	123, 234.
Mount Quamby Workings (Au)	8	20°22′40″	140°10′40″	123, 200, 234.
Mount Remarkable Fault	8	20°13′40″	139°53′50″	184, 248.
Mount Scheelite (Au, W)	8	20°57′50″	140°44′40″	241.
Mount Wheeler Mine (Au, Cu)	8	20°59′10″	140°44′40″	252.

Name	Atlas Plate No.	Co-ordinates		Reference
		S Lat.	E Long.	
Mullera, Parish of	3			119.
Musselbrook Creek	3	18°32′	138°11′	18, P6.
Myally Creek	7	19°09′50″	139°37′20″	97, 98, 103.
Naraku Railway Siding	8	20°17′25″	140°14′10″	94, 148, 250.
New Year's Gift Quarry (Ls) (See Wilgar Quarry)				
Nicholson River	2 & 3	17°53′	138°16′30″	26, 28, 35, 43, 55, 58, 111, 114, 115, 116, 117, 118, 119, 128, 130, 133, 135, 155, 188, 198, 230.
Noranside Homestead		22°09′35″	139°59′40″	23.
Normanton				15, 192, F5.
Northern Leases (Ag, Pb, Zn)	5	20°34′20″	139°28′10″	198, 218, 219, 222, **226**, 236.
O'Briens Soak	9	21°13′	139°33′	237, 252.
Old Man Waterhole	8	20°33′05″	139°58′30″	97, 153.
Old Slaughter Yards	5	20°38′00″	139°24′40″	164, 165, 170, 288.
Oona Railway Siding	7	20°00′00″	139°59′15″	61, 145, 215, 278.
Orphan Mine (Cu)	7	19°47′	140°120′	193, 204, 208, **214**, 247.
O'Shanassy River	4	19°09′	138°43′	20, 26, 127, 128, 252, 253.
Overhang Deposit (Mn)	9	21°00′	140°25′	**242.**
Overshot Waterhole	4	19°08′15″	139°25′30″	294.
Paradise Creek	4	19°43′	139°10′	31, 32, 104, 105, 106, 131, P5, P22, P23.
Paradise Valley Deposits (Cu)	4	19°46′25″	139°02′30″	195, 217, 251 (also see Lady Annie).
Paroo Creek	5 & 8	20°13′	139°39′	99.
Peter's Creek	2	17°38′20″	138°19′50″	115.
Pilpah Range	5	20°23′	138°38′	29, 121.
Ploughed Mountain	3	18°33′10″	138°43′20″	101, 102, 110, 111, 187.
Prospector Creek	8	20°16′	139°54′	35, 62, 89.
Pumpkin Gully	8	20°42′20″	140°38′00″	27, 192, 234, 235, 242, 243, P26.
Quamby	8	20°22′15″	140°17′	15, 217, 238, 244, 246, 251.
Quamby Queen Quarry (Ls)	8	20°21′	140°17′	246.
Queen Sally Mine (Co, Ni, As)	8	20°05′	140°09′	237, 238, 243, 244.
Quilalar Fault	8	20°11′50″	139°45′50″	52, 187, 188.
Quita Creek	6	21°55′40″	139°02′10″	242, F12.
Razorback Mountain	8	20°23′20″	139°49′00″	63.
Redbank Area (See Wollongorang-Redbank Area)				
Redtree (Livingstone's) Deposit (Ur)	2	17°30′50″	138°06′20″	229, 230, P15.
Referee Mine (Cu)	8	20°19′05″	139°48′50″	61, 145, 206, 207, 208, 250.
Ridgepole Deposit (Cu)	3	18°35′55″	138°18′35″	226, 243.
Rifle Creek	8	20°57′20″	139°35′30″	66.
Rifle Creek Dam	8	20°57′20″	139°35′30″	20, 24, 60, 61, 62, 104, 174, 284, P19.
Rio Grande (See Mount Isa Orebody)				
Riversleigh Homestead	4	19°01′25″	138°44′05″	26, 38, 226, 251.

Name	Atlas Plate No.	Co-ordinates		Reference
		S	E	
		Lat.	Long.	
Robert Heg Lease (Ur)	9	21°12′40″	140°33′30″	246.
Robin Lease (Ls)	8	20°41′20″	139°46′10″	247.
Rocky Creek	6	21°35′50″	139°08′20″	151, 165.
Rose and Thistle Mine (See Falcon Mine)	8			
Rosebud Mine (Cu)	8	20°50′10″	139°58′20″	88, 139, 164, 165, 167, 168, 186, 193, 204, 206, 208, **216**, 247, 250.
Roxmere Homestead	8	20°50′10″	140°31′15°	93.
St George Mine (Cu, Ag)	9	21°23′	139°52′	237.
St Mungo Mine (Cu)	9	21°29′	139°49′	204, 208, **215**.
St. Pauls Creek	7	19°47′40″	139°56′05″	143, 167.
Salmon Mine (Ls, Cu)	8	20°46′	140°26′	193, 246, 247.
Sandy Creek	8	20°59′	140°47′	20.
Sandy Creek	4	19°06′35″	139°20′40″	31, 154, 294, P31.
Selwyn	9	21°31′20″	140°30′10″	15, 20, 24, 85, 126, 138, 168, 177, 185, 204, 211, 237, 239, 251, 252, P9.
Settlement Creek	2	17°10′	138°00′	116, 120.
Seymour River	4	19°16′30″	19°52′30″	98, 218, F12.
Shamrock Mine (Au, W)	8	20°49′20″	140°47′40″	241.
Silver King Mine (Pb, Ag)	3	18°45′	138°55′	199, 220, 222, 226, **227**, 241.
Silver Phantom (Ag)	9	21°19′	140°24′	**237,** 251.
Silver Ridge Lodes (Pb, Au)	7	19°57′	139°51′	219, 243.
Six Kangaroos Lease (Ur)	8	20°33′	140°07′	229, **234**, 245, 246.
Skal Deposit (Ur)	5	20°28′	139°28′	198, 229, 232, **233**, 246.
Slaty Creek	8	20°53′10″	140°21′00″	242.
Smoky Creek	1	22°06′30″	139°13′35″	150, 167.
Snake Creek	8	20°57′20″	140°40′00″	70, 134, 139, 140, 163, 164, 168, 218, 250, P32.
Snake Creek East	8	20°46′40″	140°39′50″	68, 70, P28.
Soldiers Cap	8	20°59′20″	140°44′40″	68, 126, 148, 163, 234, 243, 250, 252.
Soldiers Cap Area	8	20°45′00″	140°42′20″	47, 68, 70, 89, 139, 164, 192, 194, 235, 238, 241, 242, 250, 251, P2, P31.
Southern Cross Mine (Cu)	9	21°01′00″	140°24′30″	77, 237.
Spear Creek	5	20°39′	139°29′	109, 244, 245.
Split Creek	6	21°41′50″	139°16′20″	250.
Spring Creek	7	19°29′30″	139°46′	103.
Squirrel Hills Homestead	9	21°46′20″	139°46′20″	148, 149.
Standish Range	9	21°50′	139°45′	26.
Star of the East Mine (Pb, Ag)	3	18°50′40″	138°36′40″	110, 226.
Staveley, Parish of	9			83.
Stockyard Creek	3	18°26′	138°11′	66.
Success Mine (Co, Cu)	8	20°52′	140°19′	237, 238, 243, 244.
Sulieman Bore	6	21°40′30″	139°22′55″	60, 151, 159, 164, 165, 170, 288.
Sunday Gully	8	20°16′40″	139°47′10″	43, 103, 143, 157, 192.
Sunset Deposit (Ls, Cu)		20°48′	139°59′	247.
Surprise Creek	8	20°01′30″	139°50′20″	47, 102, 146.
Sybella Creek	5	20°52′40″	139°26′50″	109, 149, 252.
Teddington Loch (See Bushy Park Homestead)				
Templeton River	5	20°40′	139°11′	28, 107, 108, 121, 127.
Thorntonia Homestead	4	19°30′00″	138°56′20″	251, 255.

Name	Atlas Plate No.	Co-ordinates		Reference
		S	E	
		Lat.	Long.	
Three Brunettes Lease (Ur)	8	20°37′50″	140°07′40″	246.
Three Inkspots Lease (Ur)	8	20°32′40″	140°10′20″	245, 246.
Three Trees Mine (Cu)	8	20°50 05″	139°50′20″	174, 284.
Tinboll Lease (Cu, Ur)	8	20°37′20″	140°41′50″	228, 229, 251.
Tip Top Mine (Cu)	9	21°25′20″	140°27′30″	83.
Tobermory Homestead				38.
Toko Range				26, 36, F12.
Tombstone Hill (See Northern Leases)				
Tommy Creek	8	20°32′30″	140°25′	35.
Toolebuc	-	22°11′20″	140°51′35″	218, 250.
Top Camp	9	21°02′	140°25′	23, 81, 89, 91, 192, 218, 234, 235, 242.
Trekelano Mine (Cu, Au, Se)	9	21°29′20″	139°54′00″	86, 89, 152, 153, 170, 175, 176, 193, 194, 195, 196, 204, 207, 208, **212**, 235, 237, 241, 244, 246, 247, P28.
Twiggievous Mine (Cu)	9	21°23′35″	140°26′40″	83.
Two Mile Diggings (Au)	8	21°01′30″	140°24′	192, 242.
Urandangi	6	21°36′30″	138°18′20″	36, 38, 125, 150, F4.
Valhalla Lease (Ur)	5	20°23′	139°18′30″	230.
Valley Deposit (Ls)	8	20°43′20″	139°46′20″	247.
Verdon Creek	3	19°00′00″	138°36′	110, 127.
Verpat Lease (Ur)	8	20°33′40″	140°06′40″	246.
Victoria Deposit (Au)	8	20°06′	139°42′	235.
Waanyee (Cu)	3	18°35′40″	138°40′	226.
Waverley Creek	6	21°26′30″	139°20′00″	108, 109, 151, 173.
Weatherly Creek	8	20°55′10″	140°45′30″	68, 70.
Wee MacGregor Mine (Cu)	8	20°54′45″	139°56′50″	67, 174, 204, 208, **214**, 251.
West Leichhardt River (See Leichhardt River, West Branch)				
Western King (Pb, Ag)	3	18°44′	138°34′10″	226.
Westmoreland Homestead	2	17°20′25″	138°15′05″	114, 116, 121, 218.
White Crossing	3	18°28′10″	138°35′10″	111.
White Hills Homestead	7	19°35′25″	139°51′25″	99.
Why Not Lease (Ur, Th)	8	20°40′30″	140°12′	245, 246.
Widdallion Creek	3	18°13′	138°37′	20, 252.
Wilgar (New Year's Gift) Quarry (Ls)	8	20°40′00″	140°21′00″	246, 247.
Williams River	8	20°52′	140°50′	16, 20, 148.
Wills River (Creek)	9	22°00′00″	139°44′00″	122, 128, 189.
Wollogorang Homestead		17°12′50″	137°56′30″	23, 116, 118, 121.
Wollogorang-Redbank Area				116, 117.
Wonga Fault	8	20°39′00″	139°58′00″	136, 152, 184, 248.
Yaringa Creek	5	20°48′50″	139°11′00″	58, 59, 107, 150, 165, P21.

PLATE 34

STRUCTURE MAP OF THE PRECAMBRIAN OF NORTH WESTERN QUEENSLAND

showing the distribution of volcanics and granite

Geology by officers of the Bureau of Mineral Resources, and the Geological Survey of Queensland.

Compiled by E. K. Carter

Drawn by P. A. Boekenstein, & G. Matveev, Bureau of Mineral Resources, Geology and Geophysics, May 1961

SCALE
10 Miles to 1 Inch

10 0 10 20 30 MILES

10 0 10 20 30 40 50 KILOMETRES

REFERENCE

UPPER PROTEROZOIC
- Sediments
- Volcanics

LOWER PROTEROZOIC
- Sediments and metavolcanics
- Volcanics and metamorphics

? ARCHAEAN
- Metamorphics and metavolcanics
- Granite

- Major anticline
- Major syncline showing pitch
- Minor anticline showing pitch
- Minor syncline showing pitch
- Overturned minor anticline
- Overturned minor syncline
- Fold axis anticline or syncline
- Fold axis of concealed strata
- Basin
- Dome
- Fault, position accurate
- Probable fault
- Regional dip of bedding
- Overturned bedding
- Horizontal bedding
- Geological boundary, position accurate
- Indefinite geological boundary
- Established unconformity
- Observed probable unconformity
- Sealed road
- Unsealed road or track
- Railway with siding
- Township
- Homestead

LOCALITY MAPS

WEST MORELAND	
LAWN HILL	DONOR'S HILL
CAMOOWEAL	DOBBYN
MT ISA	CLONCURRY
URANDANGI	DUCHESS
GLEN ORMISTON	BOULIA

Map showing position of area dealt with in report and reference to Australian Four Mile Map Series

QG 34-24

Printed by Mercury Press, Hobart.

SCHEMATIC CROSS-SECTIONS THROUGH THE PRECAMBRIAN OF NORTH WESTERN QUEENSLAND.

Based on Geological Map (Atlas, Plate 1). Units as on Structure Map (Plate 34)
Section Lines shown on Plate 34

A — A′

B — B′

C — C′

D — D′

E — E′

F — F′

G — G′

139°30′E

H — H′

VERTICAL AND HORIZONTAL SCALES

10 Miles to 1 Inch

10 0 10 20 MILES

10 0 10 20 30 KILOMETRES

REFERENCE

- Upper Proterozoic sediments
- Upper Proterozoic volcanics
- Lower Proterozoic sediments
- Lower Proterozoic volcanics
- ? Archaean
- Granite
- Precambrian, Undifferentiated

Bureau of Mineral Resources, Geology and Geophysics, May 1961

To accompany Bulletin 51.

QG 34-25

H.F.D.

MERCURY