BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS
DEPARTMENT OF NATIONAL DEVELOPMENT
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A Commentary on the Metallogenic Map of Australia and Papua New Guinea

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BY

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INTRODUCTION

A metallogenic map depicts concentrations of deposits of metals within their geological framework, and attempts to relate one to the other. The more familiar mineral deposits map, on the other hand, is designed to show the geographical distribution of mineral deposits, possibly with indications of their size, state of exploitation, and other factors.

The exact nature of the legend for a metallogenic map is governed by the relationships assumed to exist between the concentrations of metals and their settings: map design can be used to emphasize the more important facts and employs symbols each of which incorporates several parameters. Metallogenic maps are not simple and easily read documents, but are complex representations of complex relationships, and so should convey a great deal of information.

In 1956, at the 20th Session of the International Geological Congress in Mexico, the Commission for the Geological Map of the World set up a Sub-Commission for the Metallogenic Map of the World. After studying available maps showing mineral deposits, the sub-commission recommended that although countries should continue experimentation towards suitable presentation of data, an Editorial Committee for the Metallogenic Map of Europe should be set up; this committee would work towards firstly a legend for metallogenic maps in general, and secondly a Metallogenic Map of Europe. The committee was fortunate in that the compilation of the Tectonic Map of Europe was well advanced when it began its work. In 1964 a legend reflecting the basic philosophy of the Metallogenic Map of Europe was prepared and compilation begun. The first two sheets of the Metallogenic Map at a scale of 1:2 500 000 were published in 1969.

Australia was represented on the sub-commission from 1960 onwards. The presentation of the legend for the map of Europe paved the way for the Australian compilation. A suitable area was selected for a pilot compilation early in 1965 and the main study began in 1966.

A suitable geographical base map of Australia at 1:5 000 000 was available and a geological map on this base was in the final stages of publication. The second edition of the Mineral Deposits Sheet of the Atlas of Australian Resources (scale 1:6 000 000) was published during 1965. In that year the Tectonic Map Committee of the Geological Society of Australia began work on a Tectonic Map of Australia, and the philosophies and preparation of that and the Metallogenic Map were developed together.

When compilation started three major reference works on mineral deposits in Australia were available: *The Geology of Australian Ore Deposits,* First Edition (1953)[1], edited by A. B. Edwards; Second Edition (1965)[2], edited by J. McAndrew; and *Australian Mineral Industry; The Mineral Deposits* (1965), edited by I. R. McLeod[3]. Each contained overall summaries of the ore deposits of Australia, the first two regionally and by individual deposits, and the last by commodity; and so served as a broad base of information. As a metallogenic study requires detailed information, about two years were spent in assembling as much data as could be gleaned from the literature. The relationships between tectonic framework and distribution of metal deposits were then examined so that provinces

1 5th Empire Mining and Metallurgical Congress.
2 8th Commonwealth Mining and Metallurgical Congress.
3 Bureau of Mineral Resources, Bulletin 72.

could be recognized and outlined. Since this process is subjective it is clear that the finished map represents only one possible interpretation—different interpretations or additional information not available at the time of compilation could produce different maps.

ACKNOWLEDGMENTS

The map and this account are entirely based on the material of previous workers and therefore their indirect contributions have been paramount to the finished work. The co-operation of the Tectonic Map Committee of the Geological Society is gratefully acknowledged, and in particular that of my fellow members of the Territories Subcommittee, Dr M. J. Rickard and Messrs H. F. Doutch and K. A. Plumb, without which my knowledge of the Australian tectonic framework would have been embarrassingly slight. My thanks are expressed to the members of State Surveys and Mines Departments, in particular Dr J. L. Daniels of Western Australia, Mr B. P. Thomson of South Australia, Mr L. McClatchie and Dr E. Scheibner of New South Wales, and Messrs J. H. Brooks, P. L. Ellis, and K. R. Levingston of Queensland, who helped so willingly during 'fact finding missions' to their various organizations, and to people from industry who offered advice during compilation. I have benefited greatly from ready access to work in progress, both in the Bureau and in State Geological Surveys. The patient helpfulness of my supervisors, I. R. McLeod and Dr G. E. Wilford, has made the task considerably more agreeable over the years of the project. The clarity of the map is entirely due to R. A. Swoboda, whose patience and cartographic skill has transformed a conflicting mass of complex data into a legible whole.

THE LEGEND

The Metallogenic Map of Europe was originally mooted as the pilot study for the world map. The proposed legend was published in 1964, after some discussion of alternative proposals for presentation; it has been modified in detail during compilation of the final map. Our legend was modified from this early European legend as problems were encountered, so that the legend for the Australian map suits our local conditions and the scale of 1:5 000 000, which was used instead of the European scale of 1:2 500 000. Some of the alterations were prompted by the work of the Tectonic Map Committee of the Geological Society of Australia, the aim being co-ordination of the philosophy of the Metallogenic Map with that of the Tectonic Map—an aspect regarded as highly desirable by overseas workers.

The Legend for the Metallogenic Map of Europe

The legend for the Metallogenic Map of Europe is based on the concept that since metallogenic events are related to tectonic events they are best depicted in a tectonic framework. Two major divisions of the framework were recognized—orogenic domains and platforms. The orogenic domains were distinguished according to age, and in accordance with the European concept of platform the basement was emphasized more than the cover rocks; so all platformal regions are depicted by the one colour, with overprints indicating age of sedimentation.

The time-honoured factors that are regarded as affecting ore deposition, such as rock type, volcanicity, time-relation of intrusions to tectonism, chemical nature of igneous activity, structure, and metamorphism were incorporated in the legend to amplify the tectonic framework; some additional factors important in exploration, such as geochemical and geophysical anomalies, lateritization, palaeogeographic conditions, and palaeosoils, were also included.

The genetic classification scheme for ore deposits in the European map is a modified version of Lindgren's classification[1]. Europeans use the broad class exogene for deposits formed at the Earth's surface and endogene for deposits formed within bodies of rocks; but these terms have different meanings in Australian literature and have not been used in the Australian map. Deposits were divided into two size categories. Large deposits were to be those that contained before exploitation more than 0.05 percent of known world reserves plus past production of a metal; no lower limit for the small deposits shown was given.

The metal content of deposits, and the chemical compounds in which they occur (sulphide, silicate, carbonate, etc.) further classify them; the metals are placed into naturally occurring groups. The European legend included some non-metallic commodities, which, except for phosphorus and fluorite, are not included in the Australian legend.

The Legend for the Metallogenic Map of Australia

During compilation of the Tectonic and Metallogenic Maps, legends suited to Australian geology were evolved, modified, and redefined.

Tectonic Domains (Time-Tectonic Units)

In the Tectonic Map of Australia (1971) the units delineated as *tectonic domains* have been recognized and classified by certain diagnostic characteristics of tectonic style such as deformation, igneous activity, sedimentary facies, and metamorphism. Three types of tectonic domain are thus recognized (Fig. 1):

Orogenic Domains (including metamorphic complexes) are precratonic, and involve flysch-like sequences in extensive linear troughs, abundant and varied volcanic and plutonic rocks, and intense deformation and widespread metamorphism.

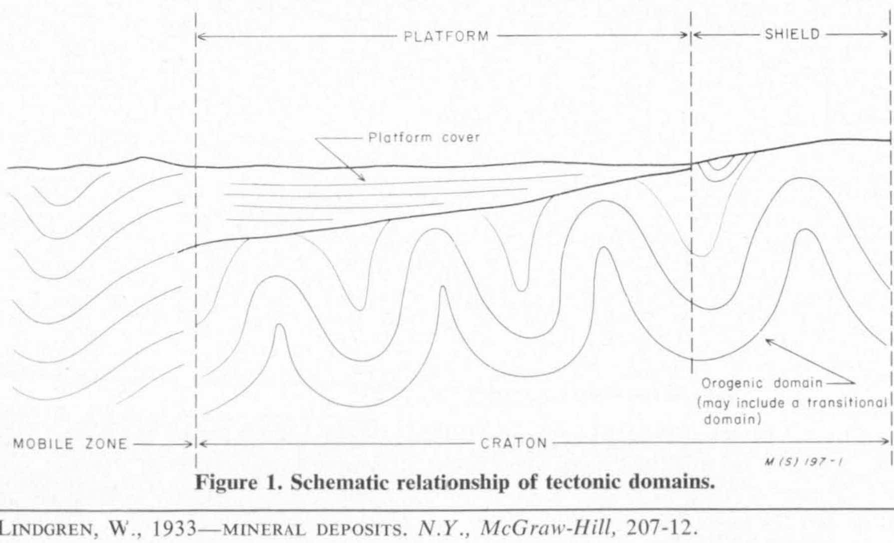

Figure 1. Schematic relationship of tectonic domains.

[1] LINDGREN, W., 1933—MINERAL DEPOSITS. *N.Y., McGraw-Hill,* 207-12.

Transitional Domains are late to post-orogenic; they are associated with cratonization and are intermediate in time and style between orogenesis and cratonic tectonism. They are characterized by downwarping and cauldron subsidence, molasse-like sedimentation, abundant volcanic and plutonic rocks, moderate deformation, and rare metamorphism. Some domains in this category are represented only by post-orogenic granites.

Cratonic Domains (*Platform Covers*) are characterized by widespread, generally thin, shallow-water and continental sediments, rare small plutons, and basaltic sheets; and by mild deformation of basement and cover. Narrow mobile zones may develop.

A formally named *Orogenic Province* is a group of broadly contemporaneous orogenic domains of similar tectonic history and style that, together with associated transitional domains, form the youngest basement to an immediately succeeding Platform Cover.

A formally named *Platform Cover* is a group of sedimentary basins which developed more or less at the same time and in the same way. Its deposits overlie the immediately preceding Orogenic Province and associated transitional domains and spread across older Orogenic Provinces and Platform Covers.

This framework has been modified for the Metallogenic Map in that transitional domains are considered with the immediately preceding orogenic domain; hence an Orogenic Province as discussed in the text consists of both the orogenic and transitional domains which form youngest basement to an immediately succeeding Platform Cover.

Five Orogenic Provinces are recognized on the Tectonic Map, but only four Platform Covers; the youngest, New Guinea, Orogenic Province has no cover as yet. There are also six orogenic domains which cannot be assigned to any Orogenic Province using the classification outlined above, because their relationship with Platform Covers does not indicate the immediate succession in time and space implied by the definition of Orogenic Province.

In the notes that follow, additional terms will be used in the sense indicated:

Shield as a general term is used to indicate both orogenic domain and transitional domain as a geographical entity exposed at the surface. The term *belt* is used for an elongate shield and *block* for a roughly equidimensional shield.

A *platform* consists of undeformed or mildly deformed rocks resting on deformed basement. The rocks are referred to as platform cover. (The formally named unit is indicated by the use of capitals.)

Craton is used to refer to an entity of both shield(s) and platform(s) which behave as a stable tectonic entity at a given period of time. Several different cratons can be recognized, depending on the period of geological time under discussion.

Mobile Zone or Belt refers to a highly active elongate region during the period of its activity; the 'New Guinea Mobile Belts', for example, constitute the currently active northern margin of New Guinea.

The sedimentary basins that have by tradition been referred to as geosynclines, in particular the Davenport and Adelaide 'Geosynclines', are distinguished in the text by inverted commas from narrow mobile troughs such as the Lachlan Geosyncline.

Time Terms

The Tectonic Map Committee has adopted a terminology based on the division of geological time into spans with tectonic significance. Although orogenies and periods of igneous intrusion occupy relatively short spans of geological time, on a regional and Australia-wide basis they have a time distribution with recognizable maxima which were assumed to have tectonic significance. Intervals were therefore chosen so that these maxima could be suitably divided one from another into tectonically useful time units. The number system shown on the face of the map symbolizes these divisions of time, and also permits the presentation of additional data on the type of event involved.

The terminology for Phanerozoic time units is based on the Australian Stratigraphic Code, 4th Edition, 1964 (*J. geol. Soc. Aust.,* 11(1), 165).

The Precambrian time units, in particular Carpentarian and Adelaidean, are used in the sense of Dunn, Plumb, & Roberts (1966).

Metallogenesis

Any metallogenic map is based on the assumption of relationships between the geological framework and the location of ore deposits. The generalizations govern the categories used in the legend; specific relationships are delineated on the face of the map.

The heavy dependence placed on the available literature (no fresh field studies were undertaken by the author during the preparation of the map) means in turn a heavy dependence on the opinions of geologists over a long period of time during which theories of metallogenesis have altered radically. The vast majority of Australian ore deposits were described during a period when all ore deposits were assumed to be hydrothermal, even if the supposed granite source was far distant or invisible. On the other hand most regional studies belong to the more recent era of 'syngeneticism', and opinion today seems to be swinging towards emphasis on tectonic mobilization, that is, the migration of ions along a pressure-temperature gradient to a location where conditions suitable for accumulation were set up—the ions (in particular copper, lead, zinc, and sulphide) having been trapped during formation of the geosynclinal pile. Theories invoking environments of sedimentation, groundwater movement, and leaching under stable land surfaces are now being applied to studies of the origin of many ore deposits; the resulting conclusions, combined with a more detailed knowledge of the geology of mineralized areas, may result in the changing of many province boundaries shown on this map.

Whatever the controlling factors nominated for ore deposits, it is still possible to describe them in a tectonic framework. The tectonic framework used for the Tectonic Map of Australia is admirably suited to the description of metallogenesis; in particular the groupings of the igneous rocks fit very well with the environments proposed for ore genesis.

Genetic Classification

In any genetic classification, grouping must be somewhat arbitrary. Every feasible combination of pressure and temperature conditions within the crust (and at the Earth's surface) very probably played an important role in the formation of some orebody somewhere—in much the same way as the various metamorphic facies are now recognized as spanning the same entire range.

It has been assumed that where the terms 'mesothermal' and the like have been used in the literature they correspond broadly to the values put on them by Lindgren in 1911 (see Lindgren, 1933, pp. 211-2). The classification scheme is intended to correspond without precise temperature values to Lindgren's range. The classification scheme may well be regarded as the weakest point of the legend: the terms are adopted from common usage, and very often bear entirely different meanings to different people. Alluvial thus may be a purely descriptive term to a field geologist but carry overtones of mechanical winnowing by flood waters, wave action, or wind to a sedimentologist, who may indeed wish to subdivide the class.

There appears to be a pressing need for detailed studies of paragenesis (in the sense of a study of the minerals present and the order in which they formed or recrystallized), followed by deductions on genesis, on nearly all ore deposits (except large deposits still being worked) in Australia. However, the material left on the mine dumps or in unproductive parts of abandoned mine workings, which is all that is still available at many known Australian occurrences of metals, is hardly ideal for such studies. Moreover, the extreme depth of oxidation and supergene effects, combined with the common practice of mining only rich supergene ore and abandoning mines at the water table, may well mean that suitable material never reached the surface during mining.

Size Divisions

The European legend suggested that the division between large and small deposits should be taken at 0.05 percent of the total world production plus reserves of the metal concerned. This total world figure has been difficult to ascertain; the values used have been obtained from various sources, mainly *Annales des Mines*, publications of the United States Bureau of Mines, and *World Mining*. Most figures are conservative; and estimates for the People's Republic of China and the USSR are inaccurate or out of date. This selection of values related to world figures helps to orient Australian deposits better in the world picture, but does magnify the importance of deposits of metals with small total world resources, so that some deposits shown as large are not likely to be economic in the foreseeable future. Large deposits are shown in two ways—either by the appropriate large symbol if isolated, or by a large colour spot if within a province. (In a few places, where provinces are small or form narrow belts, it became necessary to use a large deposit symbol to combine the functions of the normal small symbol on the province boundary which indicates the properties of the province, and the colour spot which indicates the site of the large deposit.) Lower limits to the size of individual deposits that would be shown were selected to weed out insignificant but common mineralization, such as small iron skarns. This left the problem of small isolated deposits that are metallogenically interesting or not yet properly explored; these are shown by small spots of colour and designated as 'minor'. Neither small nor minor deposits within provinces are shown; the areas where such deposits are concentrated are indicated by hatching. The figures used for the division into large and small deposits are given in Table 1.

Chemistry

Metals were grouped according to their most common association. Nothing short of one colour to each metal seems to be ideal; but the breakdown used is the best compromise that could be found between map design and possible groupings.

TABLE 1: SIZE LIMITS ADOPTED FOR VARIOUS COMMODITIES

COMMODITY (metal content unless otherwise stated)	SIZE LIMITS: Large deposit lower limit (tons)	Small deposit lower limit (tons)	Small deposit % of large deposit
Antimony	2 500	25	1
Aluminium	750 000	4 000	0.5
Asbestos	80 000	400	0.5
Barium ($BaSO_4$)	80 000	400	0.5
Beryllium (BeO)	50 (i.e. 450 tons beryl)	2 (beryl)	0.5
Chromium	425 000	2 300	0.5
Cobalt	1 750	10	0.57
Columbium (R_2O_5)	Combined with tantalum		
Copper	150 000	1 000	0.7
Fluorite (CaF_2)	50 000	500	1
Gold	1 500 000 (oz)	10 000 (oz)	0.7
Iron (Fe in 50+% ore)	40 000 000	500 000	1.2
Lead	68 000	350	0.5
Lithium (Li_2O)	16 000 lepidolite 10 000 amblygonite 20 000 petalite 12 000 spodumene	Prod.	—
Magnesite	4 600 000	23 000	0.5
Manganese	500 000	2 000	0.4
Mercury	500 000	Prod.	—
Molybdenum	1 750	10	0.5
Nickel	20 000	500	0.5
Phosphate (P_2O_5)	25 000 000	120 000	0.5
Platinum	25 000 (oz)	120 (oz)	0.5
Osmiridium	5 000 (oz)	25 (oz)	0.5
Silver	13 000 000 (oz)	100 000 (oz)	0.7
Sulphur	500 000	2 500	0.5
Tantalum (R_2O_5)	50 (200 ton conc.)	1 ton conc.	0.5
Thorium (ThO_2)	310	Prod.	—
Tin	10 000	50	0.5
Titanium (TiO_2)	120 000	600	0.5
Tungsten (WO_3)	1 000	5	0.5
Uranium (U_3O_8)	750	5	0.5
Zinc	65 000	320	0.5
Zirconium (ZrO_2)	10 000	50	0.5

The value of showing the chemical composition of the deposits seems marginal at the scale of the map. Moreover, our knowledge of the chemistry of deposits is very patchy, for several inter-related reasons.

The long stability, with associated peneplanation, of the present craton from the late Mesozoic onward has led to the extensive oxidation of sulphide orebodies, commonly to depths of 50 to 100 m. In some orebodies an initially very low-grade sulphide deposit has produced a small but rich body of supergene ore, and the literature records that many bodies were mined only in the oxidized zone, or abandoned because of low grade below the water table; and in many cases the composition below the water table is only hinted or not recorded.

For copper, many deposits of which were worked only or mainly in the oxidized zone, the composition of individual deposits is shown as recorded in the literature, and provinces were drawn according to the overall chemistry recorded. Many gold mines proved economic above the water table, where the oxidation of pyrite from complex gold-pyrite primary ore (found below the water table) freed the gold for easy recovery. The presence of pyrite is frequently not recorded, and its absence from the chemistry shown for provinces and deposits is a reflection of this bias in the literature, as well as of the ubiquity of pyrite in base-metal sulphide deposits.

Again, the European legend allowed for the showing of areal zones of oxidation; but oxidation is ubiquitous in Australia, so this was not appropriate for the Australian map.

Metallogenic Province

The concept of metallogenic province has evoked much discussion and several definitions have been proposed. The Working Group for the Metallogenic Lexicon under the direction of E. T. Shatalov proposed:

'Metallogenic Province. It is a vast folded or platform section of the earth's crust of a definite type and of the period of the tectonomagmatic and metallogenic development with the associations of the mineral deposits characteristic of the latter (with a definite type of mineralization—a complex of basic, secondary and sporadic metals and minerals). The metallogenic provinces can be formed during one tectono-magmatic cycle or they can be bicyclic or polycyclic ones.

'The metallogenic provinces cover the areas of hundreds of thousands to the first millions of square kilometres within which orebearing areas of a smaller order—metallogenic regions or zones—can be distinguished. Due to this, the metallogenic provinces cover groups of orebearing areas with various parageneses of mineralization, and they are polyparagenetic.'

This definition fits into a hierarchical classification of units by increasing complexity and areal extent.

A somewhat similar view is given by N. E. Petrascheck (1965, *Econ. Geol.*, 70, p. 1620):

'A metallogenic province is the entity of mineral deposits that formed during a tectonic-metallogenic epoch within a major tectonic unit and which are characterized by related mineral composition, form of the deposit, and intensity of mineralization.'

In the compilation of the Australian map no one definition has suited the problems encountered. Some ore deposits have been studied in their regional setting, but most have not. The main problem was the recognition of common factors among deposits, and the emphasis has been placed on common genetic factors. Provinces have been delineated by the grouping of adjacent deposits with apparently common genesis (as far as could be judged from the literature). In European terms each such province has a characteristic and unique *metallotect* or overall genetic environment. The number of factors recognized in the metallotect varies from province to province; some provinces were long ago recognized and are well defined in the literature, but others are either given passing recognition or are introduced in this map. Some 'provinces' in the literature have proved to cut across tectonic boundaries, or have been shown by isotopic dating to be invalid. Age determinations on the other hand have helped to show that deposits form complex provinces.

Monoparagenetic and polyparagenetic provinces in the European sense have not been distinguished. Some provinces are definite monoparagenetic units: for example the Hamersley Iron Province or the phosphate province in the northwest of Queensland. The most complex polyparagenetic provinces, shown as single provinces in the main map, are the zoned tin-tungsten-molybdenum-copper-lead-zinc provinces. The map is biased towards the common broad or regional genetic factors, not the common metal, in a province. Evaporite sequences within platform sequences are indicated only where drill holes have intersected halides; usually sodium chloride only has been present.

The Role of Age Determinations

Isotopic age determinations, mainly carried out at the Australian National University by a combined University-BMR team, have helped to fit stratigraphic relationships observed in the Precambrian into an absolute time scale, and thus serve as the underpinning for the tectonic relationships; they have also helped to evaluate the sequence of Phanerozoic events, particularly igneous activity. Ore deposits, the spectacularly large ones again apart, have received little attention as yet; reliance has been placed on observable field relationships with nearby dated events. It must be conceded that considerable doubt has been thrown on the validity of recorded ages, the relationship between events observed in the field and those isotopically recorded on the rocks, and the wisdom of founding tectonic systems on very limited dating.

TECTONIC FRAMEWORK OF AUSTRALIA

As already pointed out, the tectonic units on this map are classified by the relationship between Platform Covers and Orogenic Provinces.

Four spreads of platform cover are recognized: the first formed in the Lower Proterozoic; the second in the Carpentarian or Middle Proterozoic; the third in the Adelaidean and early Palaeozoic, i.e., late Proterozoic to mid-Devonian times; and the fourth began in the Permian and continued its development to the present. These are called, in order, the *West Australian, North Australian, Central Australian,* and *Trans-Australian Platform Covers.*

From the relationship of these to the orogenic domains which they overlie, five Orogenic Provinces are outlined:

The *West Australian Orogenic Province,* spanning from about 3100 m.y., or even earlier, to about 2400 m.y., i.e., mainly Archaean fold belts and shields;

The *North Australian Orogenic Province,* containing orogenic domains and transitional domains formed between about 2200 m.y. and 1900 m.y.;

The *Central Australian Orogenic Province,* containing rocks deformed between about 1800 m.y. and 1200 m.y.;

The *East Australian Orogenic Province,* which contains rocks laid down and deformed between the Cambrian and the Triassic;

The *New Guinea Orogenic Province,* containing rocks ranging in age from Triassic to Holocene, including rocks geosynclinal in facies but relatively undeformed. It is assumed that these constitute an evolving orogenic region.

In addition to these groupings there are four unassigned Precambrian orogenic domains. These are all metamorphic complexes; age determinations from metamorphic and igneous rocks within each indicate a wide time interval between the orogenesis and observed overlying Platform Covers. There are also two late Pro-

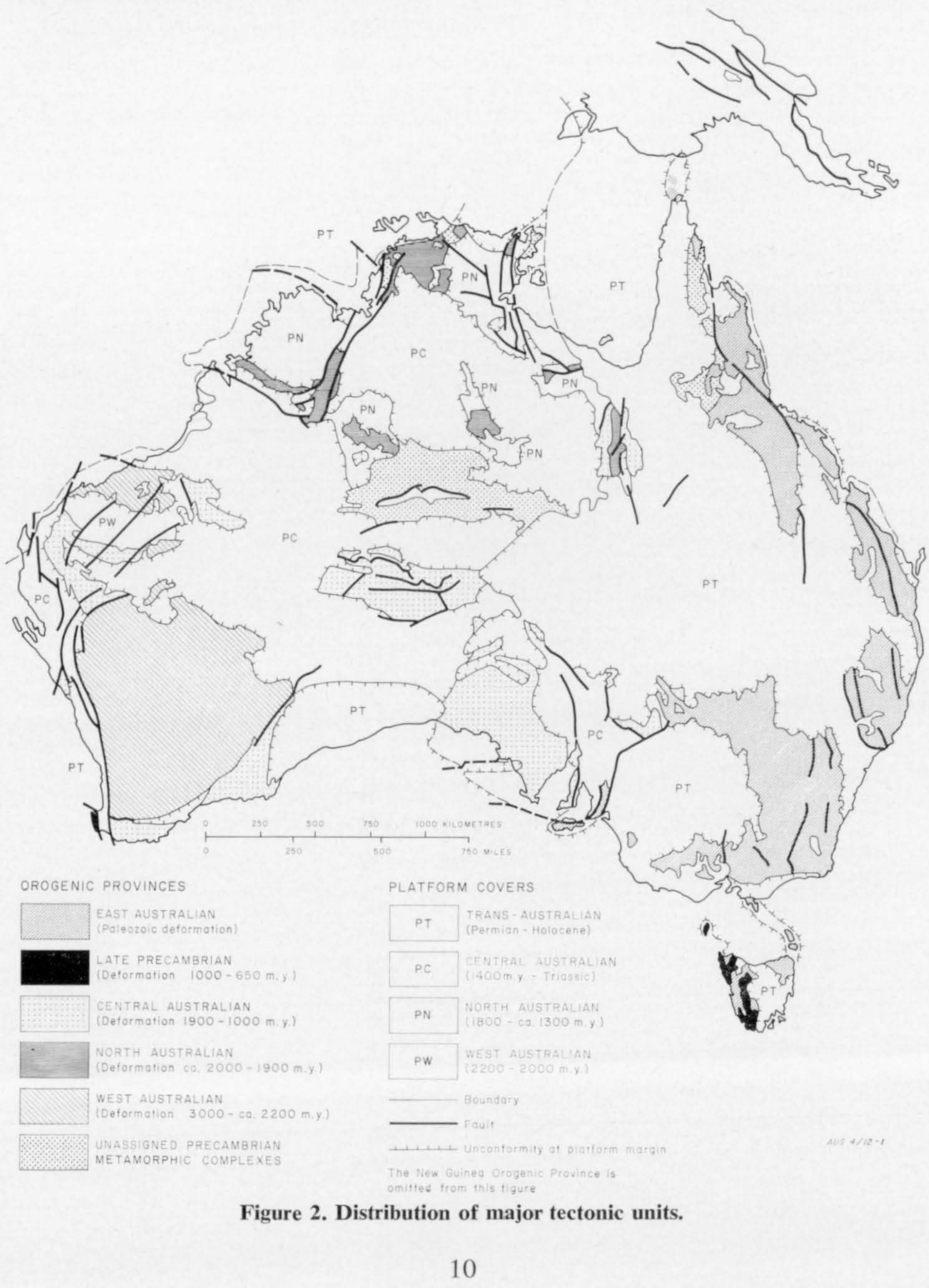

Figure 2. Distribution of major tectonic units.

terozoic orogenic domains, one in Western Australia overlain by Trans-Australian Platform Cover and one in Tasmania overlain by 'geosynclinal' deposits during the development of the East Australian Orogenic Province. Both are thought to have been deformed during the late Proterozoic (see Figs 2 and 3).

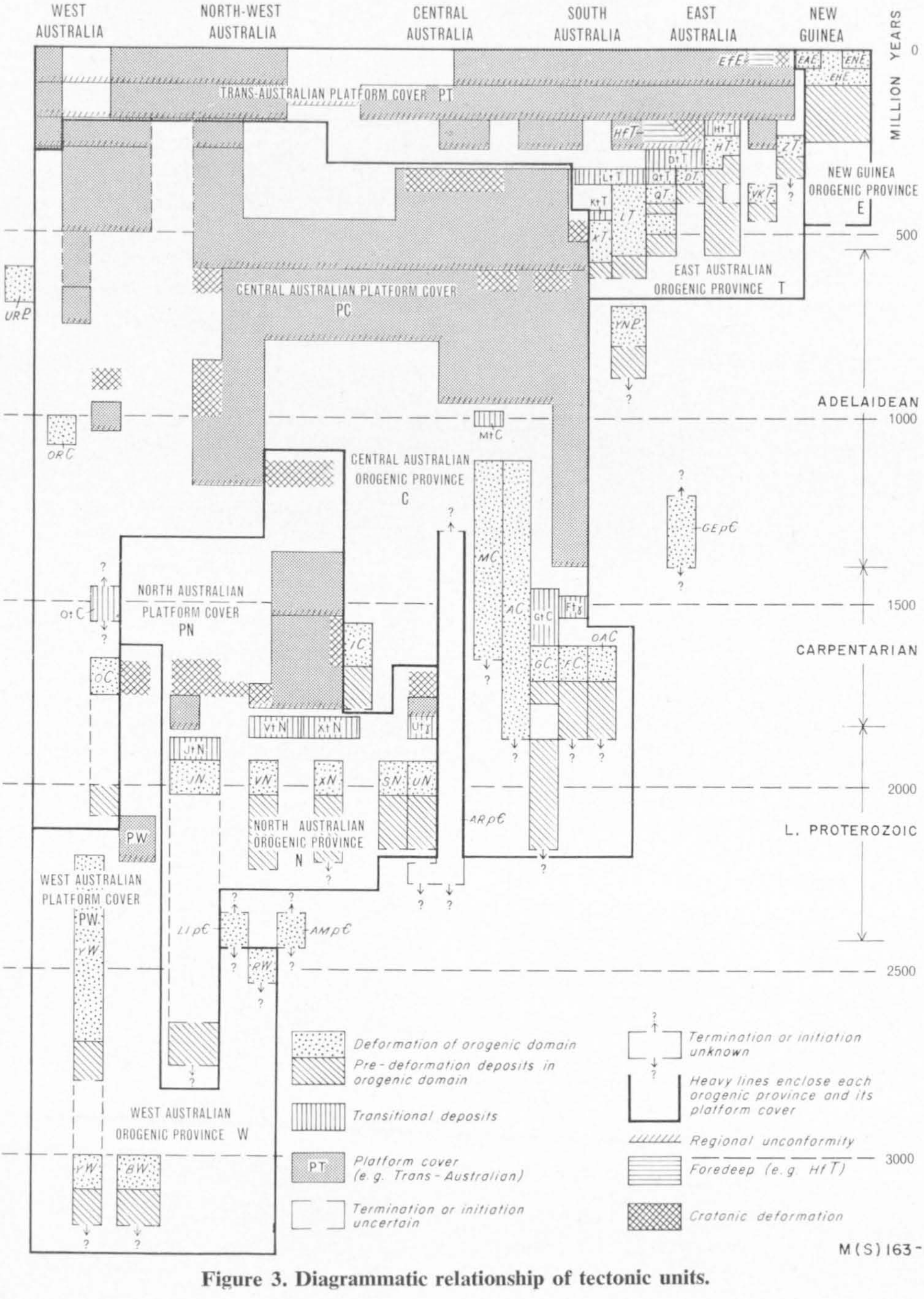

Figure 3. Diagrammatic relationship of tectonic units.

METALLOGENIC EPOCHS

The term 'metallogenic epoch' generally refers to a limited time span during which the mineral deposits of a given area were formed. Attempts have been made to assess epochs by Browne (1949), Jones (1953), Hills (1965), and Webb (1969), mainly for eastern Australia, where the overlap of tectonic events is extremely complex, so that several similar patterns of mineralization have been formed by overlapping tectonic evolutionary patterns. No attempt is intended here to define or redefine metallogenic epochs in Australia.

The pattern of tectonic evolution of a region is accompanied by one of metallogenic evolution. During the early development of geosynclines the extensive basic and intermediate volcanic activity with associated black shales is accompanied by the deposition of base metals; it appears that these are mobilized during faulting and metamorphism and syntectonic granite intrusion. Gold may be emplaced at this point, but in general seems to be introduced late in the orogenic cycle, commonly during the transitional phase along with antimony. Late-phase granites are generally accompanied by tin-copper-lead-zinc mineralization; ultrabasic intrusions generally tend to be associated with the presence of manganese, copper, or chrome; and in Australia a halo of mercury sometimes also occurs. Platform cover mineralization includes iron, aluminium, and reconcentrated detrital minerals.

Also, a spatial pattern of metal distribution can be followed from platform cover through the mobile edge of the craton and the edge of the geosynclinal zone into the deep-water 'geosynclinal facies' zone. The most marked features of this distribution appear to be an assemblage of tin, copper, molybdenum, and tungsten along the edge of the craton and the adjacent edge of the mobile zone, and a 'deep-water' facies association with gold-antimony and manganese mineralization.

The temporal and spatial patterns have been superimposed on each other during the complex tectonic evolution of the East Australian Orogenic Province.

WEST AUSTRALIAN OROGENIC PROVINCE

The West Australian Orogenic Province is the oldest part of the Australian continental crust. The greatest ages determined, in the vicinity of 3050 m.y. (Arriens, 1971), are from granites, implying a sedimentary history extending back well beyond this. The two main units, the Pilbara and Yilgarn Blocks, have lithological characteristics that mark them apart from all younger orogenic domains. They consist of belts of low-grade metasediments and metamorphosed acid and basic volcanics in predominantly gneiss and granite terranes, with no visible base to the 'sedimentary' piles, a feature shared by other Archaean regions of the world.

H. D. B. Wilson (1971) has suggested that Archaean terranes in general have a distinctive metallogeny; this certainly appears true for the nickel-copper and copper-zinc associations toward which exploration is being directed at present.

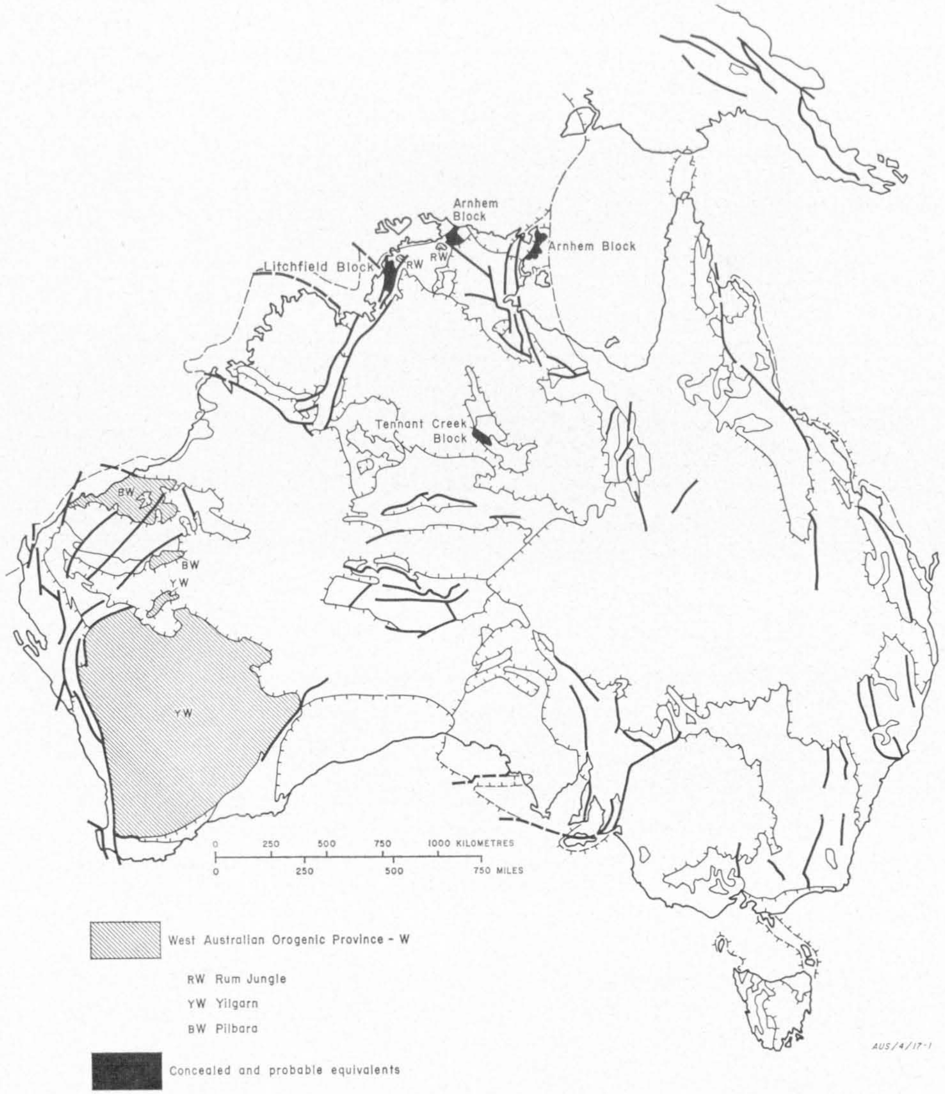

Figure 4. The West Australian Orogenic Province and its probable equivalents.

However, the distinctive Archaean copper-zinc association has not, so far, been reported from the West Australian Orogenic Province, although the Mons Cupri and Whim Creek copper orebodies contain some zinc. Although the types of gold mineralization in the Pilbara and Yilgarn Blocks have features in common, they seem to have little resemblance to oversea types. Tin mineralization is common in the Pilbara, but only one worthwhile producing area has been discovered in the Yilgarn Block; the tin mineralization is mostly of the pegmatitic type of Sainsbury & Hamilton (1967), although it is difficult to classify Greenbushes within their scheme. Antimony appears to be confined to the older parts of the Province—the Pilbara Block and the northwest of the Yilgarn Block.

The only folded rocks outside the Pilbara and Yilgarn Blocks definitely assigned to the West Australian Orogenic Province are in the Rum Jungle Block, basement to the Pine Creek Geosyncline in the northern part of the Northern Territory. However, equivalents of the West Australian Orogenic Province may well form basement to a large part of the Australian continent—Archaean basement has been recorded beneath the Tennant Creek Block (Crohn & Oldershaw, 1965), and Thomson (1969) regards parts of the Gawler Block as equivalent in sedimentary style and age to the West Australian Platform. The Arunta Complex in central Australia may extend back into the Archaean, if a single age determination of 2400 m.y. (Compston & Arriens, 1968) is to be accepted.

Pilbara Block

All the metasedimentary rocks of the Pilbara Block are assigned to the Roebourne Group (Ryan, 1964). Parts of the sequence have been subdivided in particular areas, but the pattern of deposition or stratigraphy of the block as a whole has not yet been studied in detail. Originally it was thought that there were two distinct sequences, an older 'Warrawoona Series', mainly a basic volcanic sequence with some interbedded banded iron formation, and a younger, mainly clastic, 'Mosquito Creek Series'; but these have more recently been shown to be lateral equivalents of each other within the Roebourne Group. More than half the area of the block is occupied by granites with gneissic and granitized margins of country rock. Locally the regional metamorphic grade reaches the amphibolite level, but away from the granites the grade is generally low. There are small masses of ultrabasic rocks which have been mapped mainly in the northwest. The block is cut by quartz veins up to 10 km long and dolerite dykes ranging up to 100 km; the dykes were emplaced after platform cover had started to form on the block (Ryan, 1964).

The Pilbara Block has been stable since 2900 m.y., a date obtained at Wodgina from a late-stage undeformed pegmatite. Granites in the block yield dates of 3050 $\pm$ 180 m.y. (Arriens, 1971).

Banded iron formations within the sedimentary sequence have been folded, and somewhat thickened at the crests and keels. Where the beds are near-vertical, supergene processes have leached out the silica, leaving bodies mainly of iron oxide; these bodies are resistant to weathering and form low hills of high-grade iron ore standing above the main land surface, as at Mount Goldsworthy (Brandt, 1965). The hematite bodies have yielded, by mechanical and chemical erosion, talus and limonite that have formed secondary deposits ranging in age from Proterozoic to Holocene in platform cover which lapped on to the Pilbara Block.

Gold occurs in quartz veins and in association with antimony. The low-temperature quartz-gold veins have been attributed to concealed intrusions of granite, but the close association between gold deposits and basic volcanics suggests that the gold may have been mobilized from the volcanics during deformation and deposited in suitable structural sites nearby.

Antimony in mineable concentrations occurs in only two areas. East of Nullagine a line of quartz lodes containing gold and stibnite extends from Blue Spec to Billjim (Noldart & Wyatt, 1962; Finucane, 1939; Finucane & Telford, 1939). Very little is known about its relationship to the regional geology; the line crosses the axial trend of folding at a low angle and therefore must transgress the bedding; there are no nearby intrusions. Cervantite occurs in outcrop at Blue Spec. East and north of Whim Creek, gold-antimony deposits at Mullina, Peewah, and Mount Negri were mined chiefly for their gold content. (Production of antimony in Western Australia was not recorded before 1916 and only spasmodically after then—these deposits were mined in the late 19th century.)

Small copper deposits, confined to the metavolcanics, were mined only if the ore was sufficiently rich to repay the cost of transport. Recently, re-examination of Whim Creek has shown a low-grade deposit of a size to warrant large-scale mining; and Mons Cupri nearby is a sizeable low-grade deposit in a volcanic plug. Both contain lead, zinc, and silver as well as copper. Reappraisal of other deposits such as those in the Copper Hills line of lodes may show that the small high-grade

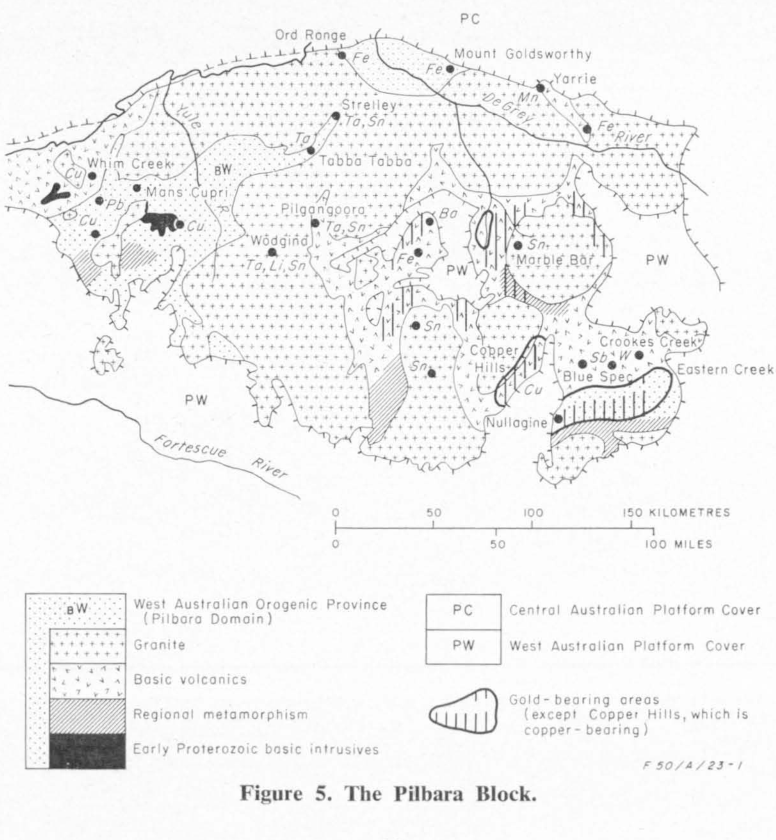

Figure 5. The Pilbara Block.

bodies that were mined are parts of larger low-grade deposits. All the copper deposits appear to be hypogene.

A barite lode about 40 km west of Marble Bar at Breens Camp was recorded by Simpson (1948) as one of the largest veins of barite known in Western Australia; but no evaluation of size, grade, or accessory minerals has been published. Simpson also records other occurrences of barite within the Pilbara Block, some as accessory minerals, others as veins or detrital boulders.

The basement inlier on the southern margin of the West Australian Platform Cover west of Jiggalong Mission is regarded as part of the Pilbara domain—it contains, besides minor gold and barite, the only mined deposit of chromite in the West Australian Orogenic Province (Matheson, 1953). The deposit, at Coobina, consists of an interlocking network of lenticular veins over about 2.5 km^2, associated with small metaultrabasic dykes.

The granites carry little mineralization except in pegmatites.

Pegmatitic deposits are an important feature of the block. Three groupings may be made. First are tantalum-bearing pegmatites, which are characteristic of metavolcanic terranes. The pegmatite dykes are large cross-cutting structures each about 600 m long, carrying tin, lithium, beryllium, cerium, and rare earths as well as tantalum and niobium. Although specimens have been collected from many dykes for identification, paragenesis has not yet been systematically studied. Ellis (1950) gives a comprehensive account of the field relationships of the dyke at Wodgina, the main producing centre, the broad distribution of the tantalite within the dyke, and the minerals present.

The second group produces only tin, from eluvial detritus; these bodies are in granite. Ellis (1967) considers that there is a third group, formed in granitic terranes; this group yields beryl, and a little columbite and lepidolite. The bodies are much smaller than those of the first group; beryl is garnered by hand-picking.

Quartz reefs in metavolcanics at the margin of a granite pluton at Crookes Creek yielded small quantities of both wolframite and scheelite; and Simpson (op. cit.) records small quantities of tungsten-bearing minerals from deposits of other metals in the Pilbara Block.

Yilgarn Block

The Yilgarn Block is a complex unit; its full geological history is far from unravelled as yet. Age determinations span the interval from 3100 to 2000 m.y. The oldest ages lie close to the western margin: the Eastern Goldfields (Kalgoorlie district) give ages ranging from 2700+ to 2600+ m.y., and granites south of Meekatharra give ages of 2580 and 2597 m.y. (Compston & Arriens, 1968; Arriens, 1971; Turek & Compston, 1971). Parts of the margins adjoin two highly mobile zones, the Ophthalmia-Gascoyne Block in the north and the Albany-Fraser Belt in the south and east, both of which belong to the younger Central Australian Orogenic Province. These must have imprinted some structures over the adjacent parts of the Yilgarn Block and probably incorporate reworked rocks from the block. The western margin is the Darling Fault, a major structure which has been reactivated several times since the late Proterozoic and possibly earlier, but along which structures have been imprinted only over a very narrow zone.

The rocks of the block may be described in two broad categories: firstly, very low-grade metamorphic derivatives of ultrabasic, basic, and acid volcanics, related

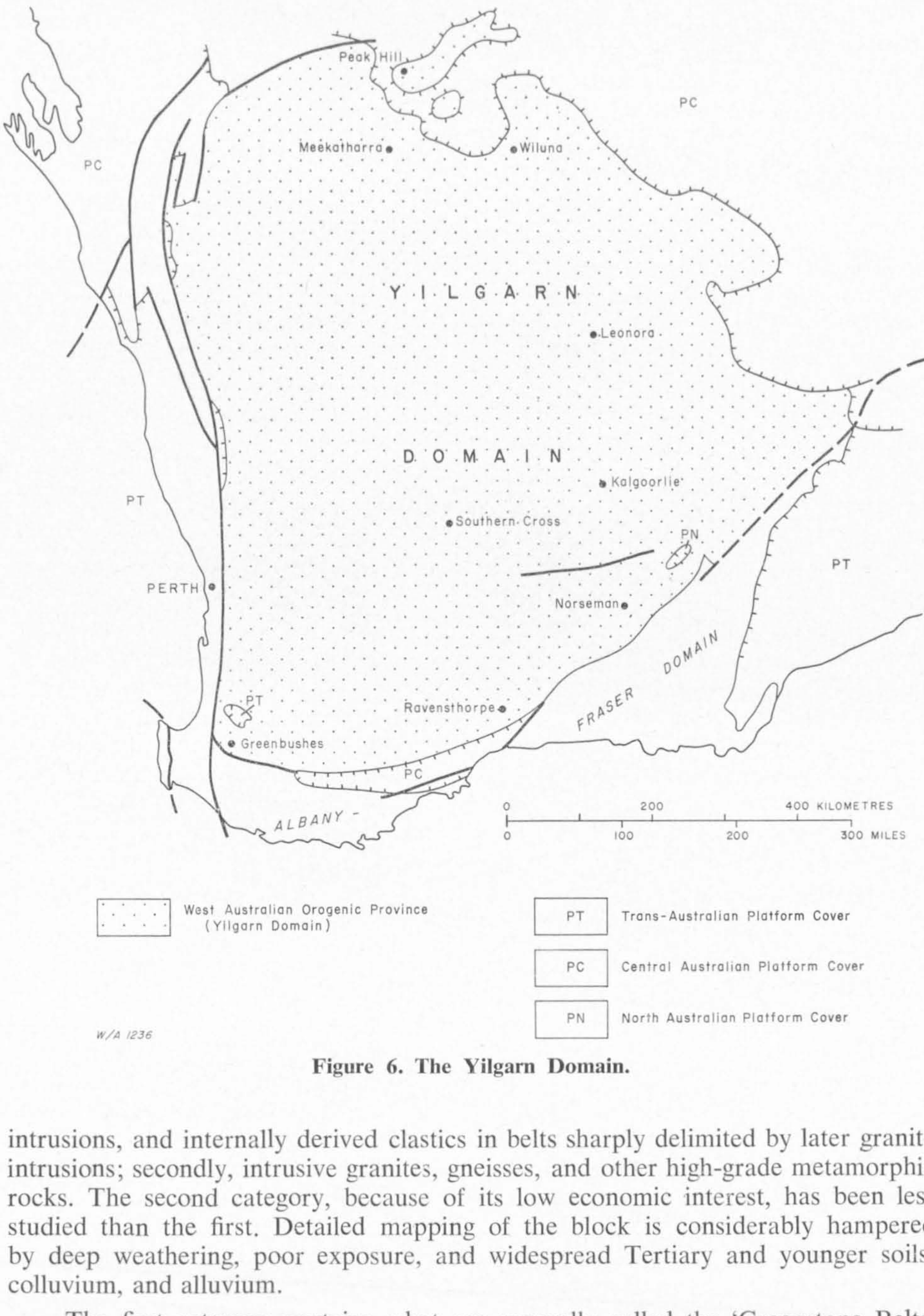

Figure 6. The Yilgarn Domain.

intrusions, and internally derived clastics in belts sharply delimited by later granite intrusions; secondly, intrusive granites, gneisses, and other high-grade metamorphic rocks. The second category, because of its low economic interest, has been less studied than the first. Detailed mapping of the block is considerably hampered by deep weathering, poor exposure, and widespread Tertiary and younger soils, colluvium, and alluvium.

The first category contains what are generally called the 'Greenstone Belts' and 'Whitestones' in the literature. At the time of writing, four 1:250 000 Sheets, Boorabbin (1963), Widgiemooltha (1966), Kalgoorlie (1970), and Kurnalpi (1971) were published, and Menzies and Norseman had been mapped, but not in time to be considered in this account.

Eastern Goldfields

The most recent mapping, of the Kurnalpi Sheet area east of Kalgoorlie (Williams, 1970, unpubl.), has revealed a framework that may extend throughout the continuous belt of low-grade rocks of the Eastern Goldfields, and with reservations and limitations may also extend to the other 'greenstone-whitestone' belts of the Yilgarn Block. Williams has recognized an evolutionary pattern made up of three similar cycles, two of two phases and the third containing only the initial phase.

The first phase essentially is a basic to ultrabasic association of volcanics and shallow intrusions with some thinly bedded local clastics (mainly chert) and carbonaceous and pyritic shale, dolomitic shale, and greywacke. The second phase is made up of acid volcanic complexes and clastics derived both from the volcanics and from the older rocks. In the succeeding cycles the first phase contains progressively less ultrabasics, less volcanics, and more fine-grained clastics, and the second phase less volcanics and more coarse clastics.

Nowhere has evidence been noted of land, during the period of sedimentation, beyond the present boundaries of the belt of low-grade metasediments running north through the Kalgoorie district.

The mining history of the belt has been dominated by gold (of which only low-grade ores now remain), and especially by the concentration in the Kalgoorlie/Fimiston/Great Boulder area. Williams (op. cit.) notes, like previous workers, that granitic terranes do not bear gold; elsewhere, though gold may be found in all types of rock, igneous bodies appear to be the most favourable hosts. He also points out a spatial and therefore presumably genetic link not previously realized between acid dykes and sills and gold mineralization. In the chief producing area, the Golden Mile at Kalgoorlie, free gold and gold tellurides occur in pyritic lodes along shears and fractures. A little gold has also been won from quartz lodes containing pyrite but no tellurides in the Kalgoorlie district (Woodall, 1965). Total production is about 35 million oz troy.

The Sons of Gwalia mine, some 190 km north of Kalgoorlie, produced 2½ million oz from lodes in a zone of intense shearing in an epidiorite. The lodes are in quartz veins and lenses within the schistose zone, and the highest gold values were found in drag folds; free gold, pyrite, chalcopyrite, pyrrhotite, some arsenopyrite, and abundant ankerite are present (Finucane, 1965).

Some 160 km south of Kalgoorlie several reefs in the vicinity of Norseman have produced 2½ million oz of gold. Two types of lode are present: gold-quartz bodies with minor sulphides and tellurides, and quartz-sulphide lodes which occur as replacements of brecciated or folded structures within jaspilites (Hall & Bekker, 1965). A pyrite orebody near Norseman has been mined for sulphur. It consists of massive lenticular pyrite replacements of siliceous metasediments and meta-agglomerates in shear zones (Ellis, 1953a).

The main interest in this area is the nickel mineralization, the potential of which is still being assessed. Reports indicate that some of the deposits also carry significant copper values; Kambalda ore contains recoverable platinum and palladium; arsenic is present in the lode at Mount Martin; and Scotia is reported to contain economic cobalt. Williams (op. cit.) notes the close association between the ultrabasic rocks that are particularly rich in magnesium and nickel deposits, and the limitation of known nickel occurrences (with the exception of Mount Windarra) to a mobile median trough through the Kalgoorlie region in which chert but not banded iron formation is present (Williams, 1971). At present the best reported deposits are those surrounding the Kambalda dome. They lie at or near the base of an ultrabasic sheet and appear to be comagmatic with the intrusion, but the ore shoots also lie in steeply plunging folds (Woodall & Travis, 1970). All except one of the nickel deposits lie within ultrabasic sills, the exception being that at Carr Boyd Rocks, where the nickel sulphide bodies are in pipes. Some nickel will probably be produced from lateritic material developed over nickeliferous ultrabasic rocks, which themselves are of too low a grade to be mined.

Copper and sulphur (from pyrite) have been produced at Eulaminna, east of Leonora, from an orebody at the contact between andesite pillow lavas and metasediments (Low, 1963). The ore also contains gold, zinc, and cobalt. In a somewhat similar assemblage at Murrin Murrin, a little to the northeast, the gold-copper ratio is higher.

Minor copper mineralization is known in three gold-mining localities within the Kurnalpi Sheet area (Williams, 1970, unpubl.): two in basic igneous rocks, and one in acid pyroclastics.

The western margin of the Kalgoorlie low-grade metamorphic belt from north of Coolgardie southwards to Widgiemooltha contains a zone of lithium-bearing pegmatites, the best known of which, at Londonderry, south of Coolgardie (Sofoulis, 1963), also contains beryllium and some tantalum. A large but unexploited deposit is currently under study at Mount Marion, between Kambalda and Coolgardie.

Small quantities of scheelite have been reported from gold-mining areas in a zone from just south of Coolgardie to Higginsville.

Application of theories developed during mapping in the Kalgoorlie region to the other 'greenstone-whitestone' belts of the Yilgarn Block will no doubt allow them to be interpreted differently. The distribution of metals in the Kalgoorlie region seems to serve as a model for the Yilgarn Block.

Ravensthorpe Region

The Ravensthorpe region, south-southwest of Kalgoorlie, was examined by Sofoulis (1958). He noted the presence of serpentinite, basic volcanic rocks, a 'whitestone phase' which is mainly argillaceous, graphitic schist, and some dolomitic rocks. In effect these constitute one cycle as defined by Williams (1971), and the low proportion of ultrabasic rocks (two lenses) and the absence of acid volcanics and conglomerate suggest that any correlation with the Kalgoorlie cycles will be with the second or the incomplete third cycle. In addition the Ravensthorpe sequence has a granite core which Sofoulis describes as a granitized sedimentary pile, a feature not recognized in the Kalgoorlie region. The zonal distribution of all the metalliferous deposits is attributed to the granitization front. The mineralization is mainly gold-copper, with some silver; no zinc is recorded, and individual deposits are small. Only two of the many pegmatites carried sufficient minerals of the beryllium-lithium-tantalum suite to be of interest. Magnesite deposits in the region are a result of weathering of the ultrabasics. The discovery of a nickel deposit was reported early in 1971.

Southern Cross Region

The low-grade metamorphic belt through Southern Cross west of Kalgoorlie has been described in the 'greenstone-whitestone' format (Clappison & Zani, 1953).

The greenstone succession is typical of the basic volcanic phase as described by Williams (1970, unpubl.): it contains basic and ultrabasic lavas and tuffs with interbedded banded iron formation. The 'whitestones' are described as metamorphosed sediments; acid volcanics are apparently absent. Gold deposits (with minor tungsten at Westonia) are confined to the 'greenstones'. Lodes are quartz replacements either in tuff or in banded iron formation where it is intersected by quartz veins. The ore is sulphide at depth. Concentrations are related to flat-pitching fold structures.

Northern Yilgarn Block

The rocks in the vicinity of the Big Bell mine at Day Dawn, 100 km southwest of Meekatharra, have been metamorphosed to biotite-garnet and quartz-muscovite schists; the latter is host rock for the ore (Staff, Big Bell Mines Ltd, 1953). The mine yielded gold and silver in a ratio of 2.3:1 from pyritic sulphide ore, which also carried some arsenic, copper, and antimony. The Hill 50 mine to the south is more like those of the Kalgoorlie region in that feldspar porphyry dykes which antedate the ore are present with 'greenstone' and banded iron formation of the country rock.

At Wiluna, basic lavas and intrusives are present (Edwards, 1953a), but no acid intrusives, although dacite flows form part of the depositional sequence. The orebodies contained large quantities of arsenic and one also contained mineable quantities of antimony.

Iron Orebodies

Although banded iron formations are common throughout the basic volcanic areas, and are commonly the loci of gold deposition in gold-mining areas, they themselves have become economic under favourable circumstances: during regional folding, banded iron formations tend to thicken at fold crests, so that where the pitch of the fold is near vertical, supergene enrichment during the prolonged evolution of the current land surface has produced hematite and limonite bodies of sufficient grade and size to be mined. Such lodes may stand 100 m or so above the surrounding plains and the enrichment processes continue some distance below the level of the plain (Connolly, 1959). Little investigation below plain level is recorded; Koolyanobbing (northeast of Southern Cross) at depth consists of bands of magnetite with pyrite (Ellis, 1958), and Mount Cauden (south of Southern Cross) consists at depth of bands of magnetite, siderite, massive pyrrhotite, and ferrosilicates (MacLeod, 1965). The Robinson Ranges contain banded iron formations which have been upgraded by secondary deposition (MacLeod, 1972).

Granites and Gneisses of the Yilgarn Block

The larger part of the Yilgarn Block is a complex of granite, gneiss, and high-grade metamorphics which appear in part to be equivalents of those in the low-grade belts. Intrusive granites, granodiorites, and tonalites have been mapped in the Kurnalpi Sheet area; and as noted earlier, all contacts with the 'greenstone-whitestone' belts and the granite or gneiss are intrusive and occasionally granitized. (It seems that much of the region called 'granites and gneisses' on the face of the map is granite alone, but the distribution and proportion of each is not known. Tomich (1964), in discussing the bauxite province in the west close to the Darling Fault, states that the amount of bauxite depends directly on the rock type, implying a range of chemical types; but much of this region is shown as granite on available maps of the area. The 'Central Wheat Belt' region contains a variety of high-grade metamorphic rocks, which A. F. Wilson (1971) equates chemically with some of the ultrabasics of the Kalgoorlie region; but again maps show this area as mainly granite.)

The only mineral deposit specifically associated with granite is the small low-grade Mount Mulgine molybdenum deposit (Matheson, 1944).

The tin-tantalum alluvial concentrations at Greenbushes (Ellis, 1953) originated from the erosion of veins in quartz-muscovite schists. Only some veins were mineable; most of the yield is from residual deposits, mainly in consolidated alluvium.

Peak Hill District

A sedimentary sequence containing banded iron formations has been mapped in the Peak Hill district (MacLeod, 1972). It appears to be a mainly clastic sequence with a mildly metamorphosed base. The gold deposits of Peak Hill occur in quartz veins occupying shear zones in the metasediments, and at Horseshoe the lodes occur in deeply decomposed and ferruginized sediments.*

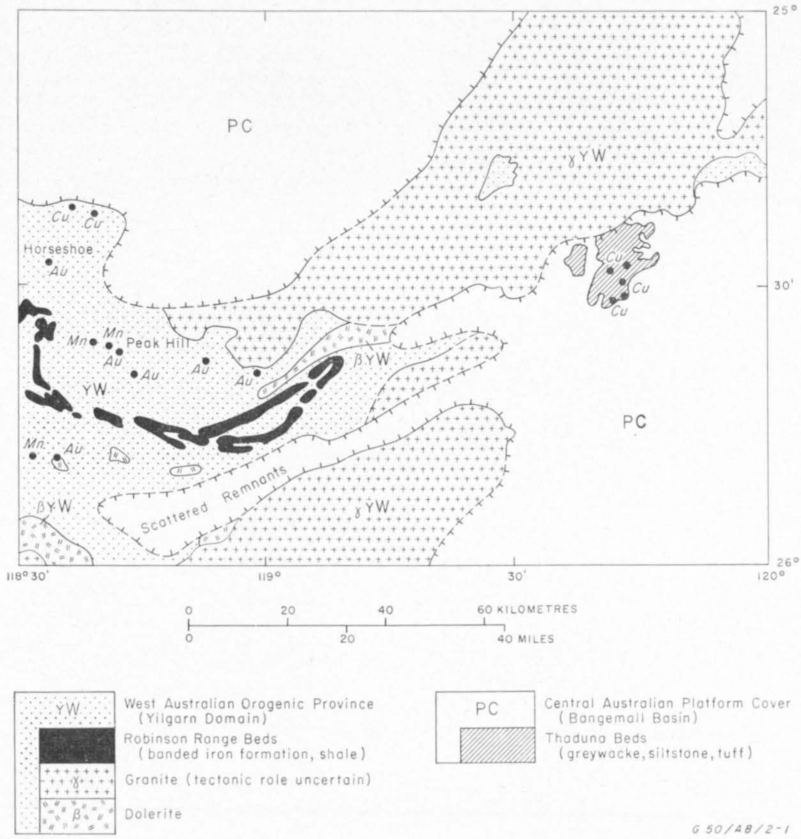

Figure 7. Peak Hill District.

* The setting of Horseshoe, Peak Hill, and the Robinson Range iron province shown on the face of the map was consistent with available information. MacLeod's work indicates that the map is wrong, but was not available until after it was drawn. See Fig. 7.

West Australian Province in North Australia

The problem of dating adequately the supposed Archaean of north Australia is discussed in detail by Dunn (1971). Definite Archaean includes the Rum Jungle Complex and other basement exposed in windows beneath the Pine Creek Geosyncline, and basement detected by drilling beneath the Tennant Creek Block (Crohn & Oldershaw, 1965). Other blocks listed by Dunn as apparently Archaean are classified as unassigned orogenic domains—chiefly because the classification used here is based not on time equivalents but on the relationship between orogenic domains and platform covers.

The Rum Jungle Complex (Rhodes, 1965), part of the *Rum Jungle Block,* which forms basement to the Pine Creek Geosyncline, is the only part of the West Australian Orogenic Province in northern Australia to have proven metallogenic significance. It is composed of schist, gneiss, and granite, and shed material from a basement rise into the overlying Pine Creek Geosyncline. However, since then it has been domed to give flank dips of 30° to 70° in the overlying sediments, and Rhodes points out its apparent similarity to one of the several types of mantled gneiss domes known in Europe. The Rum Jungle Complex is richer in uranium and thorium than normal granites (Heier & Rhodes, 1966), and may have provided the uranium concentrated in sediments of the Pine Creek Geosyncline overlying the dome. No mineralization is known within the Complex itself.

The recently discovered uranium deposits east of Darwin appear to have similar relationships to other outcrops of the Rum Jungle Block.

WEST AUSTRALIAN PLATFORM COVER

Deposition of the West Australian Platform Cover on the Pilbara Block of the West Australian Orogenic Province began with basic volcanics. Trendall & Blockley (1970) have outlined the data on the age of the units making up the Platform Cover: the basal Fortescue Group gives an age of 2200 m.y. on unsatisfactory material; the Hamersley Group contains volcanics with an age close to 2000 m.y.; and the only reliable guide to the age of the Wyloo Group, the third and uppermost unit, is provided by later intrusives with an age of 1700 m.y., although an unreliable age of 1850 m.y. has been obtained on a siltstone.

Though the platform cover now laps the Pilbara Block on all margins except the northwest, and outliers rest on the block, sedimentation was thickest in the southern part of the preserved cover in a downwarp with a west-northwest axis.

Early sedimentation was dominated by outpourings of pyroclastics and lavas, some acid but most basic. These were followed by chemical sediments containing chert, dolomite, and banded iron formation, and then by more clastic sedimentation. The iron in the banded iron formations is thought to have had its source in a belt of fumarolic activity west of the site of outcrop of the Hamersley Group (Trendall & Blockley, p. 286). The platform was folded about 1700 m.y. ago, most strongly in the southwest, next to the Ophthalmia-Gascoyne domain, and diminishing northeasterly.

Isoclinal folding within the basin has produced structures in the banded iron formations that have facilitated leaching of silica during long periods of peneplanation and leaching in the Phanerozoic and possibly earlier. Consequently, very large bodies of near-pure hematite have formed in the Hamersley Ranges, such as those at Mount Tom Price, Mount Whaleback, and Mount Brockman (MacLeod, 1966; Trendall & Blockley, 1970). During the Tertiary, iron-bearing run-off from this region precipitated goethite in swampy drainage basins flanking the ancestral Hamersley Ranges. Subsequent dissection has revealed blankets of goethite 10 to 30 m thick and several hundreds of square kilometres in extent. Several overlapping iron provinces may now be recognized: each of the primary banded iron formations forms a metallogenic province within the terms of the definition; the pockets of supergene enrichment are a superimposed province; and the dissected goethite deposits form a third. 'The Hamersley Iron Province' as used by MacLeod (1966) and subsequently by other authors includes all three units. The banded iron formations and the area of supergene enrichment have been shown combined as a province on the map, with the boundary outlining the limits of the primary banded iron formation, and the hatching showing the main areas of supergene enrichment. The Tertiary (?) goethite-bearing province is shown separately.

The small copper and lead deposits in the northwest of the Hamersley Basin are structurally controlled and may have their source within the platform sediments or in the underlying basement. They lie northeast of the area of granite intrusion but may have been mobilized during the folding movements. The Kooline Lead Field lies near the folded southwest margin of the platform. It contains several small deposits. Dated at 1700 ± 150 m.y. on a galena sample, they postdate the main folding and are structurally controlled by it. They contain accessory barium (Daniels, 1966b).

Uneconomic uranium has been reported in conglomerate to the west of Nullagine (Richards, 1972, unpubl.).

At Braeside, east of Marble Bar, lead-vanadium ores in quartz veins were apparently introduced during the mobilization of the folded region to the east.

The literature contains a profusion of names based on this platform cover. The sediments were first noted resting on the folded Pilbara Block, which was always assigned an Archaean age, at the gold mining centre of Nullagine, where the basal gold-bearing conglomerate was referred to as the 'Nullagine conglomerates'. The term 'Nullagine' has been extended indiscriminately to undeformed ancient sediments elsewhere in Australia, and hence was applied to stratigraphically unrelated units of similar appearance, and generally with a younger Proterozoic connotation. Much of the confusion has now been removed by regional mapping and isotopic dating. The time term Nullaginian was then tentatively proposed for the lower Proterozoic time span (Dunn, Plumb, & Roberts, 1966), but has not gained wide acceptance. Daniels (1966a) proposed that the deep basin that laps onto the Pilbara Block, and of which the Nullagine Conglomerate is a basal unit, should be called the Nullagine Basin, but subsequently it has been called the Hamersley Basin by Daniels & Horwitz (1969). This basin, the only known depositional basin of the West Australian Platform Cover, then corresponds in part to the area of the Hamersley Ranges, incorporates within its sequence the Hamersley Group (Daniels, op. cit.), and contains the Hamersley Iron Province (MacLeod, 1966). 'Nullagine Basin' has also been informally used to apply to the small embayment of West Australian Platform Cover immediately west of the township of Nullagine (Richards, 1972).

NORTH AUSTRALIAN OROGENIC PROVINCE

The five orogenic domains and their associated transitional domains within the North Australian Orogenic Province are all overlapped by North Australian Platform Cover.

They are generally areas of low-grade metamorphic rocks, derived from sediments laid down partly on continental crust during the early Proterozoic. They characteristically lack synorogenic granites, but post-tectonic granites and acid volcanics are known in all except the Granites-Tanami Block.

HALLS CREEK AND KING LEOPOLD BELTS

The Halls Creek Belt and King Leopold Belt (together labelled 'Halls Creek Province' on the face of the map) are two linear belts in which the main deforma-

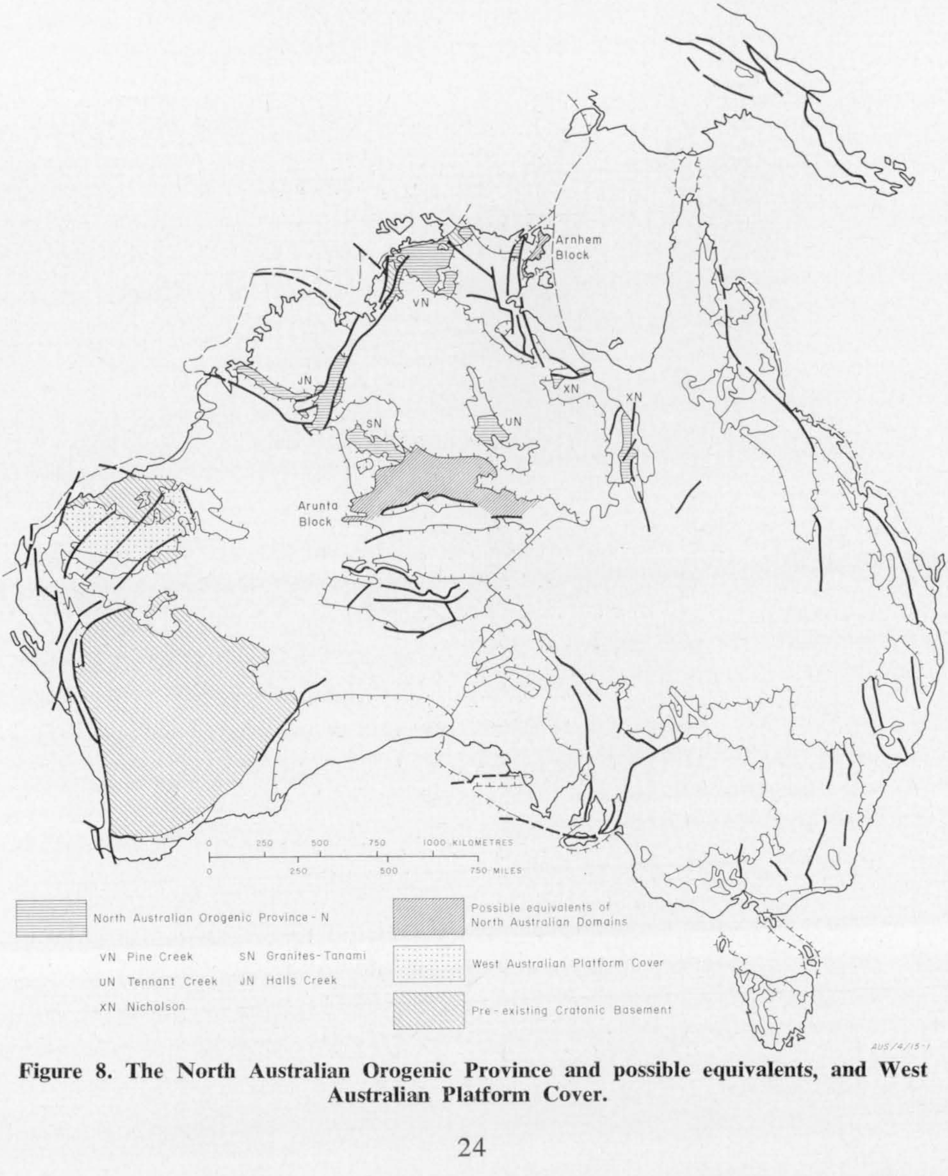

Figure 8. The North Australian Orogenic Province and possible equivalents, and West Australian Platform Cover.

tion took place in the early Proterozoic, but which have been partly reactivated at widely spaced intervals since. There is no reason to suppose that the present narrow zones exposed between the cover of younger platforms represent the original extent of the activity, and correlations with the Granites-Tanami Block and possibly the northern margin of the Arunta Block have been inferred; mapping in the Granites-Tanami Block appears to offer some confirmation (D. H. Blake, pers. comm.).

In the northeast-trending *Halls Creek Belt* the basal unit consists mainly of basic volcanics, followed by a thin shallow-water clastic formation, and then by the Biscay Formation, a mixed clastic and basic volcanic sequence with dolomitic interbeds. The uppermost unit is a thick monotonous sequence of turbidites and some conglomerates.

The sedimentary sequence was tightly folded, slightly metamorphosed, and intruded by dolerite dykes and sills and large gabbroic masses containing some ultrabasic basal differentiates. A second, more intense, period of deformation produced metamorphism ranging up into the granulite facies and anatectic granite. The metamorphics of the second cycle yield a date of 1961 $\pm$ 27 m.y. (Rb/Sr).

Acid volcanics postdating the deformation are intruded by numerous granitic stocks and some more basic rocks (Dow & Gemuts, 1969).

The *King Leopold Belt,* which trends northwest, appears to have a similar history; the areal extent of the preserved sedimentary sequence is less and metamorphism is more widespread but of lower grade (Gellatly, Sofoulis, & Derrick, in prep.).

Neither belt is known to contain any sizable mineral deposits. Early mining activity concentrated on the gold near Halls Creek, initially on alluvial material but later on conformable quartz veins. The richest veins are at the base of the turbidite sequence, but others occur in the dolerite dyke at the top of the underlying Biscay Formation and in that formation itself. The lodes are pyritic below the oxidized zone (Dow & Gemuts, op. cit.).

Several small copper-lead-zinc occurrences in the Biscay Formation examined in detail have so far proved to be uneconomic, although the Angelo Prospect contains 500 000 tons of low-grade ore (McNeil, 1966).

Small chromite lenses in the ultrabasic phases of the basic intrusives appear to be more interesting for their platinum content than as sources of chromium.

Tin and columbite have been obtained from pegmatites and derived alluvium at Mount Dockerell in the southern part of the Halls Creek Belt. A small showing of tungsten and tin in the King Leopold Belt consists of cassiterite and wolfram in metamorphic rocks, and appears to be suitable only for small-scale selective mining (Finucane, 1938).

PINE CREEK BLOCK

The rocks in the Pine Creek Block were deposited in the Pine Creek Geosyncline during the early Proterozoic on an Archaean basement of metamorphic and igneous rocks. They were folded at about 1900 m.y. and intruded by post-tectonic granites at 1830 to 1820 m.y. Walpole, Crohn, Dunn, & Randal (1968, p. 19) describe the setting as an intracratonic basin rather than an orogenic belt, and point out the shallowness of the depositional basin and the lack of severe regional metamorphism.

The following description and the accompanying Figure 9 are taken from Walpole et al. (op. cit., p. 1).

'The Pine Creek Geosyncline is a shallow composite structure developed during Lower Proterozoic time. Initial sedimentation was from the north and east into a northwest-trending asymmetrical basin (the Primary Basin). The sediments comprise an arkose/quartz greywacke/siltstone/chert/dolomite assemblage (Goodparla and Batchelor Groups) in which the proportion of clastics decreases towards the centre of the basin. The second phase of sedimentation was from the west into a newly developed north-trending Western Fault Zone and the central part of the Primary Basin (the Central Trough). The sediments comprise a turbidite assemblage of greywacke and siltstone (Finniss River Group) and minor volcanics; the coarser-grained sediments lens out to the east. Easterly derived sediments were still being deposited in the Central Trough when the second phase of sedimentation started, but they were cut off when the Eastern Trough was formed on the eastern side of the Primary Basin. The Eastern Trough contains a siltstone-chert-dolomite assemblage (South Alligator Group). The final phase of sedimentation in the Pine Creek Geosyncline was the deposition of sandstone (Chilling Platform) in the southwestern part of the geosyncline.'

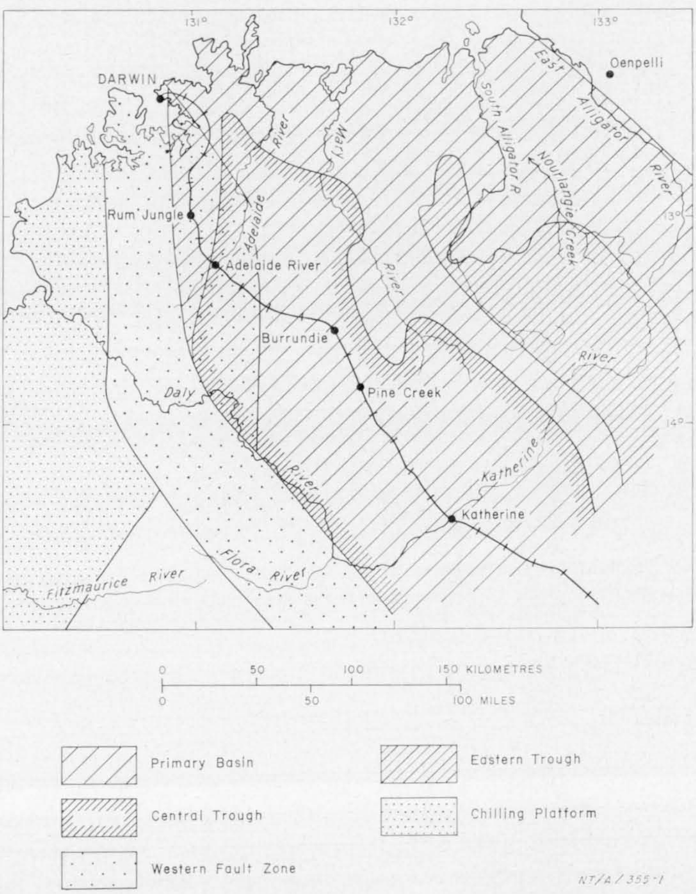

Figure 9. Major structural elements, Pine Creek Geosyncline (after Fig. 8 of Walpole et al., 1968).

The folding is moderate to tight—some incompetent beds are isoclinally folded and occasionally overturned; the trend of the axes ranges from northwest through north to a few degrees east of north, and is modified by intrusive granites and to some extent by cross-folding. It appears that the three principal fault directions also controlled the form of the depositional basin, and were therefore features of the pre-existing basement. The Giants Reef Fault, a major wrench fault which cuts across the Rum Jungle Dome, is in its present form a much later feature, cutting later platform cover. However, Walpole et al. suggested that it follows a much older lineation.

The region was intruded by transitional granites, of which the Cullen Granite is the largest, and which also domed up parts of the basin; they were accompanied by acid volcanics and minor sediments.

Crohn (in Walpole et al., op. cit.) points out the marked stratigraphic control apparent in much of the mineralization; but some appears to be zoned around the granites, and some is related to fault zones.

In recent years the most important metal has been uranium. It occurs in two main areas, and in scattered occurrences, including several recent large discoveries southwest of Oenpelli and one to the east. In the west the Rum Jungle area has been the focus of exploration for the last twenty years. Heier & Rhodes (1966) point out that the Archaean Rum Jungle Complex itself has a higher content of thorium and uranium than most granitic rocks. Euxinic sediments dip steeply off the complex; original depositional dips have been increased by subsequent upward movement of the complex. This structure has provided excellent conditions for the migration of uranium into the sediments and its localization in favourable sites. Subsequent tectonic events have modified the deposits, and their origin has been the subject of considerable dispute.

The main deposit at Rum Jungle, Whites Orebody, contained disseminated uranium-copper, and some cobalt and lead. Several low-grade lead deposits also occur in the zone rimming the Rum Jungle Complex (Spratt, 1965; Berkman, 1968; Crohn, Langron, & Prichard, 1967).

Most of the literature on Rum Jungle, and on other uranium-bearing areas in northern Australia, dates from a time when syngenesis was accepted almost undisputed as the mode of origin of uranium orebodies; and so must be appraised with some caution. Little attention was paid to the effects of land surfaces and groundwater movements on distribution of uranium.

The second important area of uranium mineralization is the northwest-trending belt along the South Alligator River. The mineralization is partly within chemical sediments of the South Alligator Group of the Pine Creek Geosyncline and partly in acid volcanics of the transitional phase and in the basal beds of the overlying North Australian Platform Cover. A zone of faulting parallel to the mineralized zone was active during sedimentation.

The association of uranium mineralization with juxtaposed acid volcanics of transitional domains and basal basic volcanics of the platform cover is widespread across northern Australia. The influence of groundwater in the distribution and redistribution of the uranium needs also to be considered. The gold occurring with the uranium in the South Alligator Valley also presents a metallogenetic problem yet to be explained. Available age determinations are much too young to be reconciled with current geological interpretations (Prichard, 1965; Taylor, 1968).

The apparent zoning of gold, lead, tin, and tungsten around the transitional phase granites, and particularly round the Cullen Granite, may be the result of a complex cycle of intrusion, or of tectonic mobilization of concentrations of metals existing before the intrusion, or even of remobilization of material from the basement. It is not a normal zonation progressing outward from the granite: various metals predominate in areas around the granite margins, as is well shown in Walpole et al. (1968, pl. 32). The Yeuralba-Maranboy region is characterized by tin and tungsten deposits; the Wolfram Hill/Mount Todd area by gold, tungsten, tin, and a little molybdenum; the Northern Hercules/Coronet Hill area by copper, lead, and a little tin. The deposits all occur in a restricted basin chemical facies of the Goodparla Group.

In the west, the setting of the tin, tantalum, and lithium deposits along the faulted and mobile western margin of the Pine Creek Geosyncline suggests possible mobilization of metals from the basement; this metal association is more characteristic of the West Australian Orogenic Province than of younger orogenic domains.

The phosphate southeast of Rum Jungle is at the surface that was developed on the Pine Creek Block before platform cover was laid down, and is thought to be a supergene concentration from the weakly phosphatic underlying dolomite in the Pine Creek Geosyncline.

Tennant Creek Block

The One-Mile Maps of Tennant Creek (Crohn & Oldershaw, 1965) and Mount Woodcock (Dunnet & Harding, 1967) give details of the Tennant Creek Block in the Tennant Creek area. (Regional mapping of the remainder of the block was begun in 1969.) At Tennant Creek the block is made up of early Proterozoic deep-water greywacke, shale, and siltstone, with marker bands of hematitic shale. Basement is not exposed, but drill holes to the southwest of Tennant Creek encountered gneiss, amphibolite, granite, and gabbro which are interpreted as Archaean basement, beneath 30 m of much younger cover. This area of the Northern Territory has been affected by several cycles of deep weathering which make mapping and exploration difficult.

The rocks are not severely folded; the main structural features are strong shears and faults, some of which are filled with quartz. The regional metamorphic grade of Tennant Creek appears to be greenschist; but this is not certain because the only fresh specimens (which are greenschist) come from the mines, and these lie on shear zones where there is considerable alteration (Crohn & Oldershaw, 1965, p. 8).

The gold-copper-sulphide orebodies of the Tennant Creek Field are closely associated with tabular and pipe-like quartz-hematite and quartz-magnetite bodies and major shear zones. The main gold producers all lie close to hematite shale marker beds, but the copper producers appear to lie at the intersections of major shear zones (Crohn & Oldershaw, op. cit., p. 38). Most orebodies contain only gold or copper-gold, but ore from the Juno mine carried bismuth. A little silver, lead, and zinc have also been reported.

Elliston (1966) postulated that the metals in the cross-cutting Peko orebody were derived from the underlying sediments and concentrated by colloidal precipitation during folding. However, the latest mapping suggests that the deposit may be typical of transitional-phase mineralization (see p. 12).

Granites-Tanami Block

The Granites-Tanami Block is a poorly exposed area straddling the boundary between the Northern Territory and Western Australia. It is difficult of access, and the geology is known only by reconnaissance mapping and some airphoto interpretation.[1] The major trends are northwesterly, and lineations on trend in the Arunta Complex suggest that the block is continuous with it (Walpole, Roberts, & Forman, 1965). The King Leopold Belt is a possible continuation to the northwest. Two different sequences are recorded: one of mica schist and metasiltstone, as at The Granites, the other of quartz-hematite beds at Tanami, comparable to those at Tennant Creek (Anon., 1961). The block has been intruded by later unstressed granites, possibly of Carpentarian age by analogy with similar granites cutting the Tennant Creek Block.

There are only two centres of mining activity in this region: the small, mainly alluvial goldfield at Tanami (Hossfeld, 1940) and the slightly larger lode and alluvial deposits at The Granites (Hossfeld, 1938; Hall, 1953; Crohn, 1961). The deposits at The Granites are varied; one area contains small quartz stringers in tightly folded schist and quartzite; in a second area, a mineralized zone may be traced over 1.5 km but appears to have contained only two rich subzones of limited extent. It is confined to a poorly exposed schist.

The mining centre of Tanami on the latest photo-interpretation of this region lies not in the orogenic domain but in the North Australian Platform Cover (C. J. Simpson, pers. comm.).

Nicholson Block

The small Nicholson Block lies across the northern part of the boundary between Northern Territory and Queensland.

It consists of metamorphosed 'geosynclinal pelitic and quartzo-feldspathic sediments and volcanics, isoclinally folded about an east-west axis and intruded by granite'. The metamorphic grade is greenschist, and the granite has foliated margins (Roberts, Rhodes, & Yates, 1963).

The Cliffdale Volcanics and the Norris Granite, which are metallogenically important, represent the transitional domain within the block. Close to the contact with overlying conglomerates of platform cover the Cliffdale Volcanics carry extensive low-grade uranium-copper deposits with a little gold, which have been mined at Pandanus Creek (Morgan, 1965) and elsewhere in the Northern Territory. A larger deposit at Westmoreland is under investigation in the Queensland part of the block. The mineralization extends from the acid Cliffdale Volcanics into the overlying conglomerates and basic volcanics, an association recognized elsewhere in North Australia as a favourable host for uranium (see p. 27); the acid volcanics are currently thought to be the primary source rocks, and groundwater the distributing and concentrating agent.

Tin occurs in quartz veins in a late phase of the Norris Granite, but most of the production has been from alluvial and eluvial material. Tungsten is also recorded, but the yield was very small.

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[1] The area is (1972) being systematically mapped by the Bureau of Mineral Resources.

NORTH AUSTRALIAN PLATFORM COVER

During the Carpentarian, widespread platform cover formed over the stabilized North Australian Orogenic Province, and is now preserved in a broad zone from the Kimberley Basin in the west across Arnhem Land and the southern shores of the Gulf of Carpentaria to the deformed Mount Isa Belt, with which it merges. A small area of exposed platform cover of similar age laps onto the Tennant Creek Block, and the Granites-Tanami Block is almost surrounded by a little known expanse of cover that also laps onto the Arunta Block.

The Kimberley Basin (Plumb, in prep.) did not extend much farther to the south and east than its present preserved limits against the Halls Creek and King Leopold Belts; the sediments dip and thicken to the northwest away from the mobile belts, on which they rest unconformably. An intensive search for uranium mineralization in the basal units of the basin adjacent to the Halls Creek Mobile Belt, on the analogy of the Nicholson and South Alligator areas, has so far been unsuccessful. Laterite developed over the basic volcanics of the Basin is the source of economic bauxite deposits in the Mitchell Plateau (Grubb, 1970). A thick dolerite sill in the sequence carries no economic mineralization.

On the margin of the Kimberley Basin near the extreme northwest end of the King Leopold Belt, beds carrying detrital hematite grade into orebodies on Koolan and Cockatoo Islands in Yampi Sound (Reid, 1965; Gellatly, 1972). The beds are tightly folded and were converted into low-grade metamorphic rocks during cratonic folding late in the Proterozoic. The deposits are unusual in that iron was concentrated mainly during sedimentation, and supergene processes played only a small role apart from the development of some canga (ironstone breccia). On the eastern margin of the basin similar detrital hematite beds form low-grade deposits; the largest is at Pompeys Pillar (Dow & Gemuts, 1969).

The North Australian Platform Cover that borders the Gulf of Carpentaria has been divided into a number of shelf and basin regions (Carter, Brooks, & Walker, 1961; Roberts, Plumb, & Dunn, in prep.; Dunn, Plumb, & Roberts, in prep.). The sediments rest disconformably or unconformably on late acid volcanics and granites of the North Australian Orogenic Province. Low in the sedimentary pile above the unconformity, basic volcanics are common; so far most of the uranium discovered is below the unconformity (but see South Alligator (p. 27) and Nicholson Block (p. 29).

The McArthur River bedded lead-zinc-silver deposit lies in relatively undisturbed tuffaceous and carbonate rocks; the ore itself, which is very pyritic, occurs in very fine-grained, thinly bedded black dolomitic carbonaceous shale. The consensus of opinion is that the metals were precipitated syngenetically (Cotton, 1965). So far the metallurgical problems raised by the fine grainsize have prevented economic exploitation, and reserves have not been released. The major fault immediately east of the McArthur River deposit is thought to have been active during sedimentation—a deep trough sequence to the west, which includes the restricted basin facies of the ore-bearing beds, passes across the fault into a thin, shallow-water, lateral equivalent. Very small lead deposits in fault zones nearby may represent mobilized material from equivalents of the McArthur River deposit.

The Bulman lead-zinc deposits, some 350 km to the northwest of McArthur River, are confined to one stratigraphic level in an undeformed dolomitic sequence in a stratigraphic correlate of the sequence at McArthur River (Patterson, 1965).

Copper occurs in volcanic breccia at Redbank to the east of McArthur River near the Northern Territory border (Roberts et al., 1963), and also in the Platform Cover adjacent to the Mount Isa Belt (Carter et al., 1961).

Southeast of McArthur River in northwest Queensland is a group of small silver-lead-zinc deposits at Lawn Hill. They are described as complex fissure veins, which in places contain brecciated country rock (Murray, 1965). The zinc content is appreciable, but no zinc production is recorded; the ore at the Silver King mine also carries cadmium. The deposits represent material mobilized during folding that extended from the adjacent Mount Isa Belt.

The end of folding in the belt and adjacent cover is marked by a regional unconformity in the North Australian Platform Cover, which passes westward into a regional disconformity. The sequence above the break includes sedimentary iron formations in two areas. Northwest of Mount Isa in the Constance Range an ironstone containing oolitic siderite, hematite, and chamosite with secondary hematite and limonite borders complex structural basins. The deposit is subeconomic because although high-grade ironstone is exposed in hogbacks, most of it is covered by a considerable thickness of lower-grade material and overburden (Harms, 1965). In the Roper River area of the Northern Territory there are two similar deposits. They are oolitic; the ore is mainly hematite in the zone of supergene enrichment, and siderite and chamosite below (Canavan, 1965).

The platform cover south of the Tennant Creek Block in the Davenport 'Geosyncline' has been intruded by small bosses of Carpentarian granite. It contains the tungsten-producing centres of Hatches Creek and Wauchope (neither now operative). At Hatches Creek, quartz veins carrying wolfram, and some also scheelite and a little copper and bismuth, occur in faults cutting quartzite, shale, and volcanic rocks. There are no granites close to the deposits (Ryan, 1961). At Wauchope the enclosing rock is described as a sericite-quartz-tourmaline hornfels, although the nearest known exposure of granite is 4 km to the northwest. The wolfram occurs in narrow quartz reefs, commonly with large 'bunches' at small faults and flexures (Sullivan, 1953a). The area also contains small gold deposits and some uranium mineralization, which has not so far proved economic.

A small trough of sediments southeast of Kalgoorlie gives an age similar to that of platform-cover sediments within the North Australian Platform Cover and is hence equated with it. It may well be the only preserved remnant of more extensive cover developed contemporaneously with downwarp in the Albany-Fraser Belt.

CENTRAL AUSTRALIAN OROGENIC PROVINCE

The blocks and belts making up the Central Australian Orogenic Province cover a wide time-span, and tectonic styles range from the intensely and repeatedly metamorphosed Musgrave Block to the strongly folded but only moderately metamorphosed Mount Isa Belt. On the whole, metamorphism and deformation are much more intense than in the North Australian Orogenic Province.

Mount Isa Belt

The Mount Isa Belt in northwest Queensland has received a great deal of attention as the locale of the Mount Isa copper and lead deposits, the Cloncurry copper district, and uranium mineralization, including the large deposit at Mary

Kathleen. The regional geology at a scale of 4 miles to the inch was mapped in the 1950s (Carter, Brooks, & Walker, 1961). Considerable detailed attention has been given to mineralized areas; and the area is being remapped in more detail at a scale of 1:100 000.

Carter, Brooks, & Walker (op. cit.) worked out a history for the development of the belt which is being confirmed, with some changes in minor detail, by more recent work. They recognized a continental-type basement, which is exposed as highly deformed metamorphic rocks, granite, and acid volcanics along the geanticlinal axis between the eastern and western troughs of the Mount Isa Geosyncline, and called it the *Median Welt*. As a result of detailed mapping, the basement is now considered to be an extension of the Nicholson Block to the northwest; and

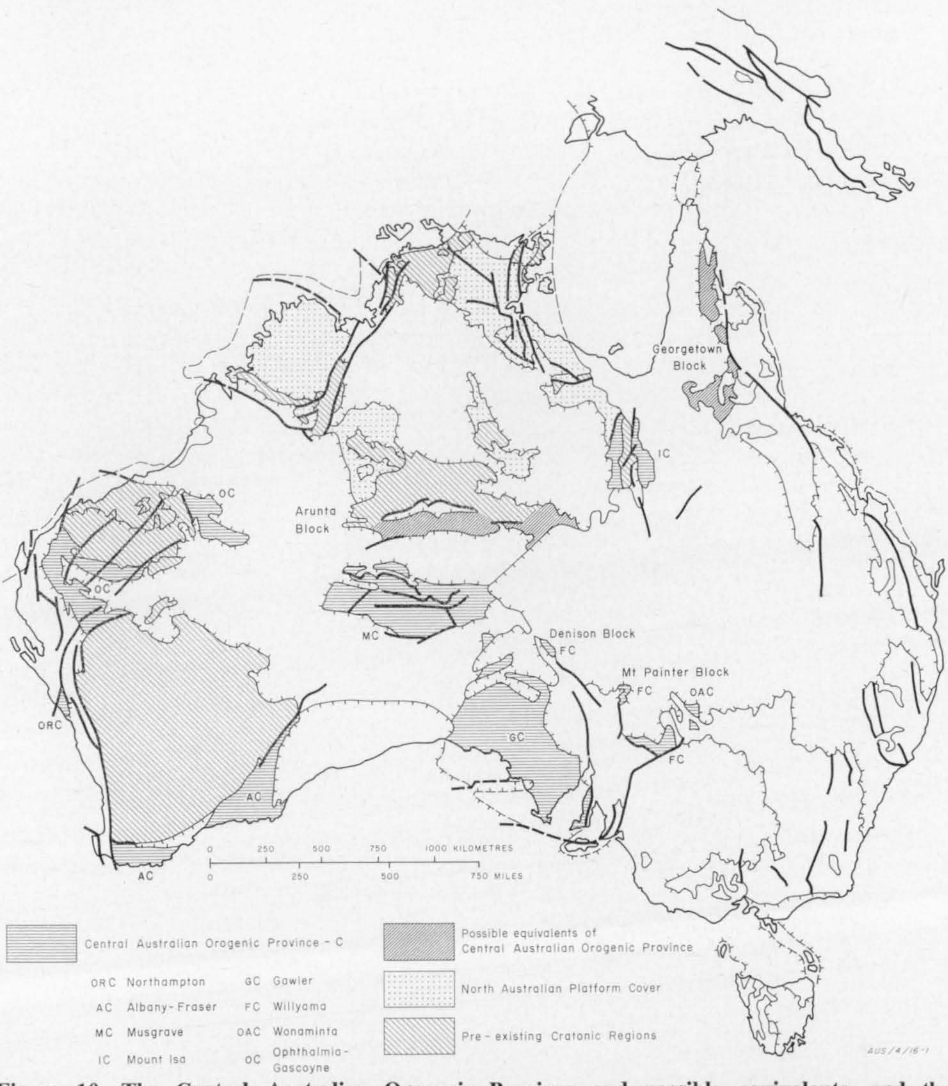

Figure 10. The Central Australian Orogenic Province and possible equivalents, and the North Australian Platform Cover.

therefore may have played an important role in the uranium mineralization of the Mount Isa Block. The sequence west of the geanticlinal ridge (the *Western Trough*) is thought to have been deposited on continental crust, and that to the east in a geosyncline (the *Eastern Trough*). Basic volcanics overlie the ridge, a sequence also recognized to the northwest in the platform cover on the Nicholson Block. After the basic volcanics were extruded, the median ridge began to rise and divide the eastern and western troughs. Carter et al. recognized two phases of deformation, each accompanied by granite intrusion. Metamorphism, generally of greenschist to lower amphibolite grade, is widespread. Two types have been recognized: regional 'thermal' metamorphism, and sodium-chlorine metasomatism widespread in the eastern trough. The metasomatism may have originated from the sodium chloride in connate water in the sediments, rather than from an extraneous addition to the elements (R. Hill, pers. comm.). Current mapping is delineating

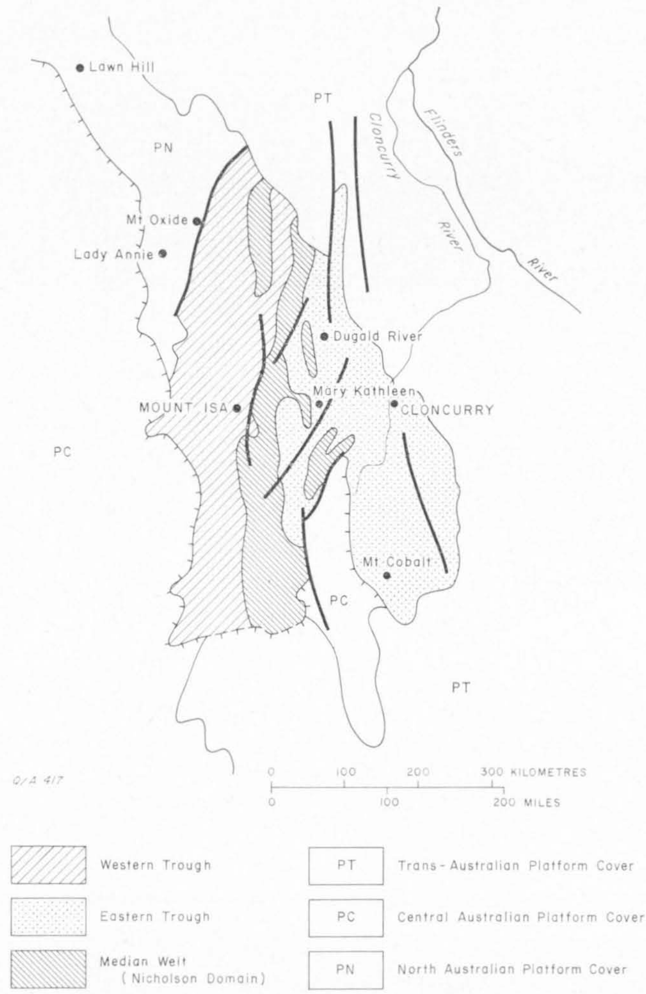

Figure 11. Structural elements of the Mount Isa Belt.

the metamorphic zones in some detail, and it is hoped to show the relationship between them and mineralization.

The region has been invaded by dolerite dykes and sills. Some may have been feeders to the early basaltic lavas; some are conformable bodies that may have been flows; and some are definite sills. All are metamorphosed and altered. Some relatively unaltered later dykes are also known.

Eastern Trough

Gold first attracted miners to the area, but it proved to be in comparatively small quantity, and most of the yield was from alluvium. Attention subsequently swung to copper, which is widespread but mostly in small bodies. Copper mineralization favours slate and shale host rocks; many deposits are in north-trending shears, and close to basic igneous rocks which are thought to have played a genetic role. Some of the larger mines were closed when the price of copper fell in 1919, and as the rich supergene ore had been removed, re-opening has not been considered economic. Small rich pockets of supergene ore have been worked for many years by single operators and small parties; but the current interest in large lower-grade deposits has caused some deposits to be re-appraised, and a few, such as the Winston Churchill and Great Australia, to be operated on a larger scale. Gold occurs in some copper lodes, particularly towards the southern end of the trough. Although the carbonate rocks are not favourable hosts, some that contain chalcopyrite have been mined for flux for the smelters at Mount Isa.

The uranium and rare earth deposit at Mary Kathleen has been interpreted as a skarn in carbonate sediments largely metasomatized to garnet and scapolite. The ore is uraninite, accompanied by allanite, stillwellite, fluorapatite, and small quantities of sulphides, and also contains some rare earths. The country rock is most intensely garnetized around the orebody. The mineralization is attributed to metasomatism by a deep-seated differentiated granite some 3 km to the east (Hughes & Munro, 1965); another granite 2 km west of the orebody is not considered to be related to it. Other small uranium deposits in the Eastern Trough carry davidite, and most are in pegmatites.

A north-south zone of very small cobalt-copper occurrences includes Mount Cobalt, where small quantities of cobalt ore were mined from a narrow shallow orebody in a north-south shear zone between metadolerite and quartz-mica schist. The ore was mainly of low grade. A little scheelite was recovered from the same shear zone about 1 km to the north.

Although scheelite has been recorded in many deposits of other metals, the only producer apart from Mount Cobalt has been a deposit northwest of Cloncurry, where it occurs in a calcite lens in hornblende schist, along with a little copper.

Banded iron formation occurs in the Eastern Trough, and iron has been recorded in skarn-type deposits. At Mount Philp a narrow body of hematite, magnetite, and quartz in a fault zone contains medium-grade ore. Small concentrations of manganese formed during weathering are common, particularly in the southern part of the trough; one deposit was mined to provide material for the Mary Kathleen treatment plant.

The Dugald River deposit, a silver-bearing lead-zinc lode, is confined to a graphitic shale bed within a dolomitic sequence. The country rocks are mildly metamorphosed and slightly metasomatized. The deposit is accepted as syngenetic (Knight, 1965). Other small silver-lead deposits have been mined only in the oxidized zone for their enriched silver content; they appear to be hypogene.

Median Welt

The Median Welt which separates the Eastern and Western Troughs is composed of granite and metamorphosed acid volcanics; it belongs to the North Australian Orogenic Province, originally formed basement to the troughs, and then was uplifted to a geanticlinal ridge. It contains only small scattered copper and gold deposits.

Western Trough

The Western Trough formed on cratonic basement and passes northwestward into less deformed North Australian Platform Cover without any sharp break. The mineralization is continuous in style from one to the other.

The large copper deposit at Mount Isa is contained in 'silica dolomite', an incomplete replacement of shale by quartz and dolomite. Bennett (1965) suggests that the dolomite was biogenic and the copper syngenetic; but Smith & Walker (1972) offer evidence that the copper was derived from basic volcanics which underlie the orebody and are depleted in copper. Smith & Walker believe the overlying lead-zinc-silver orebodies to be syngenetic.

Other copper lodes occur where the Western Trough merges into Platform Cover. Three have been shown to contain substantial tonnages of ore, though of lower grade than that originally mined. Mount Oxide lies in a crush zone in moderately folded, slightly metamorphosed siltstone and shale. The Lady Annie has been described as 'a disseminated replacement deposit in shale on the hanging wall of a prominent easterly-trending fault plane' (Carter et al., op. cit., p. 217). The third, the Mammoth, is a chalcocite and malachite occurrence in brecciated quartz sandstone (Brooks, 1965a).

The Mount Isa lead-zinc-silver orebodies are generally agreed to be syngenetic. The ore beds, containing pyrite, galena, sphalerite, argentite, and tetrahedrite, form part of a bedded sequence of black carbonaceous dolomitic shale, isoclinally folded and contorted into intricate microfolds. Some of the microfolds are interpreted as slump structures and others as tectonic. The ore minerals have flowed into the crests and keels of the microfolds, where there is a consequent increase in grainsize. Cadmium is recovered from the ore.

Similar orebodies extend discontinuously in a narrow zone from the Hilton mine, 21 km north of Mount Isa, to the Bernborough, about 10 km south of Mount Isa. Only the Hilton mine (Mathias, Clark, Morris, & Russell, 1972) is of major importance.

Pegmatites along the eastern margin of granite about 10 km southwest of Mount Isa have yielded beryl and small quantities of tin and tantalum minerals, mostly from alluvials (Brooks, 1963; Brooks & Shipway, 1960).

Ophthalmia-Gascoyne Block

The Ophthalmia-Gascoyne Block lies to the north of the Yilgarn Block in Western Australia, and may incorporate parts of both the Yilgarn Block and highly deformed western extensions of the Hamersley Basin. Only sketchy information was available at the time of writing. Large northeast shear zones in the block die out as flexures in the Hamersley Basin; and northwesterly isoclinal folds in the western parts of the Hamersley Basin become much more intense in the block itself (cf. West Australian Platform Cover). The mineral deposits so far mined are isolated and small.

The pegmatites at Yinnietharra which lie within the Ophthalmia-Gascoyne Block have yielded small quantities of beryl and also contained small amounts of tantalum minerals (Matheson, 1945). Most of the production was eluvial.

According to Low (1963), the Dalgety Downs copper deposit was introduced by acid dykes in a gneissic country rock. Low also mentions other very small copper deposits which may fall within the boundaries of the block.

Carbonatites are reputed to be present in the block, but their exact location has not been disclosed, nor have they been assessed.

The Paterson Province east of the Pilbara Block is equated with the Ophthalmia-Gascoyne Block on the map. J. L. Daniels (pers. comm.) now considers that this region contains folded Bangemall Basin sediments (Central Australian Platform Cover) over probable Lower Proterozoic metamorphics which may also incorporate some reworked Archaean rocks; but very little is known of the area, which may equally well be a continuation of the Musgrave Block to the southeast. The Braeside lead-vanadium deposit, in West Australian Platform Cover, was probably introduced by igneous activity occurring in the adjacent mobile region to the east.

Willyama Block and its Correlates

From western New South Wales westwards to about 132°E a number of basement blocks of approximately the same age are now separated by the Central Australian and Trans-Australian Platform Covers. The Willyama Block in the east and the Gawler Block in the west are large; the remainder are small inliers in the broadly folded Adelaide 'Geosyncline': three in the mountains east of Adelaide, and the Mount Painter Block and the Denison Block in the central north of South Australia.

The *Willyama Block* extends from western New South Wales into South Australia, where it is referred to as the 'Olary Province' (Campana & King, 1958). The eastern part contains the Broken Hill lead-zinc-silver orebodies and has therefore been intensively studied, mainly in the vicinity of the orebodies. This part is a triangular block with a narrow embayment of platform cover. The metamorphic grade is highest in the southeast and decreases northwesterly, subparallel to the general fold trend. In the northwest the Block has been invaded by transitional-type granites about 1560 m.y. old. The gneiss in the southeast gives ages from 1650 m.y. to 1700 m.y. (Vernon, 1969; Compston & Arriens, 1968). The metamorphic rocks around the main Broken Hill lode are probably altered arenaceous or argillaceous sediments: the lode consists of three lensoid bodies conformable with the compositional banding of the enclosing argillaceous facies rocks. Each lens has its own characteristic metal ratio and gangue (Carruthers, 1965; Pratten, 1965; Lewis, Forward, & Roberts, 1965). A number of geologically similar but much smaller orebodies are known in the region (Anon., 1968).

A much later event corresponding to deformation in the Kanmantoo Fold Belt to the east (see p. 47) is represented by resetting of biotite ages and the introduction of pegmatites with an age of 495 m.y. Small cross-cutting bodies of lead-silver ore appear to have been introduced during this event, mainly in the north and west; they are mineralogically distinct from the Broken Hill lodes, and are typified by the Thackaringa deposit (King, 1953).

The pegmatites carry beryl and felspar; small quantities of beryl have been mined by small-scale operators at several localities, and eluvial tin from one locality north of Broken Hill.

The South Australian portion of the Willyama Block is noted chiefly for its uranium (davidite) deposits. King (*in* Campana & King, op. cit.) has reviewed the mineralization in the Olary Province; he considers that the deposits are genetically related to the intrusive granites, and in one locality recognized five zones rimming the granites; however, he also relates the granites and pegmatites of the area to the one event. Thomson (*in* Parkin, 1969, p. 35) states that the uranium deposits are of the same age as the Broken Hill mineralization, that is, antedating the granites. Although the uranium occurrences have been thoroughly investigated in both states (see also Rayner, 1960), only three deposits were mined, all in South Australia. The largest, at Radium Hill (Parkin, 1965), contains davidite, and appreciable quantities of rare earths from which only a small quantity of scandium has been recovered.

Copper has been mined from small deposits in South Australia, where traces of cobalt and nickel are also recorded. Scheelite is common, but of unknown metallogenic significance, in the Broken Hill area (B. P. Thomson, pers. comm.), and Campana & King (op. cit., p. 101) report scheelite in calcareous sediments in South Australia.

Banded iron formation is poorly exposed near the State border, but it appears to have no economic potential at present (Whitten, 1965).

The *Wonaminta Block* is the small area of metasediments and volcanics northeast of Broken Hill along the eastern margin of the Bancannia Trough. It is thought to be equivalent to the Willyama Block (Scheibner, 1972a). The only mineral deposits are small bodies of copper ore introduced during Kanmantoo events.

The *Denison Block* carries small copper deposits, and some gold. It is a structurally complex area with early Palaeozoic granites intrusive into low-grade metasediments; the mineralization is akin to that in the folded Adelaide 'Geosyncline' (Reyner, 1955; Thomson *in* Parkin, 1969, p. 37-8).

What little mineralization there is in the small inliers near Adelaide appears rather similar to that within the surrounding platform cover, and was probably introduced by the Ordovician Kanmantoo event. However, the uranium mineralization at Myponga, where two small erratic lodes occur in shear zones, may be related to the uranium mineralization of similar type on Eyre Peninsula in the Gawler Block and in the Mount Painter and Willyama Blocks (Parkin, 1957).

The *Mount Painter Block* consists of two inliers along a basement ridge in the northern part of the Adelaide 'Geosyncline'. The block consists of metamorphosed deltaic sediments and acid volcanics intruded by two phases of granite, one Proterozoic and the other Palaeozoic. The block contains a number of low-grade uranium-thorium deposits, of which Mount Painter is the only one large enough to have been mined (Coats & Blissett, 1971).

Gawler Block

The Gawler Block occupies Eyre and Yorke Peninsulas, and is split by the Tertiary downwarp of Spencer Gulf. It is poorly exposed beneath a veneer of Tertiary and Quaternary consolidated and unconsolidated sediments.

The oldest rocks are folded high-grade metamorphics with evidence of granitization in places, dated at about 1780 m.y. A granite gives an age of 1730 m.y., with a broad scattering of values (Thomson *in* Parkin, 1969, p. 30). The metamorphics are overlain by a deformed porphyry and intruded by granite dated at 1590 m.y. The porphyry and granite are overlain by relatively undeformed sediments and a vast spread of acid volcanics, and intruded by small acid stocks which constitute the transitional domain.

By far the most important mineral deposits are the iron ores. They have been mined for many years in the Middleback Ranges, where the iron-bearing beds occur in a much folded linear belt with a strike length of 40 km. The important deposits are all in tight synclines. The original jaspilite ores have been converted by surface enrichment to high-grade hematite ore, but at depth contain magnetite, dolomite, and talc, as well as hematite (Owen & Whitehead, 1965).

Many magnetic anomalies have been drilled to reveal iron formations below the veneer of superficial cover. The very fine-grained jaspilite deposits near Tarcoola in the northwest of the Gawler Block contain 40 to 50 percent iron in parts, and farther northwest at Mount Christie metajaspilites in granulite terrane show some degree of surface enrichment (Whitten, 1965).

Some of the quartz veins in low-grade metasediments and intrusive granites near Tarcoola have been mined for gold—the lodes contained iron oxides at the surface and probably became pyritic at depth. Lead and bismuth were noted in the gangue of one deposit (Gee, 1908, pp. 284-307).

Gold was mined near Earea Dam, 56 km southeast of Tarcoola, and a little tin in a quartz vein has been recorded.

A minor occurrence of molybdenum and tungsten is recorded on Spilsby Island (Blissett & Warne, 1967).

Along the eastern margin of Eyre Peninsula a number of small deposits of lead, silver, and copper occur in metasediments. Production appears to have been very small, although rich specimen material was obtained. Radioactive anomalies have revealed only traces of uranium (Johns, 1961).

The copper deposits of Wallaroo and Moonta on Yorke Peninsula were large and initially very rich, but before production ceased the grade fell below 4 percent copper. The Moonta lodes occur in transitional phase acid volcanics. They form three concentric arcs convex to and dipping steeply to the northwest. Pyrite became dominant at depth. The nearby Wallaroo lodes were in schist and phyllite, and contained galena and scheelite with chalcopyrite as the principal copper mineral (Crawford, 1965). Smaller deposits in the area were rapidly worked out.

Albany-Fraser Belt

The Albany-Fraser Belt wraps round the southern and eastern margins of the Yilgarn Block. It has been interpreted as a metamorphic belt imposed on Archaean rocks (Morgan, Horwitz, & Sanders, 1968). However, Wilson (1969a) considers the Albany-Esperance (the southern) section of the belt to be a 'late Proterozoic orogenic belt', and the northern, Fraser, section to resemble the Grenville Front of Canada, as it is cut off from the Yilgarn Block by a marked fault zone. Wilson suggests that the Fraser Range was metamorphosed at about 1330 m.y., and intruded by gabbro and lastly pegmatite in the late phases of metamorphism. In the Albany-Esperance section both the homogeneous and folded foliated granites postdate the metamorphism, and a foliated granite occurs at the southern end of the Fraser section.

Only scattered traces of metalliferous minerals, mainly copper in the Fraser section, have been found in the Belt. The best prospect of economic mineralization appears to be the possibility of finding nickel in laterite on the gabbros. The Tertiary Eucla Basin covers the belt relatively thinly for a considerable distance eastward, but thickly enough to defeat current geophysical prospecting methods.

MUSGRAVE BLOCK

The Musgrave Block straddles the western part of the border between the Northern Territory and South Australia and extends into Western Australia. Its tectonic history is complex; multiple deformations make its evolution very difficult to unravel.

Thomson (*in* Parkin, 1969, pp. 39-46) states that the oldest rocks are granulites and metagranites; these and younger rocks overlying them were affected by two periods of severe deformation at about 1150 m.y. and 1040 m.y. Between these periods basic and ultrabasic intrusives were emplaced about 1090 m.y. ago in a pattern determined by block faulting.

Daniels (in prep.) has mapped the Western Australian part of the block. Again granulites form basement to later sequences. He has noted the same sequence of events, but has interpreted them differently. The granulites are overlain by acid and basic volcanics, and sediments, including quartzite, which were folded and then intruded by thick gabbroic and ultrabasic sills. The cauldrons, filled with acid volcanics and the associated high-level granites and occasional basic intrusives, may have been contemporaneous with the gabbro-ultrabasic sills. Acid and basic volcanics with some interbedded conglomerates overlie this sequence, and the whole was folded at about 1040 m.y.

Nickel is the main metal so far discovered in the area; the largest occurrence is known as Wingelinna. The ultrabasic intrusions contain a little nickel substituted for iron and magnesium in the olivine lattice. The nickel was liberated during weathering and concentrated in laterites, but the low grade (1 percent Ni or less) and the remoteness of the deposits have not encouraged exploitation (Sprigg, 1965).

Minor copper deposits are present in the block in South Australia and Western Australia; a little oxidized copper ore has been mined in the Warburton Ranges. Daniels (1969) noted copper minerals in basalt interbedded with conglomerate, and tungsten with lead and zinc in the acid volcanics filling a cauldron subsidence area.

The layered gabbros in the Jamieson Range and at Domeyer Hill in Western Australia contain magnetite bands enriched in titanium and vanadium. Daniels (in prep.) quotes an average content of 1.21% V_2O_5.

Pegmatites in the southeastern part of the Musgrave Block contain thorium-bearing monazite, but no production has been recorded.

Wilson (1969b,c) has suggested that the sparse mineralization of the granulites of the Musgrave Block is due to two factors: the absorption of available metal ions by substitution in small proportions into mineral lattices which do not normally accommodate them; and the formation of unusual mineral species with a high content of desirable metal. In view of these possibilities attention should be paid to geochemical methods of exploration and to laterite on the granulites.

Northampton Block

The Northampton Block in Western Australia, also referred to as the Greenough Block (Daniels & Horwitz, 1969), consists of garnet-bearing granulites with an apparent age of 1040 ± 50 m.y. (Compston & Arriens, 1968) and a high Sr^{87}/Sr^{86} ratio, which suggests reworked older material. The only well defined units are complexly folded quartzites (Jones & Noldart, 1962).

The block is cross-cut by numerous dolerite dykes, all with a northeast trend and, where followed in mine workings, a steep dip to the northwest. All known metalliferous deposits lie in or next to the dolerite dykes, which are hydrothermally altered. The lodes bear either lead or copper: each contains only a little of the other. The lead lodes also contain zinc and a little silver. Information on the copper lodes is scant, but they carried no gold and were small (Campbell, 1965).

CENTRAL AUSTRALIAN PLATFORM COVER

The Central Australian Platform Cover was deposited during Adelaidean and early Palaeozoic times in a broad north-south zone westward from about 142°E across Australia.

The Arafura Basin, which developed late in the Proterozoic, appears to extend from the Northern Territory under the Arafura Sea into West Irian. The only known metalliferous deposits in the basin are on offshore islands and are the outcome of lateritization of favourable rock types. Small beds of sandy hematite and hematitic sandstone have been derived from ferruginous sediments on Elcho Island. Bauxite occurs along the chain of islands (Wessel Islands) which includes Elcho Island; it apparently formed from one favourable formation and now occurs along its strike (Owen, 1954; Roberts, Plumb, & Dunn, in prep.).

The Central Australian Platform Cover occupies a broad swath across northern Australia. In the west are the Adelaidean sediments of the Victoria River Basin and the Adelaidean and lower Palaeozoic of the Ord Basin; and farther east are the Daly River, Wiso, and Georgina Basins, in which deposition started very early in the Palaeozoic as basic volcanics flooded across the region (Dunn & Brown, 1969). These basalts carry a little copper in the west, but mineable concentrations have yet to be discovered. In the east, where the cover laps onto the Mount Isa Block, Middle Cambrian siltstone and limestone have recently been recognized as host rocks for sedimentary phosphate deposits in the Georgina Basin. The deposits are probably estuarine, and some secondary processes are involved (Thieme, 1971; Thomson & Russell, 1971; de Keyser & Cook, in press). Phosphates were also deposited in the Amadeus Basin and the Adelaide 'Geosyncline' during the lower Palaeozoic (Cook, 1972), but no large deposits have yet been found.

Large galena crystals have been recorded in Cambrian dolomite near the southern and eastern margins of the Georgina Basin (Smith, 1965; Smith, 1972), but the occurrences appear to be only of mineralogical interest.

Apart from a little copper, no mineralization has been detected in the Amadeus Basin, nor in the Ngalia or Officer Basins. The Adelaide 'Geosyncline' is the site of widespread mineralization, but it has been treated in this commentary with the Kanmantoo Belt because the mineralization is continuous from one to the other, and appears to be the result of Kanmantoo diastrophism (see p. 47).

The manganese deposits in the northern part of the Bangemall Basin, east of the Pilbara Block, are secondary concentrations in manganiferous late Proterozoic sediments, probably formed mainly during the Tertiary (Noldart & Wyatt, 1963). The residual and sedimentary deposits in the Horseshoe/Peak Hill district have a similar origin (MacLeod, in press). The copper-mining centres of Thaduna (Blockley, 1968) and Ilgarari (Low, 1963) lie in sediments of the Bangemall Basin.

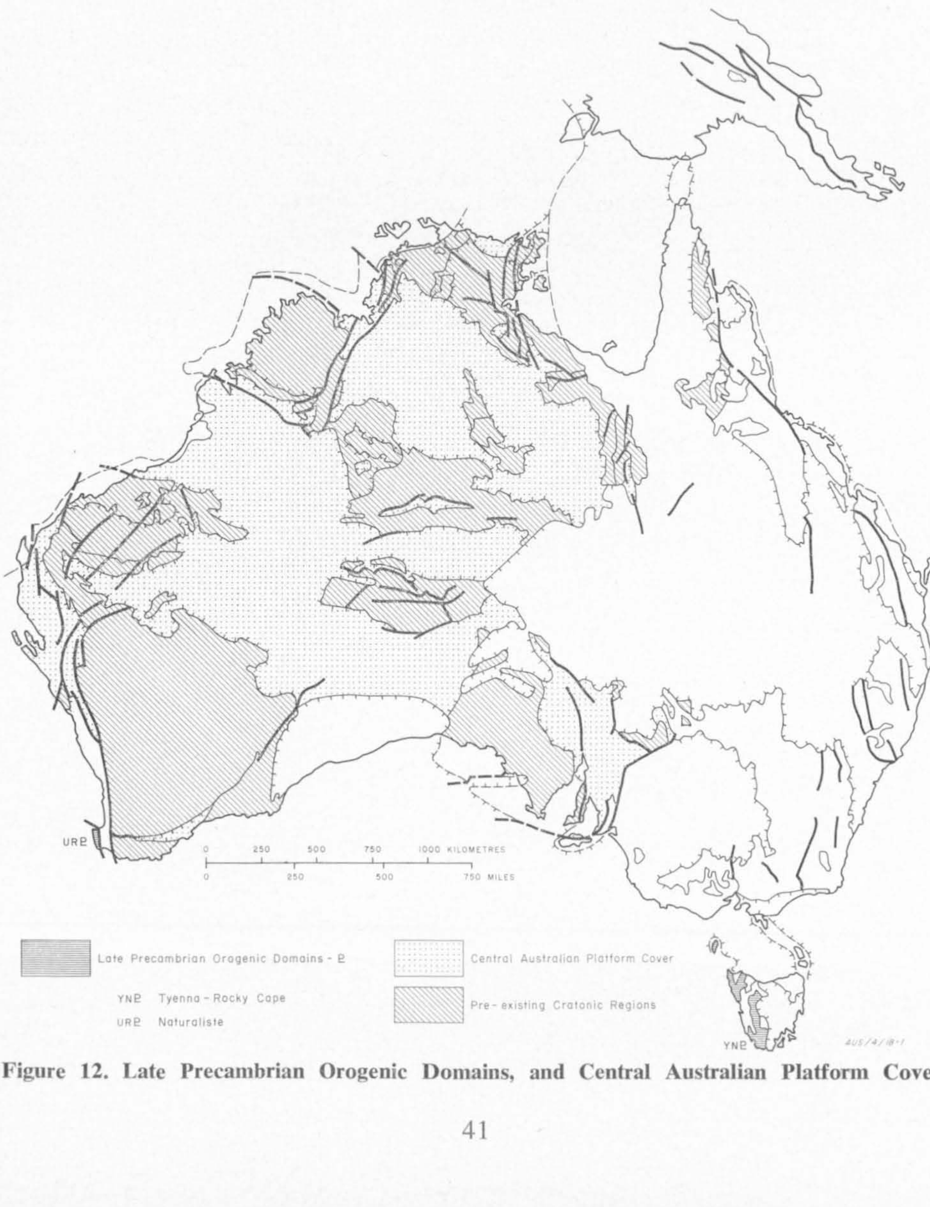

Figure 12. Late Precambrian Orogenic Domains, and Central Australian Platform Cover.

At Thaduna the mineralization is in a fault zone and at Ilgarari in discordant quartz veins.

In Western Australia the Canning and Carnarvon Basins began to form in the late Proterozoic and sedimentation continued until the Permian. The Narlarla lead-zinc deposit is situated in Devonian limestone (Halligan, 1965) in the mobile margin of the Fitzroy Trough, close to its boundary with the King Leopold Mobile Belt. It is an irregularly shaped body of coarse-grained ore material within the limestone, with no obvious hypogene characteristics. It has been suggested that the ore minerals were introduced by groundwater percolating from the basement; but Gellatly (1970) states that structures of the ore 'provide strong evidence of syngenetic sedimentary origin . . . but do not preclude post-depositional movement.' He suggests emplacement by slumping or mudflow intrusion as an alternative to deposition *in situ*.

LATE PRECAMBRIAN OROGENIC DOMAINS

Two units belong to the Late Precambrian Orogenic Domains. One is the Tyenna/Rocky Cape Block in Tasmania; the other, the Naturaliste Block, in the extreme west, may form basement beneath the Perth Basin.

There is evidence of mobility within the craton in several other areas. The King Leopold Belt and the southern margin of the Kimberley Basin (North Australian Platform Cover) were folded by an event about 600 m.y. ago, after which the Fitzroy Trough and the Bonaparte Gulf Basin were initiated. The northern margin of the Musgrave Block and the southern margin of the Amadeus Basin were involved in folding movements toward the end of the Precambrian, with a subsequent downwarp in the Amadeus Basin. Aeromagnetic and seismic work suggests that similar structures continue northwest beneath the southwestern margin of the Canning Basin.

The Adelaide 'Geosyncline' was mildly folded at intervals during its downwarping in the late Proterozoic: the sequence contains a number of regional unconformities and diapirs.

TYENNA/ROCKY CAPE BLOCK

The basement beneath Cambrian and later platform cover in western Tasmania is made up of two low to medium-grade deformed metamorphic units referred to in Tasmanian literature as the Older and Younger Precambrian. The Older Precambrian consists of schist, phyllite, and amphibolite, and the Younger Precambrian of relatively unmetamorphosed quartzite, slate, dolomite, conglomerate, and volcanics. The two may be separated by an orogenic event, or the Younger Precambrian may be the undeformed equivalent of the Older. Lower limits are set to their age by a 700 m.y. date from a dolerite dyke and a total rock age of 835 ± 60 m.y. on an intrusive granite on King Island (Solomon, 1965b; Compston & Arriens, 1968).

The mineralization in the block was introduced by Devonian granites which belong to the transitional domain of the Lachlan in Tasmania; but some iron deposits were apparently introduced before the Cambrian. They include the small iron occurrences of the Penguin district on the north coast and the large deposits of the Savage River region in the west. The Savage River deposits consist of concentrations of magnetite in or adjacent to schistose amphibolites. Some pyrite and a little chalcopyrite are present. Carbonate metasomatism affected the area at about the same time as the orebodies, which are interpreted as hydrothermal, were formed (Urquhart, 1966).

Naturaliste Block

The Naturaliste Block has been shown by regional mapping to consist of three layered units, all granulites, intruded by sheets of granite gneiss (Lowry, 1967). It is separated from the Perth Basin by a fault zone. Age determinations give a date of 650 m.y. for the metamorphism (Compston & Arriens, 1968).

There is no recorded mineralization in the block.

UNASSIGNED PRECAMBRIAN OROGENIC DOMAINS

Several blocks cannot be assigned to Orogenic Provinces, either because their age is unknown, or because the platform that overlaps them is so much younger than the age of stabilization of the block that the relationship between Platform Cover and Orogenic Province does not hold. They are: the Arunta Block (probably a composite unit), the Georgetown Block (definitely composite), the Arnhem Block, and the Litchfield Block.

Arnhem Block

The Arnhem Block appears to be Archaean in age (Dunn, 1971). Its main economic interest lies in the important bauxite deposits developed on an outlier of Trans-Australian Platform Cover—the Cretaceous or pre-Cretaceous land surface at Gove (Grubb, 1970). The large deposit of uranium at Nabarlek, 250 km east of Darwin, lies close to schists thought to be Archaean and therefore part of the Arnhem Block.

Litchfield Block

The Litchfield Block may in part be Archaean (Dunn, 1971), but the granites that intrude it may be younger. Because of the uncertain relationships between rocks of the block and those of adjacent blocks it was treated separately on the Tectonic Map. No economic mineral deposits have yet been found in it.

Arunta Block

The metamorphic rocks of the Arunta Block are poorly exposed, and regional mapping has mainly been confined to the margins, adjacent to younger platform cover. The Granites-Tanami Block may well be continuous with the northern Arunta Block. At least two periods of sedimentation and deformation can be deciphered (Shaw & Warren, in prep.), and the block may contain equivalents of both the North Australian and Central Australian Orogenic Provinces.

Detailed studies are revealing several overprinted events in the Precambrian, and a well defined Devonian-Carboniferous event—mobilization along the northern margins of the Amadeus and Ngalia Basins (Wells, Forman, Ranford, & Cook, 1971), when structures were overprinted on the existing metamorphic complex.

Age determinations in the range 1700 to 1800 m.y. indicate affinities with the Central Australian Orogenic Province. Two facts tend to support this: the platform cover on the Arunta Block is no older than Central Australian Platform Cover except in the Barrow Creek district, where dubious correlates of the Carpentarian Hatches Creek Group rest unconformably on Arunta Complex; and the Tennant Creek Block and the North Australian Platform Cover to the northeast are cut by platform granites with similar ages to syntectonic and post-tectonic granites along the northern margin of the Arunta Block. Nevertheless, part of the block must be older than the Central Australian Orogenic Province.

Mineralization is sparse and most known metal occurrences are small.

In the northeast, the Jervois area contains copper lodes over a belt 10 km long, with some lead, bismuth, and tungsten. Small-scale operations have produced less than a thousand tons of copper in various forms (Smith, 1964), but recent drilling indicates the presence of at least two larger orebodies with good grades of copper, lead, silver, and bismuth. The lodes lie along one stratigraphic horizon within a synform with a northerly plunging axis. The pattern of metal distribution suggests a syngenetic origin. The area also contains stratigraphically controlled but hypogene scheelite mineralization and some fluorite (Robertson, 1959).

The Home of Bullion lode lies close to the northeast margin of the block at a discordant junction between two groups of metamorphic rocks. It was mined for copper, but lead and zinc are also present. Sullivan (1953) estimated the reserves of ore to be considerably larger than the recorded production to 1955, when the mine closed. Small-scale production has begun again more recently.

Some very small lead, copper, and gold mines close to the Devono-Carboniferous structures north of the Amadeus Basin are presumed to be of this age.

The only carbonatite so far definitely identified in Australia lies in the Arunta Block (the presence of others in Western Australia is rumoured—see p. 36). It has been disjointed by faults; it contains rare earths, zircon, and phosphate, but appears to have little economic potential (Gellatly, 1969).

Georgetown Block

The Georgetown Block consists of three exposures separated by Trans-Australian Platform Cover: the Georgetown Inlier, the Yambo Inlier to the north, and a narrow basement ridge along Cape York, the Peninsula Ridge. The three appear to have acted as a single unit since the early Palaeozoic, but their interrelationship before that time is not clear.

Georgetown Inlier

At least two cycles of deposition and deformation are known in the Georgetown Inlier: a sequence of high-grade gneiss intruded by granite, and a younger, less deformed but thick sequence also intruded by granite. The age of the rocks is uncertain. The Forsayth Granite gave an age of 1200 m.y., and the Robin Hood Granite appears slightly younger*; and the Croydon Volcanics in the west have an age of 1460 m.y. (Richards, White, Webb, & Branch, 1966).

Much of the mineralization in the Inlier has been introduced by activity spreading from younger mobile zones.

The Woolgar Goldfield is situated in an inlier of high-grade metamorphics south of the main Georgetown Inlier; the lodes occur along the margins of pegmatitic granite dykes which intrude the metamorphics (Saint-Smith, 1922).

* The difference in age between the two granites may well not be significant; it is based on only two K/Ar determinations, and is suspect (J. R. Richards, pers. comm.).

The Halls Reward copper lode, close to the Burdekin Fault which marks the southeast margin of the Inlier, is also situated in the old metamorphics, but within a shear zone. The ore came mainly from the oxidized zone and carried variable gold and silver values. The age of mineralization is not known.

The younger and lower-grade metamorphics have been mapped in more detail (White, 1965). They serve as host to silver-lead mineralization southwest of Georgetown, copper at Ortona and near Gilberton south of Forsayth, and gold adjacent to later granitic intrusions. None of these deposits is large.

The Inlier is cut by granites of several ages. The oldest include the Forsayth and Robin Hood Granites, both of which are hosts to pyritic gold mineralization. The lodes in the Forsayth Granite are localized in fissures. All the information available has been summarized by White (1965): few mines produced more than 10 000 oz; below the water table ore is refractory and little has been mined.

The Croydon Volcanics and Esmeralda Granite were at one time thought to be Permo-Carboniferous by analogy with the neighbouring cauldron volcanics and the Elizabeth Creek Granite (Branch, 1966); but isotopic age determinations indicate that they are Precambrian. The volcanics have an age of 1460 m.y. and the granite a reset age of 515 m.y., although a more probable age is 1200 m.y. (Richards et al., 1966). These are consistent with field observations by Jensen (1940) and Clappison (1940) that the Esmeralda Granite intrudes the Croydon Volcanics. Both granite and volcanics are hosts to gold-silver ores at Croydon (Edwards, 1953b). The main control seems to be fissuring, but richer zones of ore contain graphite. South of Croydon the Esmeralda Granite carried minor tin mineralization (Clappison, 1940; Jensen, 1940).

The Middle Devonian granites seem to be barren, but ultrabasics, also Middle Devonian, which lie partly in the Georgetown Block and partly in the Broken River Embayment, introduced chromite (see p. 58).

Igneous activity of the Hodgkinson Transitional Domain is manifested by ring structures and cauldron subsidence areas (Branch, 1966) within the Inlier, and is more widespread along the margin adjacent to the Hodgkinson Belt (see p. 60 for detail). Branch (1966) is of the opinion that much of the mineralization, including tin, tungsten, lead, copper, and fluorite, in the Georgetown Inlier was introduced during this period. The copper ore at Einasleigh occurs in high-grade metamorphics which were intruded by basic rocks, deformed, and intruded by aplite and porphyry, which all antedate the orebody (Queensland Mines Dep., 1953a). Since the porphyry is part of the Hodgkinson Transitional Phase, this mineralization is also a late Hodgkinson event. The lodes, localized in favourable bands in the schists, contain copper, molybdenum, and zinc sulphides in pyrrhotite.

Yambo Inlier

The Yambo Inlier (Willmot et al., in press) appears to be best correlated with the high-grade metamorphics in the northern part of the Georgetown Inlier. Granite samples have given middle Palaeozoic isotopic ages. Mining activity in the Inlier has been confined to the recovery of alluvial gold which was carried by the Palmer River from lodes in the Hodgkinson Belt.

Peninsula Ridge

The Peninsula Ridge is a ridge of Precambrian and middle Palaeozoic rocks which extends from 12°S to 16°S down the eastern side of Cape York. It consists of low to high-grade metamorphics, intruded by granites which are similar to those in the Yambo Inlier. The late Carboniferous to Permian volcanics and granites which intrude the Peninsula Ridge may correlate either with transitional Hodgkinson or early New England/Yarrol events to the south—the two overlap in time. The ridge is separated by a shallow trough of Trans-Australian Platform Cover from the Cape York/Oriomo Ridge, which contains only late Palaeozoic volcanics and granites without any visible older basement. Several units have been recognized in the metamorphics. At Iron Range, metamorphosed ferruginous sediments contain hematite and magnetite lodes (Canavan, 1965b). Apart from some small antimony lodes, the main metal mined has been gold. Two goldfields, Coen and Ebagoola, are aligned with shear zones.

The tungsten at Bowden and in Torres Strait, and small tin deposits, seem to have affinities with Hodgkinson Transitional Phase mineralization farther south, having been introduced by the late Palaeozoic acid igneous activity.

EAST AUSTRALIAN OROGENIC PROVINCE

The folded rocks of eastern Australia were deformed by a number of partly overlapping tectonic events from Cambrian to late Triassic, which gave rise to sub-parallel belts elongated nearly north-south, with the older rocks to the west and the younger in the east. The area has been referred to in older literature as the 'Tasman Geosyncline', a term now falling into disrepute.

The Kanmantoo Belt in South Australia and western New South Wales is the oldest part of the province; the only deformation occurred early in the Ordovician, and affected the adjacent platform margin. Contemporaneous movements occurred in Tasmania, but did not mark the end of sedimentation in that area.

Apart from the Kanmantoo Belt, the western part of the East Australian Orogenic Province is made up of the Lachlan Belt and its time equivalents in north Queensland, the North Queensland Blocks. The western margin is visible only along the fault-bounded trough of the Broken River Embayment in north Queensland. The Cork Fault under the Eromanga Basin appears to be both the linear continuation of the margin of the Broken River Embayment and the division between Precambrian and Palaeozoic basement beneath the basin. Several deformational events from early Ordovician to mid-Devonian are recorded in these domains, and transitional domains developed during the late Devonian and the Carboniferous. Granites corresponding to all phases of deformation are known. Rocks thought to be originally deformed by early Palaeozoic events are known in the younger fold belts to the east of the Sydney-Surat-Bowen Basins.

The folded Hodgkinson Belt is separated from the Precambrian Georgetown Block by a major fault, the Palmerville Fault (de Keyser, 1963), whose suspected southeasterly extension would also divide it from the North Queensland Blocks. The Hodgkinson Belt was deformed in the Lower Carboniferous; then a short period of sedimentation was followed by widespread acid volcanism along the faulted margin, which with comagmatic granite intrusion extended into the older craton. This activity died down by the Permian. However, the Hodgkinson Belt was twice intruded by granite and block-faulted during the Permian, at times that may be correlated with movements in the New England/Yarrol area.

The youngest fold belt, formerly known as the Hunter-Bowen Belt from its approximate southern and northern limits, has been called the New England/

Yarrol Belt in the Tectonic Map. It may incorporate a basement of early Palaeozoic age, but the major phases of deformation occurred in the late Carboniferous, Permian, and earliest Triassic, with transitional developments during the Triassic. Instead of the recognizable sub-belts and basins of the Lachlan Belt, this region is characterized by block faulting. The only recognized troughs are along the western margin: the Tamworth Trough and the Yarrol Basin, the latter passing into deformed platform cover to the west and north of the Gogango Zone of overfolding.

KANMANTOO BELT
(and adjacent folded Central Australian Platform Cover)

The Kanmantoo Trough in South Australia developed as a marked downwarp along the eastern margin of the Adelaide 'Geosyncline' in the Cambrian, and was

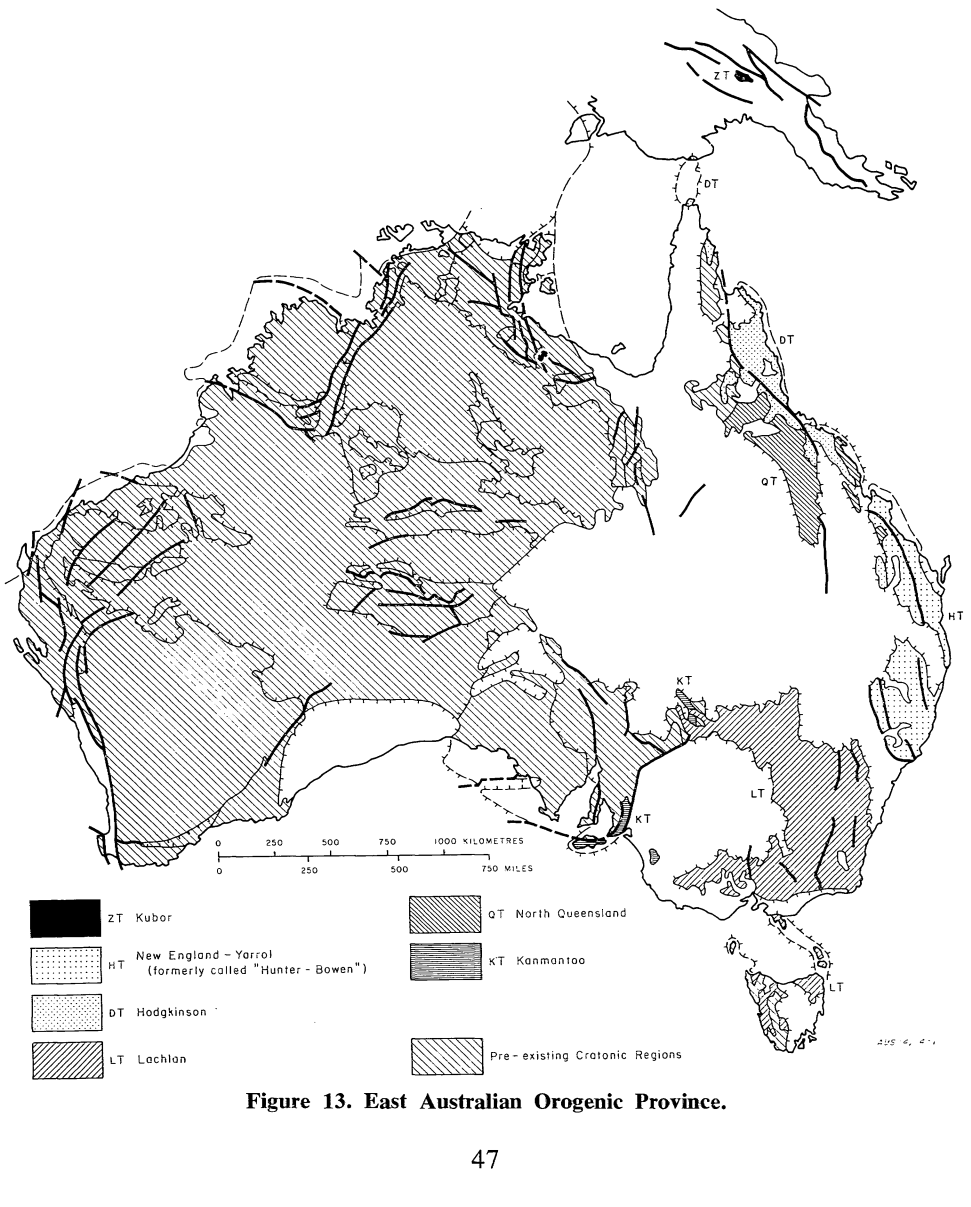

Figure 13. East Australian Orogenic Province.

deformed early in the Ordovician to form the Kanmantoo Belt. The deformation extended into the Adelaide 'Geosyncline' and severely affects the platform cover as far north as the Willyama Block. Deformed Kanmantoo rocks have also been recognized northeast of Broken Hill.

The Adelaide 'Geosyncline' is regarded as platform cover: although it is very thick, basement is exposed on both margins and the deformation is in the form of broad folds and faults which widen into breccia zones and 'diapirs'. Much of the deformation is attributed to movement of basement blocks at several stages during the sedimentation, which began about 1400 m.y. ago. Basic volcanics appear close to the base of the succession in the west and against the basement upwarp of the Mount Painter Block. The succession includes a persistent bed of sedimentary magnesite and two episodes of glacial sedimentation (Thomson, 1965; Thomson *in* Parkin, 1969, pp. 49-83). The diapirs appear to have been formed by the upward movement of fine-grained semiplastic sediments from the lower part of the sequence at times of tectonism. Those studied in detail carry large exotic blocks, and their margins show evidence of several upward movements (Coats, 1963).

The Kanmantoo Belt and the adjacent Adelaide 'Geosyncline' are characterized by widespread deposits of copper, lead, gold, zinc, and barium, and a more restricted zone of manganese deposits. Thomson (*in* Parkin, 1969, p. 107) considers that most of the mineralization was introduced during the early Ordovician deformation and metamorphism of the Kanmantoo Trough (Delamerian Orogeny). Gold is confined to the eastern section of the folded region—a zone in the Mount Lofty Ranges in and to the east of the basement inliers, a small area near Orroroo and Peterborough, and a zone along the southwest margin of the Willyama Block. This rims broadly the area of granite intrusion and corresponds to the biotite zone of Offler & Fleming (1968). The richest deposits, now worked out, were in the southern section. Dickinson & Sprigg (1953) also show occurrences in the Flinders Ranges, but these are very small.

Copper, lead, and zinc mineralization is more widespread. The largest copper mines have been mostly either in the Kanmantoo Belt (e.g. Kapunda) or not far from it (e.g. Burra). There are two exceptions, the Blinman mine and the Mount Gunson deposit. The Blinman mine is situated in an exotic block within the Blinman Dome, one of the diapiric structures. The diapirs form one locus of copper mineralization in the Flinders Ranges; another is unconformities, especially those associated with glacials, and a third the basic volcanics rimming the Mount Painter Block (Johnson, 1965). The Mount Gunson deposits lie in the thin, relatively undeformed western margin of the Adelaide 'Geosyncline'. They are irregular tabular bodies, almost horizontal, in subhorizontal sandstone, grit, and dolomite (Johns, 1965). Recent studies by Lambert, McAndrew, & Jones (1971) indicate that circulating groundwater is leaching the old deposits and reprecipitating minerals in the adjacent lagoon. They consider that the older deposits are not hypogene. Manganese and barite occur nearby (Pernatty Lagoon, see below).

Lead is less common than copper; the deposits tend to be small. Johnson (op. cit.) observes that Lower Cambrian dolomite is the most favourable host rock—the Ediacara deposit is a large low-grade dissemination of silver-bearing galena with minor copper in Lower Cambrian dolomite. Sedimentation appears to have a control over the location of mineralization.

Zinc was largely ignored in early mining. The complex oxidized zinc-copper-silver-silicate ores at Mount Fitton, in the extreme north, received some attention, but metallurgical problems discouraged progress (Ridgway, 1950). A large zinc silicate deposit has been reported at Beltana.

Barite is widespread, both in the folded region and in the shelf zone at Mount Whyalla southwest of Port Augusta. Most lodes are either veins or lenses; there seems to be no stratigraphical control. Many of the deposits contain iron oxides as impurities. The Pernatty Lagoon deposit (Mount Gunson area) contains barite closely allied to manganese. The Pernatty Lagoon manganese deposit consists of residual cappings over manganiferous dolomite. Other manganese lodes are confined to an area northeast of Port Augusta in the folded zone—they are either veins or in fault and crush zones, perhaps enriched by supergene processes.

Within the Kanmantoo Trough a sedimentary pyrite bed has been traced over many kilometres. Although it is quarried for its sulphur content, the bed also contains several times background values of lead, zinc, copper, and silver (Mirams, 1965).

In northwestern New South Wales, rocks of similar age to those in the main Kanmantoo Belt have been mildly to extensively deformed by events during the late Cambrian and Ordovician. They are overlain unconformably by less deformed Ordovician sediments (Kanmantoo Transitional Domain, also referred to as the Gnalta Transitional Province by Scheibner, 1972a). The region carries minor copper and lead mineralization. The small gold deposit at Tibooburra was introduced by a granite that has been dated as Silurian (Rose & Brunker, 1969; Pogson & Scheibner, 1971; Scheibner, 1972a).

Lachlan Belt

The Lachlan Belt in southeastern Australia extends northwards from Tasmania to Bourke in central western New South Wales and westwards to the border between Victoria and South Australia. The eastern margin lies beneath the Sydney Basin, and the junction in the west with the Kanmantoo Belt is obscured beneath basin fill of the Darling Basin (part of the Lachlan Transitional Domain) and Trans-Australian Platform Cover. The granites near Hungerford on the southern Queensland border are inliers of the Lachlan Belt. The older rocks caught up in the New England/Yarrol Belt will be discussed as part of that belt.

The Lachlan Belt may be divided into a number of units with different histories (Fig. 14), both in style and time of sedimentation and in style and time of deformation. Boundaries between them are rarely clearcut, but broad division has been suggested, as for example that outlined by Packham (1969, p. 1). It is unfortunate that Scheibner's (1972b and in prep.) detailed and logical analysis was too recent to be available to the compilers of either the Tectonic or the Metallogenic Map. The units into which the Lachlan Belt is divided in the map and in the text that follows are used for convenience; they are in no way definitive.

Ballarat Trough

In western Victoria, west of the Mount William, McIvor, and Mount Ida faults (the Heathcote Line), an area of sedimentary rocks ranging in age from Cambrian to late Ordovician has been strongly folded along north-south axes. The Cambrian is exposed only as thin slices immediately west of the Heathcote Line, as a mainly basic volcanic sequence with interbedded cherts and black shale (Talent & Thomas, 1967). The Ordovician is a deep-water sequence of geosynclinal greywacke with some interbedded pyritic shale (Singleton, 1965). The age of the

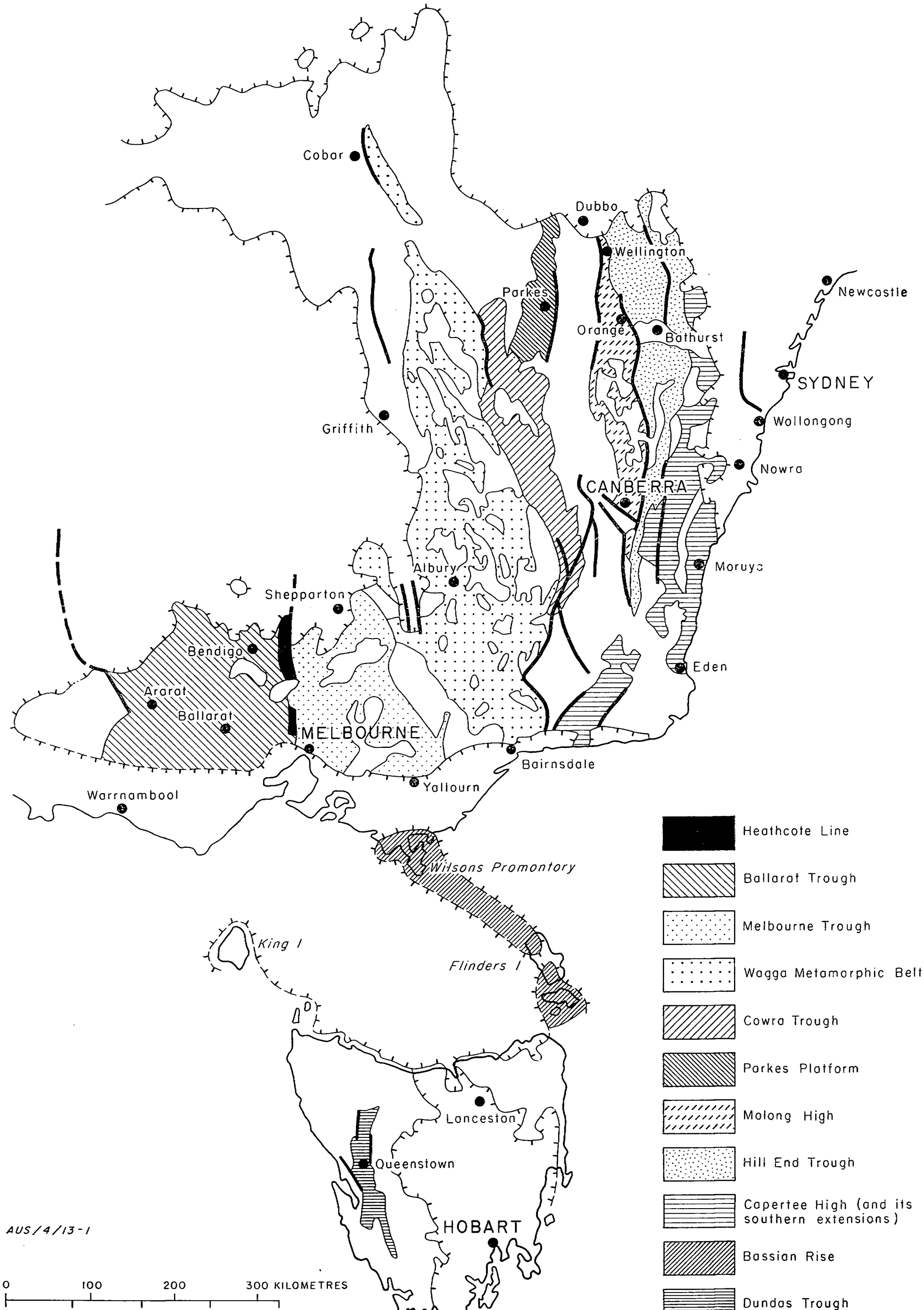

Figure 14. Elements of the Lachlan Belt.

deformation is uncertain; early workers thought it to be mid-Devonian, but as part of the Lachlan region it is more likely to have occurred late in the Ordovician during the Benambran Orogeny.

This region of folded rocks has been shown on the map as virtually coincidental with a gold province, but the pattern of metallogenesis is quite complex. The close, often isoclinal, folding has provided suitable lower-pressure sites for mineralization at the crests of folds—Bendigo was famed for its saddle reefs (Thomas, 1953), but saddle reefs were also prominent in other fields. On the Ballarat-Wedderburn line of lodes, faults with strikes nearly parallel to the fold axes postdate the folding and cut the axial planes of the folds at acute angles, in places following the limb of a fold. These faults bore gold, but concentration increased spectacularly where the fault crossed certain favourable beds, in particular a pyritic shale (Baragwanath, 1953).

The granitic intrusives in the area are of several ages; Singleton (op. cit.) states that gneissic granodiorites at Ararat and Pyrenees have gneissic margins, and so are possibly synorogenic; whereas a number of later granites such as the Harcourt Granodiorite cut across the grain of the country and have been classified as part of the late Devonian to Carboniferous Lachlan Transitional Domain, extending beyond the Ballarat Trough (see p. 52).

The information on gangue minerals and associated metals is far from complete, and detailed studies should prove rewarding; at present only generalizations are possible. McAndrew (1965) implies that most of the lodes in the Ballarat Trough were quartz-gold with pyrite. However, zinc and lead sulphides occur in the lodes at St Arnaud and Pyrenees (where there are syntectonic granites); arsenic-bearing lodes have a wide distribution; and antimony-gold lodes occur but are more widespread in the tectonic units to the east, which suggests that they at least belong to the later phases of tectonism.

Molybdenum and bismuth at Maldon lie close to the margin of a transitional domain granite.

Mining concentrated on gold, and the literature is therefore extremely biased toward gold. Studies are also handicapped by the lack of geological mapping in the mines during their working history, and of mineragraphic studies. Mining began with the readily accessible alluvial gold and extended to deep leads beneath the Tertiary basalt cover, and only as the easily won surface gold was depleted did attention swing to the lodes, some of which were found by tracing alluvial leads to their source.

Melbourne Trough

The Melbourne Trough lies between the Heathcote Line and the southern part of the Wagga Metamorphic Belt. Both the western and eastern margins supplied sediments, which were deposited mainly in shallow water. The trough formed in the early Silurian on a relatively undeformed Ordovician sequence after the Benambran Orogeny and was terminated by the Tabberabberan Orogeny in the Middle Devonian, the effects of which were most marked along the eastern margin. The eastern margin was also later the site of volcanic activity during the Lachlan transitional phase, and Lachlan Transitional Domain granites were intruded both along this margin and within the trough.

The folded rocks of the trough are extensively mineralized; most of the deposits were mined for gold and recorded primarily as such, but antimony seems to have been present in many lodes. At Costerfield the quartzose lodes were mined first for their gold content but later also for their antimony content; they postdate folding and faulting (Stillwell, 1953), but are not close to any igneous activity.

Many of the gold deposits in the Walhalla Synclinorium occupy fracture systems within basic dykes. All the lodes are quartzose, but the small sulphide content varies—antimony, arsenic, lead, zinc, and copper are all recorded (Edwards, 1953). At the southern end of the synclinorium the Thompson River copper mine has yielded small quantities of copper and platinoid metals. The lode also contains nickel, but it is associated with a hornblende diorite dyke; there are no ultrabasic rocks in the vicinity.

The dykes in the Melbourne Trough are referred to by Edwards (op. cit.) as Devonian—they presumably either antedate or belong to the same Kanimblan igneous activity as the Lachlan Transitional Domain volcanics along the eastern margin of the Melbourne Trough and may therefore be late Devonian or early Carboniferous. As the mineralization postdates the intrusions (though the time interval may be slight) it must be regarded as late Kanimblan. Also, as both the Kanimblan granites and the gold-antimony association are known west of the Heathcote Line, it is likely that detailed field analysis would subdivide the single gold province shown west of the Heathcote Line into two provinces, one Benambran (gold) and the other Kanimblan (gold-antimony).

Eastern Lachlan (excluding the Hill End Trough)

East of the Melbourne Trough and excluding the Hill End Trough, the elements that make up the Lachlan Belt in mainland Australia have a sufficiently simple history to be treated as one unit for the purposes of this commentary.

The oldest dated rocks are Ordovician, although highly deformed rocks near Moruya are tentatively assigned to the Cambrian. The Ordovician sequence consists of quartzose greywacke, acid to andesitic volcanics, and black shale and carbonate rocks, folded by the Benambran Orogeny, which began late in the Ordovician and continued into the Silurian. Metamorphism is limited to the Wagga Metamorphic Belt in the west and a discontinuous belt extending from Cooma southwards into Victoria in the east. Granites giving an age of 415 m.y. have been recognized in northeastern Victoria (Evernden & Richards, 1962) and granites of similar age may exist in the Cobar, Nymagee, and Cargelligo 1:250 000 Sheet areas.

After the Benambran events the region fell into several ill defined units (Fig. 14). Silurian sedimentation, which was thin and of shelf type over the Benambran welts, thickened in the Cowra Trough along the western margin of the Molong Arch. Widespread acid volcanics, erupted towards the close of the Silurian, are preserved in belts parallel to Benambran structures; they precede granites of the Bowning Phase at the close of the Silurian. Along the eastern margin of the Wagga Metamorphic Belt in southern New South Wales a discontinuous narrow belt of serpentine is thought to have been emplaced during Bowning deformation. Previous workers have suggested that a northern extension of this belt swings northwest, apparently across the Benambran structural grain, to include basic intrusions at Fifield and Honeybugle. Post-Bowning sedimentation is confined to small structural basins near Yass and Lobbs Hole, which contain volcanolithic sediments and marine limestone. The basins are mildly deformed, by either the Tabberabberan or the Kanimblan orogeny. The only recognized Kanimblan granites occur in and east of the Hill End Trough.

Because of the limited information on the age of mineralization, and intrusive rocks in the Eastern Lachlan region, only broad generalizations have been made; postulated provinces have been confined to tectonic units.

The serpentinite zone along the eastern edge of the Wagga Metamorphic Belt highlights a dominant trend of mineralization in the Belt. Clustered along the serpentinite zone in the south are deposits of chromite and very small base-metal deposits. The Fifield platinum-gold deposit in the north lies on the postulated northern extension, but the source of the platinum and gold is an ultramafic intrusion, not a serpentinite (Jaquet, 1896). West of the serpentinite zone is a zone of gold-quartz deposits corresponding in the south to the axis of the metamorphic zone. The metamorphic effects wane to the north, but the zone of gold occurrences persists to Lake Cargelligo. Still farther west, but overlapping the gold zone, a zone of tin-tungsten deposits stretches discontinuously from Glen Wills in Victoria to Tallebung, south of Cobar (Cochrane, 1971). Molybdenum also occurs in northern Victoria and southernmost New South Wales, but not farther north. There seems to be a spatial relationship between these deposits and a belt of granites, of which those that have been dated belong to the Benambran Orogeny. However, tin deposits in general trend to be introduced by high-level transitional phase granites.

The CSA mine, 11 km north of Cobar, is the largest occurrence in a narrow zone of deposits stretching over some 30 km. The basal sequence in the Silurian Cobar Trough is a volcanolithic greywacke, followed by slate and a siltstone that has been metamorphosed to greenschist facies. Ore deposits occur in all three units. Although there seems to be some degree of stratigraphic control, the main control is structural; suitable structures developed during folding and shearing. All lodes contain pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena; silver is common and the deposits close to Cobar also contain gold (Kappelle, 1970).

McClatchie (1970) has pointed out the widespread association between Silurian andesitic volcanics and copper occurrences throughout the Lachlan Belt of New South Wales. Few of these deposits are of any size.

Copper mineralization has been recorded at several localities within the Girilambone Beds east of the Cobar Trough. The age of the beds is unknown, as is the age of mineralization. Any genetic link amongst these deposits is obscure, though McClatchie (op. cit.) postulates a link with ultrabasic bodies to the west; but the haloes of base-metal deposits about ultrabasics tend to be narrow, whereas these deposits are spread over a broad area.

The gold-bearing zone that extends northwards from Grenfell through Forbes, Parkes, and Peak Hill to Tomingley is sited in a belt of Ordovician sediments and andesitic volcanics overlain conformably by Silurian sediments (Andrews, 1910). The area lies on the eastern margin of the Parkes Platform as defined by Packham (1969, p. 6), but seems to have been more mobile than the remainder of the platform. The copper and gold lodes of the heavily faulted northern section of the Molong Arch, where its separation from the Hill End Trough is indistinct, have been related by McClatchie (op. cit.) to Ordovician andesite. E. Scheibner (pers. comm.) considers that the Forbes-Tomingley zone and the small lodes in the north of the Molong Arch are part of the same province, which has been disrupted by later events; the source of the metals appears to be the Ordovician andesite, affected by the mobility of the region.

Within the Molong Arch, scattered very small tungsten and tin deposits in the Frogmore district may be associated with Bowning granites, but the small copper-lead-zinc deposits belong to McClatchie's Silurian acid volcanic group. A gold-bismuth occurrence at Nanima, northwest of Canberra, and numerous very small gold-quartz lodes, are in Ordovician rocks, and may have been introduced during the Benambran deformation.

To the east of the Hill End Trough folded Ordovician sediments were intruded by Benambran, Bowning, and Kanimblan granites. The small gold deposits that straddle the Victorian border near Delegate, like those in the axis of the Wagga Metamorphic Belt to the west, lie on the axis of a less well defined metamorphic belt through Cooma.

Very little is known about the deposits of the molybdenum province from Mallacoota north to Bega, with the exception of the well documented Whipstick mine, which produced gold, molybdenum, and bismuth (Jack, 1953) from pipes near a granite margin. Other deposits in the province are considerably smaller.

Numerous gold occurrences are recorded in the folded belt north of the Bega Batholith of Bowning age, but the information concerning even the chief producing areas near Braidwood and Araluen is slight. The lodes are confined to a small area of the Braidwood Granite (which may be part of the Bega Batholith—see Strusz, 1971), but much of the production was from alluvium. The gold deposits at Yalwal to the north are adjacent to a Kanimblan granite (Gibbons & Le Messurier, 1962).

A complex copper-tin-arsenic lode at Tolwong in the gorge of the Shoalhaven River occurred in a vein which cuts across the structure of the folded Ordovician rocks. Extraction proved difficult and the amount of metal recovered was not large (Carne, 1911).

The lead deposits at Yerranderie, west of Sydney, are Kanimblan; they occur in veins cutting Upper Devonian tuff and lava near the contact with a Carboniferous acid intrusive (Lawrence, 1953).

Hill End Trough

The Hill End Trough had a markedly different history during the Silurian and early Devonian. The belt is at its widest north of the Kanimblan granite at Bathurst and becomes narrower southwards; it is hemmed in between faulted margins towards Captains Flat, south of which it is faulted out.

The basal Ordovician sequences consist of andesitic volcanics, with greywacke and some limestone. During the Ordovician there seem to have been no clear-cut margins to the Hill End Trough—preserved sequences in the northern part of the Molong Arch and the Capertee Geanticline are very like those exposed in parts of the Trough. In the Silurian, however, much thicker sequences, containing acid and andesitic volcanics, were laid down in the Trough, and this pattern of sedimentation persisted to the middle Devonian, where it was terminated by the Tabberabberan Orogeny; the Bowning Orogeny had little effect on the Hill End Trough.

The mineralization in the Hill End Trough may be divided into three main groups.

1. Stanton (1955) noted the close spatial relationship between copper deposits and nearby Ordovician andesitic volcanics containing limestone lenses, and concluded that the source of copper was the andesite; the copper migrated during

folding movements into nearby favourable beds containing large quantities of iron sulphides, and was localized in replacement-type orebodies. These deposits occur south of the Bathurst Granite.

2. The second group is associated with Silurian volcanics, as at Captains Flat. The deposits contain copper, lead, and zinc, and some gold. Most lie close to the western margin of the Hill End Trough, which is defined by heavy faulting. The concentration of metals may have been syngenetic, but the deposits have many features that suggest that they were formed by replacement. The best documented occurrences are those in the Captains Flat Syncline (Oldershaw, 1965). Deposits with a similar suite of metals occur south of the Captains Flat Syncline in Silurian rocks in a trough in the Molong Arch in the Bega 1:250 000 Sheet area, but on the regional trend of faulting marginal to the Captains Flat Syncline.

3. The gold deposits of the Hill End Trough, nearly all of which lie north of the Bathurst Granite, are most probably all transitional Lachlan (Kanimblan) in age. They occur in a wide variety of host rocks in an area of extensive intrusion by transitional Lachlan granites.

Lachlan Domain in Tasmania

The rocks of Tasmania involved in major tectonism during the Palaeozoic are broad correlates of the Lachlan Domain of the mainland. However, although sediments were deposited during the same span of time as on the mainland, the detailed pattern of sedimentation and diastrophism is somewhat different.

The sediments of western Tasmania were laid down on a basement of late Proterozoic deformed rocks. During the Cambrian, sediments with a high proportion of lithic fragments accumulated in unstable basins on the present west coast. To the east, volcanics probably partly of the same age include keratophyres, quartz porphyry, and quartz-feldspar porphyry, with interbedded pyroclasts. Small areas of sediments along the central north coast are disrupted by younger rocks; and a Cambrian sequence is known in the northwest. The Jukesian movement late in the Cambrian or early in the Ordovician considerably reduced the area of sedimentation in the west, so that sedimentation in the Ordovician-Devonian was on a shallow and less extensive shelf. Three small granite bodies are thought to have been emplaced during the Jukesian event, but the larger igneous intrusives were ultrabasic (Solomon, 1965a).

The Cambrian volcanics served as host rocks, and very probably also as source rocks, for the important copper-gold deposits centred on Mount Lyell, which antedate an early Ordovician land surface (Solomon, 1967). However, the overlying Ordovician rocks also contain probable syngenetic copper (Solomon, 1969), which may have been recycled during erosion of the nearby volcanics. The Read-Rosebery lead-zinc deposits appear to have had a similar genetic history to the Mount Lyell deposits. Hall et al. (1965) regard them as replacement bodies, but concede the possibility of Devonian remobilization of Cambrian concentrations.

The Jukesian granites appear to have carried only minor mineralization. The serpentinites are more important; they serve as the source of alluvial platinoids, are responsible for copper-nickel deposits at Cuni, and are the source material for primary and lateritically derived (currently uneconomic) nickel deposits on the west coast and at Beaconsfield.

The Middle Devonian Tabberabberan Orogeny impressed widespread folding and faulting on Tasmanian rocks. Some low-temperature mineralization, such as the lead-silver-zinc lodes at Mount Farrell, is localized in Tabberabberan structures—the source of the metals appears to be nearby Cambrian volcanics (Solomon, 1965b). The ores at Mount Lyell and between Mount Lyell and Mount Farrell were affected and mobilized to varying extents by the orogenic events.

The Tabberabberan Orogeny was followed by a period of granite intrusion ranging from mid-Devonian into early Carboniferous: most intrusives antedate the Kanimblan Orogeny in its type area, and are possibly better described as late-orogenic than transitional. Those in northeastern Tasmania are the older, with ages of 370 m.y.; the western Tasmanian granites give ages ranging from 360 m.y. to 340 m.y. (McDougall & Leggo, 1965). Tin, tungsten, and base metals accompanied their intrusion. In the northeast molybdenum also occurs, and the primary mineralization shows apparent zoning around granite bodies. The presence of alluvial tin along the basement ridge that stretches from northeast Tasmania through Flinders Island to Wilsons Promontory suggests that the tin deposits of southern Victoria and those of Tasmania belong in the same regime.

Uranium has been recorded from several places in the tin-tungsten province centred on Aberfoyle (Ostle, 1956), but not in economic quantities. The large Aberfoyle tin-tungsten and Storeys Creek tungsten deposits are situated in metasediments close to an intrusive granite margin.

In the far west a zoned tin/iron/base-metal province extends from Trial Harbour to Mount Bischoff. The zoning in the Heemskirk-Zeehan area (Edwards, 1953a; Both & Williams, 1968) is broad: the zones are spread over 15 km, with tin lodes in the granite giving way to aureoles of pyrite-lead-zinc followed by siderite-lead-silver. A little copper is present, and Edwards also recorded small amounts of bismuth and tungsten. Farther to the northeast the zones are compressed within single orebodies, as at Mount Cleveland. In the northwest, a deposit at Interview River and an apparently zoned province centred on Mount Balfour appear to be similar to the Trial Harbour/Mount Bischoff province, but are of little economic significance.

The distribution of gold in Tasmania was outlined by Carey (1953). However, he assigned only broad ages to the mineralization. Solomon (1965b) mentions only late (Kanimblan) gold; but some of the gold deposits in the Rocky Cape/Tyennan folded rocks may be linked with pre-Lachlan events. The gold deposits near Golconda lie close to small granitic intrusives, but there is no granite farther west at Lefroy and Beaconsfield; Tasmanian workers, however, regard all as falling in the one metallogenic province. A distinct linear belt of gold deposits trends from Mathinna north-northwest to Forester, but the nature of the controlling structures and the age of mineralization are unknown; a Kanimblan age might be conjectured.

The scheelite on King Island has been interpreted as pyrometasomatic replacement of carbonate rocks during the intrusion of an early Kanimblan granite (345 m.y.) into a Precambrian carbonate sequence (Knight & Nye, 1965).

Lachlan Transitional Domain

The rocks laid down as tectonic activity waned over the Lachlan Domain in the late Devonian and early Carboniferous were mainly sandstone and siltstone, but a zone of acid volcanics east of the Hill End Trough stretches from Cape Howe northwards to the Bathurst Granite.

The Kanimblan granites that followed have been variously estimated as Lower to Upper Carboniferous; they are confined to the Hill End Trough and the belt to its east in New South Wales, and appear to have introduced gold mineralization.

The post-orogenic sediments become progressively less deformed west of the Hill End Trough, and their equivalents west of the Cobar Trough have virtually the character of platform cover; they are only mildly deformed, but their thickness and the nature of the basement beneath them are unknown.

Volcanics and some sediments occur in ring structures and cauldrons in Victoria. Granites of late Devonian age may have introduced the gold and gold-antimony mineralization.

In Tasmania late granites introduced tin, tungsten, copper, and base metals.

North Queensland Blocks

The exact relationship of tectonic events represented in folded lower Palaeozoic rocks in northern Queensland to those affecting the Lachlan Belt proper is not known, although they appear to be continuous under the Trans-Australian Platform Cover.

Three distinct tectonic units together constitute the North Queensland Blocks —the Anakie High*, the Lolworth-Ravenswood Block, and the Broken River Embayment.

Very little is known about the ages of the folded rocks in either the Anakie High or the Lolworth-Ravenswood Block beyond metamorphic dates falling in the Ordovician. Most of the granitic intrusives (the Ravenswood Granodiorite Complex) in the Lolworth-Ravenswood Block also are thought to be Ordovician (Wyatt, Paine, Clark, Gregory, & Harding, 1971). It is possible that these two blocks are in part equivalents of the Kanmantoo Domain (Plumb, in prep.). The Broken River Embayment contains sediments ranging from Silurian to Middle Devonian in a fault-bounded trough trending southwest across the grain of the older Lolworth-Ravenswood Block.

Anakie High

The Anakie High consists of poorly exposed schist and acid volcanics intruded by Devonian granite. Mineralization is sparse. A copper deposit a few kilometres southwest of Clermont is localized in a zone of shearing in greenstone. The primary ore is disseminated chalcopyrite and pyrite—the zone of secondary enrichment yielded most of the ore won (Queensland Mines Dep., 1953b). An area of small gold deposits north of Clermont is in schistose rocks, but most of the yield was from workings in Permian, Tertiary, and Quaternary alluvia.

Lolworth-Ravenswood Block

The Lolworth-Ravenswood Block is a complex of metamorphic rocks and granite which crop out as two large and several small basement inliers in an area of about 150 kilometres square to the west of Townsville. The metamorphic rocks are mainly metasediments, with some metavolcanics southeast of Charters Towers. The granites which form part of the Block are probably mainly Ordovician, but some are Middle Devonian. A series of granite intrusives ranging from Carboniferous to

* Also, more recently and more precisely, known as the Anakie Inlier. Because 'Anakie High' is the term used on the Tectonic Map, it is used here.

Permian was introduced by igneous activity spreading out from adjacent younger mobile zones (Wyatt, Paine, Clark, Gregory, & Harding, 1971; Heidecker, 1972, unpubl.).

Along the edge of the coastal alluviated plain northwest of Townsville, small inliers of low-grade metamorphic rocks also probably belong in the lower Palaeozoic. They are too small to show on the map, but seem to indicate that basement of the North Queensland Blocks extends virtually to the coast near Townsville; so that the postulated extension of the Palmerville Fault along the coast appears to mark the junction between the younger Hodgkinson Belt and the North Queensland Blocks.

The Lolworth-Ravenswood Block has yielded a considerable amount of gold, mainly from three centres: Charters Towers, Ravenswood, and Cape River. The Ravenswood and Charters Towers mining centres lie within the Ravenswood Granodiorite Complex, but the age of mineralization is not known.

The mesothermal lodes at Charters Towers occupy two intersecting sets of faults; they consist of quartz lodes carrying pyrite, galena, and minor sphalerite (Blatchford, 1953). Charters Towers produced more than 6 million oz of gold, some silver, and a little lead; Ravenswood also, though principally a gold-mining centre, was a centre of silver and lead mining (see also Heidecker, 1972; Levingston, 1972).

At Ravenswood the intrusives that on field evidence were thought to have introduced the ore have been shown to be older than the ore-bearing rocks by isotopic age determination (Clarke, 1971). Since the ore-bearing rocks are Devonian, the mineralization is either Devonian or else postdates the North Queensland Domain.

The lodes at Liontown, south of Charters Towers, lie close to the intrusive contact of the Ravenswood Granodiorite Complex with older folded rocks. As at Charters Towers, the lodes yielded gold and silver as well as lead, but they were generally regarded as lead mines.

The lodes of the Cape River Goldfield in the western part of the Lolworth-Ravenswood Block appear to be related partly to the Ordovician and Devonian intrusions and partly to Permian intrusions of a later tectonic cycle. In the north, several small silver deposits are recorded, but their age is unknown. The small gold deposits north of Mingela postdate the folding of the transitional basin, in the early Carboniferous, but again their age is unknown.

Broken River Embayment

The Broken River Embayment is a partly concealed trough with a strongly faulted margin against the Georgetown Inlier to the northwest and a suspected but masked fault zone against the Lolworth-Ravenswood Block. The oldest exposed sediments are marine Silurian, and marine sedimentation continued until the mid-Devonian, when the axis of sedimentation shifted into the basins of the transitional North Queensland domains. Devonian granites intrude the Georgetown Inlier adjacent to the Embayment, and the Lolworth-Ravenswood Block to the southeast, but have no effect on the Embayment itself.

The mineralization associated with the Broken River Embayment may be divided into three groups. First, the large lateritic nickel deposit at Greenvale on the northwest margin has resulted from the weathering of ultrabasic rocks emplaced during Devonian folding movements; nickel and cobalt have been concentrated in the deeply weathered zone. The second group consists of two small antimony deposits, one in the sediments of the Broken River Embayment and the other in Middle Devonian sediments of the Burdekin Basin, suggesting that the mineralization is related to events in the younger Hodgkinson domain. Small tin and tungsten deposits, the third group, are an extension of similar mineralization introduced by transitional Hodgkinson granites.

Transitional North Queensland Domains

After the igneous events in mid and possibly early Devonian, acid volcanics were laid down in either side of the Anakie High; they may be traced as far as the coast near Sarina, where they become andesitic, and into the Connors Arch; but their major exposure today is west of the Anakie High, where they form the basal units of the Drummond Basin, a non-marine basin of late Devonian to Carboniferous age. To the north of the Lolworth-Ravenswood Block, sedimentation in the Burdekin Basin began in the mid-Devonian and spread across the folded Broken River Embayment and onto the Block itself; the basin was folded in the mid-Carboniferous. Unlike most transitional basins. which are characteristically non-marine, the Burdekin Basin is partly marine. It contains only minor mineralization, probably related to much later events.

The silver, gold, and copper deposits of Selheim and Rutherfords Table lie in a zone rimming a late Devonian to Carboniferous intrusive about 120 km south-east of Charters Towers.

The gold deposits at Mount Coolon are in Devonian to Carboniferous andesite, associated with pyrite in a siliceous lode that is, according to Malone et al. (1964) 'apparently an end-product of silicification of the andesite'. Coldham (1953) had earlier ascribed an early Permian age to the andesite, at the base of the Bowen Basin succession (see p. 63).

Tin mineralization, and a little gold and silver, in the Townsville 1:250 000 Sheet area, although contained in host rocks of the North Queensland domain, were most probably introduced by tectonic activity in younger overlapping domains (Levingston, 1971).

Hodgkinson Belt and Transitional Domain

The Hodgkinson Belt developed northeast and east of the Georgetown Block as a sedimentary basin in the Silurian with shelf-type mixed clastics and limestones deposited along the margin. The main downwarp is filled by a monotonously alternating sequence of arenite and shale with sporadic beds of chert, volcanics, and limestone, whose thickness is not known. Fossils from the limestone indicate a Middle Devonian age and plant fossils from apparently high in the sequence a late Devonian age, but most of the sequence cannot be dated (de Keyser & Lucas, 1968). The whole sequence is strongly folded and in the east metamorphosed, the highest-grade gneisses being exposed at the coast and on coastal islands (de Keyser, 1965). The age of deformation likewise is not precisely known. A small downfaulted block of sediments unconformable on the folded Hodgkinson sequence contains a Middle Carboniferous flora, and is underlain by two sequences (part of the transitional development), also unconformable on the Hodgkinson sequence; so the folding presumably took place in the early Carboniferous. No event of comparable age is recorded in nearby tectonic units—isotopic dates in the Georgetown

Block are partly reset by a Devonian event, which may correspond to the inception of geosynclinal sedimentation, but no early Carboniferous event has had any effect in the Georgetown Block, and sedimentation in the Burdekin Basin shows no major break during the early Carboniferous. The junction between the Hodgkinson and Georgetown domains is the Palmerville Fault, which, if it extends southward as postulated by de Keyser (1963), would also separate the Hodgkinson from the North Queensland Blocks.

Late in the Carboniferous, acid volcanism broke out along part of the Palmerville Fault, accompanied by several phases of acid intrusion. Both spread widely into the Georgetown Block and the postulated southward extension of the fault is marked by similar acid volcanism, although the individual intrusions are smaller in the south. These igneous events have been classified as transitional Hodgkinson events. Two distinct suites of cratonic granite, one of early Permian and the other of late Permian age, correlate with movements in the New England/Yarrol Belt to the south.

The mineralization within the Hodgkinson Belt proper has not yet been studied in detail; de Keyser & Lucas (op. cit.) offer some comments on regional structural and stratigraphic controls in their account of the geology of the Hodgkinson Basin. The pattern of mineralization introduced by the transitional Hodgkinson granites has been examined in some detail by de Keyser & Wolff (1964) and Blake (1972).

The only mineralization that can be confidently assigned to the pre-orogenic phases is a little manganese which was mined south of Cairns (Morton, 1943). The Cairns district contains manganiferous metasediments, but no other deposits are known.

The gold, antimony, and gold-antimony mineralization which lies in a zone sub-parallel to the Palmerville Fault but some 30 km to the east may be syntectonic. However, this zone is also west of the early Permian granites and may have been introduced during their intrusion. No gold lodes occur close to granite and the richest producers were far removed from outcrops of granite. The Palmer Goldfield in the north of this zone was a major producer, but most of the yield was from alluvial sources; the Palmer River spread the gold for more than 60 km downstream across the Yambo Inlier. Lodes were generally difficult to mine and the rewards were poor—the best producers were in the Hodgkinson Goldfield at the southern end of the zone, where some antimony was also mined. The central parts of the zone have yielded mostly antimony.

Gold-antimony deposits to the north of Cooktown may be syntectonic, or may have been introduced by late Permian intrusives.

The transitional phase granites are confined to the margin of the Belt, but extend into the pre-existing Georgetown Block and into Cape York as far north as the Cape York/Oriomo Ridge. Southward, granites of this phase extend as far as the Auburn Arch. The best studied region is the Mungana-Herberton zone (de Keyser & Wolff, 1964; Blake, 1972). Here the close association between a single phase of the high-level granites and mineralization can be demonstrated. De Keyser & Wolff consider all the mineralization in the Mungana-Almaden district to be high-temperature, either hypothermal or pneumatolytic; Blake considers the mineralization in the Herberton/Mount Garnet district to be partly mesothermal, but mostly hypothermal. Mineralization includes tungsten, molybdenum, tin, copper, lead, fluorite, and bismuth. Zoning is sometimes compressed (Wolfram

Camp lodes contain tungsten, molybdenum, and bismuth) or more broadly spread as in the Herberton/Mount Garnet district, where tungsten, tin, and copper occur in separate deposits.

Intrusions of the Hodgkinson transitional phase within the Georgetown Inlier have introduced tungsten, tin, and copper deposits, including the copper deposits at Einasleigh (p. 45) (Queensland Mines Dep., 1953a; Branch, 1966). Deposits in Cape York at Bowden (tungsten), Cape York (tin), and Banks Island (tungsten) also are contained in acid igneous rocks. The Cape York/Oriomo Ridge may contain zoned tungsten-tin-copper mineralization, but the incomplete exposure limits detailed studies (Wilmott, Whitaker, Palfreyman, & Trail, in press).

The Kangaroo Hills mining district, northwest of Townsville, contains tungsten, molybdenum, tin, and copper deposits introduced by high-level granites of Hodgkinson transitional age along the southeasterly extension of the Palmerville Fault. Some similar deposits occur within the Broken River Embayment (de Keyser, Fardon, & Cuttler, 1964).

The granites of the Hodgkinson transitional phase which occur in the Urannah Arch and Auburn Arch are virtually devoid of associated mineralization; but they are very deep-seated: high-level intrusions either were absent or have since been eroded.

The gold province extending south from west of Cairns corresponds both to the zone of biotite-grade metamorphism (de Keyser & Lucas, 1968) and to the area of intrusion of the late Permian Mareeba Granite. Of the small goldfields making up the province, only the Jordan River Goldfield is actually situated in granite, but the others are not far removed from granite.

The tin and wolfram deposits south of Cooktown and at Noble Island correlate with the late Permian granites which intrude the area.

New England/Yarrol Belt

The New England/Yarrol Belt is a region best considered for the present as consisting of subunits each of which has a somewhat different history of development. Some boundaries between them are clearcut, others are so ill defined that they may merge into each other.

Northwards from the Gogango Overthrust Zone the belt passes into platform cover overlying transitional phase volcanics of the older North Queensland Blocks; and the late-phase acid volcanism and intrusions from the Hodgkinson Belt extend southwards so that there is a complex area of overlap. Most of the mineral deposits of the Gogango Overthrust Zone are related to later events. Small gold deposits at Grasstree and Yatton may have been introduced during Permian block faulting, but may equally well have been introduced during the earlier North Queensland Transitional Phase. Cratonic granites of Cretaceous age occur in this area also; they have introduced gold lodes west of Mackay.

South and east of the Gogango Overthrust Zone the New England/Yarrol Belt may be split into two main divisions, the Yarrol/Tamworth Trough system and a more complex eastern region.

The Yarrol/Tamworth Trough system, known as the Yarrol Basin in Queensland and the Tamworth Trough in New South Wales, is separated from the eastern unit by a series of thrust faults, with some serpentinites. The oldest sediments in the Tamworth Trough are Ordovician; the main period of sedimentation was from late Devonian to early Permian. Scheibner (1972b) interprets the Tamworth Trough as a Devonian-Carboniferous marginal sea over an older frontal arc region. The Tamworth Trough contains no known metal deposits. Silurian marine sediments in the Mount Holly Block south of Rockhampton are the oldest sediments recognized as part of the Yarrol Basin succession, but the main period of sedimentation in the Yarrol Basin was from mid-Devonian to early Permian. The middle to late Devonian sedimentation was characterized by acid to intermediate volcanics which appear to have affinities with the transitional phase of the North Queensland Blocks. At Mount Morgan a granitic stock intrudes comagmatic middle Devonian volcanics; and at the same time or immediately after, hypogene gold-copper-pyrite-quartz mineralization was introduced into tuffs and volcanics around its margin (Staff, Mount Morgan Ltd, 1965). The remainder of the Yarrol Basin carries only minor mineralization, generally of post-orogenic origin.

The Bowen-Surat-Sydney Basin is a downwarp of Trans-Australian Platform Cover which began to form and fill in the earliest Permian, at about the same time as the earliest phase of orogenesis in the New England/Yarrol domain. The basin

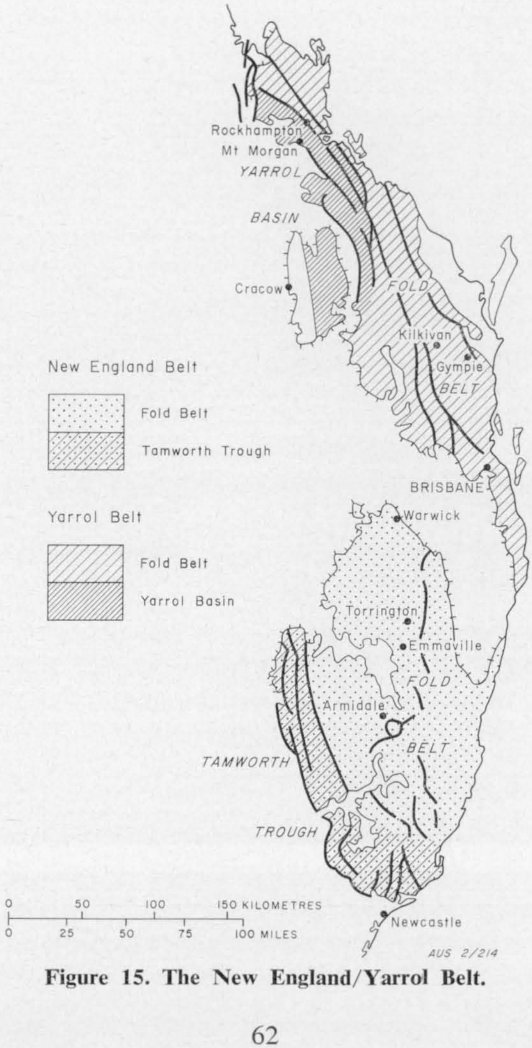

Figure 15. The New England/Yarrol Belt.

is asymmetrical; the deepest and most folded parts are close to the mobile belt, whereas the edge lapping onto the Lachlan and North Queensland domains is thin and undeformed. The silver-gold deposits at Cracow (Brooks, 1965b) are in early Permian andesite near the base of the Bowen Basin succession.

Within the main New England/Yarrol domain the most intense phase of deformation ranges in age from latest Carboniferous in parts of New England to Triassic in the Gympie district, but in general is Permian. Syntectonic granites are rare.

The eastern complex unit may be best subdivided into two geographically distinct subunits separated by the east-west transgression of Trans-Australian Platform Cover. They have been treated separately in previous literature because of their geographical separation, and as they have slightly different tectonic histories they are also treated separately here.

The Queensland part of the fold belt east of the Yarrol Basin has been referred to in previous literature (e.g. Hill & Denmead, 1960) as the 'South Coastal Structural High'—a term which applies to the behaviour of the unit in the late Mesozoic and Cainozoic. Both Kirkegaard et al. (1970) and Ellis (1968) avoid use of the term and describe the deformed Palaeozoic and early Mesozoic in terms of fault-bounded blocks: the area is broken into elongate blocks by a series of north and north-northwest trending faults with some east-west cross faults. Broadly the rocks in this belt may be subdivided into highly deformed metamorphics and a mainly Permian succession slightly metamorphosed in the Triassic (Ellis, 1968; Runnegar & Ferguson, 1969).

Deposition appears to have started during the Silurian. A thick monotonous quartzose sequence east and northeast of Rockhampton is regarded as lower Palaeozoic (Kirkegaard et al., 1970), and repeatedly deformed schists near Brisbane are traditionally referred to the lower Palaeozoic, but without indisputable fossil evidence in either case. The Maryborough 1:250 000 geological map shows lower Palaeozoic sediments and volcanics, but in the accompanying text Ellis (1968) refers to them as undifferentiated Palaeozoic, pointing out that the only indication of their age is a possible unconformity with a Permian formation. It is possible that these sequences represent, in terms of plate tectonics, melange zones that developed during the late Devonian or Carboniferous. They contain a little manganese, which has been mined at Mount Miller near Gladstone (Kirkegaard et al., 1970) and in the Upper Mary Valley (Brooks, 1965c).

An ultrabasic belt stretching from east of Rockhampton northwest towards Marlborough separates the supposed lower Palaeozoic rocks from a Permian trough filled with volcanics. The serpentinite has been interpreted by Murray (1969) as Devonian intrusives remobilized in the Permian. Chromite has been obtained from small lenticular bodies (Ridgway, 1953). Deep weathering has produced magnesite from the ultrabasics, but individual deposits are small (Ridgway, 1941; Brooks, 1964). Nickeliferous laterite has developed over the ultrabasics south of Marlborough. Gold deposits in the serpentinite may be Permian or introduced by younger granite intrusions to the south.

The small ultrabasic bodies at Kilkivan, north-northwest of Brisbane, are at the focus of varied mineralization. A number of very small mercury-bearing lenses and stockworks occur in a broad north-northwest belt over a distance of about 20 km. The total mercury production has been less than 10 tons (Queensland

Mines Dep., 1953e). The Kilkivan district also contains small copper and gold deposits with some arsenic, bismuth, and cobalt, probably also introduced by the same intrusions.

Apart from the deposits mentioned above, most of the mineralization appears to have been introduced during the transitional phase in the Triassic.

The copper-gold ores at Mount Chalmers, northeast of Rockhampton, follow local schistosity in Permian volcanics and sediments (Fisher & Owen, 1952). If, as is probable, they were introduced by late Permian or Triassic quartz porphyry, they may be part of the widespread Triassic mineralization farther south; but it is also possible that the mineralizing solutions were mobilized by the intrusives from within the Permian andesitic sequence.

Glassford Creek copper lodes occur as skarns in limestone within the Yarrol Basin close to a Triassic granite (Queensland Mines Dep., 1953c). Small gold deposits westward also lie either close to or within Triassic granites intruding Yarrol Basin sediments.

Near Mount Perry, both east and west of a major north-northwest fault, copper, copper-gold, copper-molybdenum, and gold-arsenic lodes have been mined (Ellis, op. cit.). Although the host rocks west of the fault are early late Permian granite, it seems possible that all these deposits may have been introduced by Triassic granite, A small rutile deposit east of Mount Perry may be metamorphic in origin. In the Biggenden area, southeast of Mount Perry, gold, gold-bismuth, copper, and magnetite lodes lie close to the margin of a Triassic granite. A zinc-silver lode about 30 km south of Biggenden lies close to a zone of faulting; it also appears to have been introduced by Triassic granite nearby.

Although similar small deposits of gold, lead, copper, arsenic, and silver southwards towards Brisbane can also be related to Triassic granites, the largest concentration of metal in the region, the gold lodes at Gympie, does not fit the pattern. The Gympie lodes lie in a series of Lower Permian to Lower Triassic marine sediments and andesitic volcanics which were deformed in the early Triassic (Runnegar & Ferguson, op. cit.). Granite intrudes the sequence, but not within the area of mineralization. The lodes lie in quartz reefs, striking with the country rocks and dipping at right angles to them. Gold content increases markedly where the reefs intersect carbonaceous shale within the sequence—the productive zone is thus limited to a small section of the total sequence. With the gold is some pyrite and occasionally a little lead, zinc, copper, silver, and tellurium, but the ore was evidently all free-milling (Queensland Mines Dep., 1953d).

The New England section of the New England/Yarrol Fold Belt extends south from Warwick in Queensland into northeastern New South Wales. Along its western margin it is separated from the Tamworth Trough by a major thrust fault which passes into a system of arcuate faults in the southeast; characteristically the faults are zones of serpentinite intrusion. Immediately east of the fault system is a narrow zone with deposits of chromite, manganese, copper, and magnesite extending from Bingara in the north to Walcha in the southeast. These deposits are regionally zoned: the chromite occurs within the serpentinite of the fault zone and the manganese generally lies closer to the fault than the copper deposits.

In the northeast (northwest of Grafton), serpentinite following a fault also contains lenses of chromite (Raggatt, 1925). In this region, however, there appears to be a halo of mercury and antimony mineralization somewhat resembling the mineralization in the Kilkivan region in southern Queensland. To the southeast, near Port Macquarie, a small lateritic nickel-cobalt-manganese body has formed on serpentinized ultrabasic rocks (Jaquet, 1898; Harrison, 1952).

The whole New England section east of the major thrust faults is complex. The earliest known sediments are Ordovician (Chesnut, Offenberg, & Blackshaw, in prep.), and small inliers of other lower Palaeozoic rocks also occur; but most of the area of folded rocks is late Devonian or younger. In the northwest, Permian rocks rest unconformably on markedly more deformed older rocks (Olgers & Flood, in press). Eastward on the coast, strongly deformed sedimentary rocks have been shown to be Permian (Leitch, Neilson, & Hobson, in press), so that the major phase of deformation appears to be progressively younger eastward.

The transitional phase is represented by two small areas of Triassic sediments in the southeast in the Lorne Basin, the all-but-concealed Triassic Ipswich Basin to the north and east, and extensive granite intrusives with coeval acid volcanic spreads.

The most important deposits of this section are the tungsten-molybdenum-tin-base metal-arsenic suite introduced by the final very acid phases of the Triassic transitional-phase granites (Robertson & Flood *in* Olgers & Flood, in press; Saint-Smith, 1914). Tin was mined mainly from alluvium and deep leads. Robertson (Robertson & Flood, op. cit.) notes that the lodes within the Queensland portion are small. Carne (1911) lists numerous lode mines in the Emmaville-Tingha district, but again all were small-scale operations, and it appears that the same was also true of the Wilsons Downfall district east of Stanthorpe.

Although molybdenum is widespread over the same region as the tin deposits, most production came from a small district at Kingsgate, where numerous pipes lie near the contact between metasediments and a coarse-grained acid granite (Andrews, 1906, 1916).

Tungsten (wolframite) is restricted to the central part of the area of acid intrusives. The main centre is at Torrington, where ore was obtained from many quartz-topaz lodes close to contacts between country rock and granite (Carne, 1912). The lodes carried a wide range of metals in the gangue, including bismuth, which was present in recoverable amounts in some mines.

Peripheral to the tin-bearing region is a zone of complex base-metal and arsenic mineralization in low-grade metasediments, presumably also introduced by the same granites. Most deposits were small, and contained several metals. The ores from the Conrad mine at Howell near Inverell were so complex as to defy economic metallurgical recovery of the metals in the ores (Carne, 1908; Robertson & Flood, in press).

The New England Fold Belt contains two gold provinces. One lies near Warwick in southern Queensland, where the lodes are scattered and small (Robertson *in* Robertson & Flood, in press); the other is in the Armidale district of New South Wales, where most mines were also small, and many fields were virtually alluvial only. Hillgrove was an important gold-bearing centre; the numerous lodes were originally worked for gold but later for antimony and finally for tungsten (scheelite); the gold and gold-antimony lodes are in early Permian metasediments and the scheelite lodes in intrusive late Permian granites. According to Harrison (1953), the mineralization was introduced in three phases along the same main lines of lode, with some earth movements between phases: gold and scheelite are mutually exclusive (Voisey, 1965).

Antimony lodes occur in the centre and east of the New England Fold Belt. No obvious factor governs their distribution.

The Drake district, east of Stanthorpe (Andrews, 1908), is a gold and copper mining area with numerous veins and lodes in silicified Permian volcanics; they may be part of the zoned province to the west, but appear to be part of a separate phase introduced during the volcanism.

Transitional New England/Yarrol Domain

The essential features of the Triassic transitional phase have already been described (p. 64). Sediments were deposited in the Lorne and Ipswich Basins, the Esk Rift, and, as thin spreads, south from Rockhampton. Acid volcanism was widespread and andesitic volcanics occur in the Esk Rift. Granites intrude the whole belt and were responsible for introducing much of the mineralization.

Kubor Block

The Kubor Block in New Guinea is an uplifted sliver of basement on the active margin between the continental crust of Australia and the mobile region of New Guinea. It consists of Permian and earliest Triassic sediments intruded by an early Triassic granite. It contains no known mineral deposits.

A small outcrop of granitic basement has been found in the Western Highlands exposed in a river gorge cutting through the Trans-Australian Platform Cover. A similar age to the granites in the Kubor Block is inferred.

TRANS-AUSTRALIAN PLATFORM COVER

The Trans-Australian Platform Cover began to develop during the early Permian and even, in small areas, in the late Carboniferous; sedimentation spread during the Triassic and reached its maximum in the Cretaceous, after which deposition has continued in the pericontinental area and the southern parts of New Guinea.

Although the cover contains most of Australia's coal reserves, mainly in the Bowen, Surat, and Sydney Basins, it contains little metallic mineralization.

In central Queensland the Dawsonvale iron deposit occurs in Jurassic sediments; it is oolitic, with massive beds ranging up to 3 m thick and a grade of 33 to 44 percent Fe (Urquhart, 1965).

During the Cretaceous marine incursion across northern Australia small manganese deposits formed through the northern part of the Northern Territory, and a large deposit on Groote Eylandt. The Groote Eylandt deposit consists of pisolitic beds of pyrolusite and cryptomelane which are thought to have been deposited in a restricted shallow marine basin during the Albian (Smith & Gebert, 1970).

Uranium mineralization has recently been reported from the Lake Frome Embayment—a Jurassic to Tertiary onlap of the Trans-Australian Platform Cover onto the uraniferous Willyama and Mount Painter Blocks. The uranium occurs in non-marine Tertiary sediments.

At Scott River, in the south of the Perth Basin, lateritization of a Tertiary ferruginous sandstone has produced low-grade iron ore (Burns & Carruthers, 1965).

Low-grade phosphatic sediments north of Perth contain too much iron and alumina for economic beneficiation. They are contained in two beds in ferruginous sandstone, glauconitic sandstone, and chalk of Cretaceous age (Matheson, 1944b).

In northeastern Australia, plugs and bosses of granite were intruded during the Cretaceous. They introduced small gold lodes west of Mackay, and copper lodes in the Bowen Basin. Acid volcanics, mostly exposed on offshore islands, were deposited at this time.

Small gold lodes occur in Cretaceous peralkaline plugs at Mount Dromedary, south of Sydney, and at Cygnet, south of Hobart.

CAINOZOIC IN THE AUSTRALIAN CRATON

From the late Cretaceous onwards the Australian craton has been extremely stable; water-laid sediments have been confined to the continental margin except for two intracratonic basins, and small local downwarps on the exposed craton.

The most extensive area of Cainozoic sedimentation on the currently exposed continent is the Murray Basin, which contains both marine and non-marine sediments. Sedimentation is still continuing in the intracratonic Carpentaria Basin. The large pericontinental basins include the Gippsland, Bass, Otway, and Bowes Basins, all of which are being explored for hydrocarbons.

The small downwarps include the Lake Eyre Basin, the surface of which is below sea level at present and which is the site of an impermanent saline lake, and numerous small basins in the Northern Territory, important as groundwater reservoirs and as possible loci of uranium deposition. In Western Australia there are numerous calcrete-filled river channels in the Yilgarn Block which are also potentially uraniferous. Salt lakes on the Yilgarn Block are the result of drainage reversals coupled with reduced rainfall. The limonitic ores of the Hamersley region are of Tertiary age; they were deposited in stream channels and swamps draining the iron-bearing Proterozoic rocks of the area.

Raised beaches in Western Australia contain heavy-mineral-bearing sands. Lake McLeod near the Western Australian coastline contains potassium-bearing evaporites which are considered to be an economic source of potassium.

During the Quaternary the Great Barrier Reef developed and sedimentation continued in the offshore basins. At various times during the Pliocene and Holocene both the Bass Rise and Cape York/Oriomo Ridge have been exposed above sea level, although at present both are a few metres below sea level. In some areas round the continental margin high sand dunes have built up, particularly along the southern Queensland coast and on Eyre Peninsula in South Australia. The interior of the continent has passed through phases of climate both more and less arid than the present. During the more arid times sand dunes built up and wind spread broad sand drifts across most of northern Australia. Most of these dunes are now stable; only small areas are mobile in the Simpson, Great Sandy, and Great Victoria Deserts.

On the eastern seaboard, the beach deposits and dunes contain appreciable quantities of heavy minerals, including zircon, monazite, and rutile, and less economically significant ilmenite, leucoxene, and garnet. The heavy minerals may have originated in the New England Batholith and in Tertiary basalts, but have been reworked through Mesozoic and Cainozoic sediments before being concentrated in beach sands. Fossil beaches exist above, at, and below present sea level. The heavy minerals have been concentrated by both wave action and longshore drift (Gardner, 1955; Whitworth, 1956).

In Western Australia there are deposits along the southern and western seaboard, the best being in the Bunbury region, in several fossil beaches above present sea level. Some of the deposits along the southern coast of Western Australia are large considered against the world supply of zircon, but are rendered uneconomic by their grade and inaccessibility (Low, 1960). Beach sands are also known to exist north of Perth, although their relationship to the present sea level and coastline is still being assessed. Heavy-mineral sands in the north of the Yilgarn Block contain vanadium-bearing minerals.

Virtually all the continent has been deeply weathered, in several episodes. The oldest probably began in the Mesozoic. The main phase in the Northern Territory is early Tertiary, although a later Tertiary land surface with deep weathering exists in the north (Hays, 1967). In Cape York Peninsula the main phase is early Tertiary (H. F. Doutch, pers. comm.).

Bauxite occurs in north Australia, at Weipa, at Gove, and in the Mitchell Plateau, in vast blanket deposits. Deep weathering during periods of rainfall higher than at present has produced chemical layering of the regolith; the zone has since been eroded and the bauxite redistributed, with pelletic and nodular concretions. Grubb (1970) postulates extensive reworking, particularly during partial submergence, of the Mitchell Plateau and to a lesser degree the Gove deposits. The deposits at Weipa generally contain 1 to 5 m of mineable bauxite under about 1 m of overburden; they extend laterally for tens of kilometres (Evans, 1965). Similar deposits also occur in the Darling Escarpment of Western Australia, both east of the Darling Fault, where they have developed over the Yilgarn Block, and to the west over sediments of the Perth Basin. Small deposits of bauxite of lateritic origin occur throughout eastern Australia, usually over volcanic rocks.

Lateritic nickel deposits have developed over nickeliferous ultrabasic rocks at Greenvale (west of Townsville), at Marlborough (northwest of Rockhampton), at Wingelinna in the Blackstone Ranges (in the Musgrave Block), and in the Yilgarn Block north of Kalgoorlie.

Residual manganese deposits developed from manganiferous sediments in the Adelaidean Bangemall Basin of Western Australia.

Magnesite has developed in the Yilgarn Block and elsewhere from the deep weathering of magnesium-rich rocks (sedimentary magnesite also exists in Australia).

The effect of deep weathering on mining in northern Australia should not be underestimated. Supergene enrichment due to deep weathering has considerably redistributed metals, particularly copper, silver, and zinc in base-metal deposits. Many small deposits in the Mount Isa, Pine Creek, and Tennant Creek Blocks could not have been economically mined without the enrichment of the upper 30 to 100 m. Many pyrite-gold lodes throughout eastern and northern Australia have proved mineable only because the gold was freed from the pyritic ore during deep weathering. Many mines were abandoned at the water table, when either grade fell suddenly or the ore became metallurgically difficult to work.

Widespread flood basalts, mainly alkaline, occur along the eastern margin of the craton, corresponding broadly to the East Australian Orogenic Province. Their age ranges from Eocene to Holocene, with one culmination in the Oligocene and a second in the Pliocene. The area of basalt corresponds broadly to the

Kosciusko upwarp, a late Tertiary uplift of the eastern seaboard of Australia by about 100 m.

Erosion of tin, gold, and other heavy-mineral-bearing deposits has produced important placer deposits throughout much of eastern Australia and in the Yilgarn and Pilbara Shields of Western Australia as well as smaller deposits elsewhere. These deep placers may represent concentrations many times that in the original lodes. Some tracts of alluvium have been large enough for dredging operations, which are still continuing in north Queensland and central western New South Wales on tin-bearing gravels. Study of both present and past landforms is often necessary to assess these deep leads. Some have been trapped beneath basalt flows so that the fossil stream patterns bear very little relation to present-day topography. Such basalt-trapped deep leads proved important in the tin-bearing Atherton Tableland in north Queensland, regions of northern New South Wales, the gold-mining districts of Victoria and southern New South Wales, and Tasmania.

NEW GUINEA OROGENIC PROVINCE*

Continental crust of the Australian craton extends northward from Australia under the island of New Guinea beneath a wedge of Trans-Australian Platform Cover to meet the mobile zone of northern New Guinea and the active island arc systems to the north and northeast along the mountainous backbone of the island.

The mobile region may be subdivided into two main units. The mountains and some of the islands contain rocks folded and metamorphosed in the late Cretaceous and early Tertiary, which constitute the Highlands Fold Belt. The second unit consists of rocks deposited since the early Miocene which have the characteristics of 'geosynclinal' sedimentation and 'island arc' environment but are relatively undeformed except for syndepositional folding and block faulting. Two subunits may be recognized within this unit: the Aure Trough between the craton edge and the geanticlinal Highlands, and the North New Guinea Mobile Belts, which include the northern margin of New Guinea, New Britain, and the islands of the Solomons, Bougainville, New Ireland, and Manus.

HIGHLANDS FOLD BELT

The boundary between the cratonic margin and the Highlands Fold Belt in the west is a major fault trending east-southeast, the Lagaip Fault, across which there is an abrupt change in type and thickness of sediments. Traced eastward this fault passes under the shield volcanic complex of Mount Hagen into the upwarped craton basement, the Kubor Block; from here the junction between craton and mobile region swings east-southeast beneath the Aure Trough and thence to the western margin of the Coral Sea Basin.

Western Highlands

North of the Lagaip Fault the sequence consists of Triassic and Jurassic marine basic volcanic rocks and Triassic to Eocene shale, turbidite, and limestone. There was apparently a hiatus in the Oligocene, but basic volcanics and reworked sediments were laid down in the early Miocene. At the end of the lower Miocene intense movements resulted in the emplacement of andesitic plugs, diorite plutons, and ultramafic bodies, and regional metamorphism to greenschist and locally eclo-

* This commentary deals only with Papua New Guinea. The units extend beyond the political boundary, as is shown on the Tectonic Map of Australia and New Guinea.

gite and blueschist grade. Volcanic rocks of island-arc style pass upward into upper Miocene clastic sediments (Dow, Smit, Bain, & Ryburn, 1972). The folded zone disappears northward beneath the Sepik plain and is cut off eastward by the Ramu-Markham Fault.

The larger valleys contain small alluvial gold and platinum prospects; the platinum comes from the ultramafic rocks, and gold from very low-grade source lodes in porphyry stocks and basic to ultrabasic intrusives. The area near Porgera has yielded about 10 000 oz of gold and some silver from occurrences within a few kilometres of the village. Miocene gabbro and Pliocene andesites intrude this region.

The main economic interest in the area is copper mineralization. Two prospects are under study, and a third is reputed to exist in West Irian. The earlier discovery was the Frieda Prospect, in which disseminated copper sulphides and pyrite are associated with hydrothermally altered stocks and dykes of andesite porphyry (Dow et al., op. cit.). The other is the Ok Tedi Prospect, a porphyry stock about 1 m.y. old, intruded into the mobile edge of the craton south of the Lagaip Fault, and containing disseminated copper sulphides.

The ultrabasic rocks might be expected to produce nickeliferous laterites under the weathering conditions of the region, but none of sufficiently high grade or size for mining has yet been recognized; nor have any chromite deposits been found, despite the favourable geological setting. Towards the east, in the mineralized area surrounding Kainantu, small deposits of gold, copper, and lead-zinc are known.

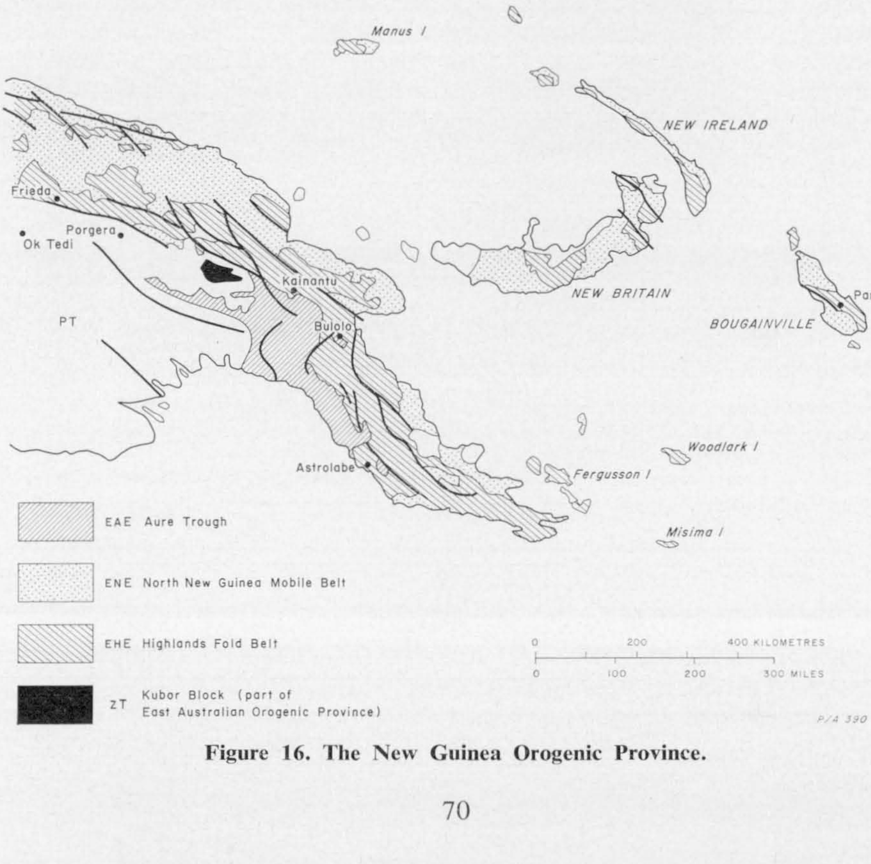

Figure 16. The New Guinea Orogenic Province.

Eastern Papua

Along strike the Highlands Belt swings more southerly and passes into the complex belts of Eastern Papua and the Louisiade Archipelago. Two major zones of sialic material are separated by basic rocks, apparently emplaced by a fault that has thrust a slice of crust and mantle westwards over an older geosynclinal pile, which was consequently metamorphosed. The region may be described as a series of partly submerged geanticlinal ridges, containing rocks of geosynclinal facies metamorphosed in or about middle Miocene time.

Along the western margin of the Papuan Ultramafic Belt a slice of ocean floor is thought to have been thrust over continental crust at the Owen Stanley Fault (Davies, 1971).

A zone of metamorphosed Cretaceous mudstone lies immediately west of the fault and is flanked to the west and south by metamorphosed Eocene sediments and Oligocene granodiorite. It contains three important areas of mineral deposits. At Riga, southeast of Port Moresby, manganese has been mined from rocks interpreted as deep-sea oozes. The deposits themselves are small, and have been remobilized during folding and later enriched by weathering. Northeast of Port Moresby, copper, gold, silver, and zinc have been mined from three larger and many small lodes within the Astrolabe district. All the larger orebodies occur in Eocene black shale and grey siltstone, and are conformable. Gabbro occurs nearby, but is thought to postdate the ore. The evidence favours a syngenetic origin (Yates & de Ferranti, 1967). The large gold production of the Wau and Bulolo Valleys has mainly been obtained from alluvial sources. Small lodes are associated with post-deformational Pliocene andesitic porphyry. Gold, in less promising lodes, also occurs in this area in older intrusives, which have also contributed to the alluvial deposits. Small gold placer deposits occur at Yodda near Kokoda within the metamorphic belt.

The Papuan Ultramafic Belt is thought to be oceanic crust and mantle of Cretaceous age thrust over sialic rocks during the Miocene and uplifted by isostasy into its present position (Davies, op. cit.). It shows little evidence of deformation and is devoid of major mineralization. Nickeliferous laterites of mineable grade that might be expected to form under local climatic conditions have been sought without success. Streams in the area carry small quantities of detrital gold and platinum, but no payable lodes are known.

A series of belts of partly submerged folded sialic rocks lies east of the Papuan Ultramafic Belt. One belt takes in the southeast of Papua, the D'Entrecasteaux Islands, and the chain of islands southeast of New Guinea, including the Louisiade Archipelago. It has a basement of metamorphics, reaching amphibolite grade locally on Misima Island; and it contains five active volcanoes and the active downwarp of the Cape Vogel Basin. Alluvial gold and platinum have been obtained from streams in the Milne Bay area, but no economic lodes are known. Traces of copper are also recorded, near the intrusive contact between gabbro and metavolcanics. The most important deposit is on Misima Island, where gold-bearing lodes have been mined in the past. One is now being reassessed; it is reputed to contain large tonnages of pyritic ore carrying gold and silver and is also reported as containing some copper and a lead-zinc body. The lodes are epithermal and lie close to the contact between greenschist metamorphics and intrusive andesitic porphyry, which is thought to be responsible for the mineralization (de Keyser, 1961).

The second belt takes in the Trobriand Islands and Woodlark Island; it appears to have a pre-middle Miocene core with a veneer of young sediments. Woodlark Island consists of volcanic detritus, lavas, and limestones intruded by dolerite and by granite bodies. Gold-bearing lodes on Woodlark Island occur in volcanics and in the intrusive granites within shear zones. They also contain sphalerite, galena, pyrite, chalcopyrite, quartz, and calcite. There are some pyritic beds within the volcanic and sedimentary pile, and iron-bearing skarns and a little manganese (Trail, 1967).

Basic References

Much of the information summarized above is taken from Thompson & Fisher (1967) and Davies & Smith (1970, unpubl.), which are themselves reviews partly based on unpublished material.

North New Guinea Mobile Belts

The area shown as the North New Guinea Mobile Belts consists of two active island arcs, the North New Guinea/New Britain Arc and the Solomon-Manus Arc along the Pacific Ocean margin.

North New Guinea/New Britain Arc

The North New Guinea/New Britain Arc includes the Torricelli Mountains, beneath which an active subduction zone dips southward, the Adelbert Mountains north of the Ramu-Markham Fault, the string of active volcanoes from north of Wewak (offshore) to the northern edge of New Britain, and the island of New Britain west of the Gazelle Peninsula. A subduction zone dips north beneath New Britain from the New Britain trench system. The only mineral deposit of economic interest has been the alluvial gold taken from the southern fall of the Torricelli Mountains north of Ambunti. Chromite beach sands exist along the northern coastline. Transient sulphur deposits form on the flanks of the volcanoes, but are not mined. The climatic conditions are ideal for the formation of bauxite, but no workable deposit has yet been located. Small showings of copper, lead, and zinc in New Britain are currently under investigation.

Solomon-Manus Arc

The Solomon-Manus Arc takes in Bougainville, New Ireland, Manus, and the Gazelle Peninsula of New Britain within Papua New Guinea. It is an active volcanic zone with trench and subduction systems. The exposed islands consist of Tertiary volcanic rocks and limestone with small late Tertiary to early Quaternary intermediate to acid intrusives (Blake & Miezitis, 1967). The zone appears to be a favoured site of porphyry copper deposits, of which the best known is the very large low-grade copper-gold sulphide orebody at Panguna on Bougainville Island, which is contained within a stock of quartz diorite and granodiorite intruded into andesite. The richest concentration of metals rims a granodiorite stock and a leucocratic quartz diorite within the intrusion which is dated at about 5 m.y. (MacNamara, 1968; Knight, Fraser, & Baumer, 1972). Other porphyry copper deposits may exist in the British Solomon Islands Protectorate (Thompson, 1972).

Again it may be said that the combination of rock type and climate is suited to the development of bauxite. One small occurrence on Manus Island has resulted from the weathering of a dacite body (Owen, 1954); no others have yet been located. Small copper showings are at present under investigation on Manus Island.

Aure Trough

The Aure Trough lies at the margin of the Australian Craton between the down-hinged margin of the Australian continental crust and the ridge of the Highlands Fold Belt. It began as a downwarp in the Miocene. The fill is mainly turbidites, partly derived from contemporary andesitic volcanism and partly from the geanticline to the northeast. No metalliferous deposits are known.

REFERENCES[1]

ANDREWS, E. C., 1906—Molybdenum. *Geol. Surv. N.S.W. Miner. Resour. Bull.* 11.

ANDREWS, E. C., 1908—Report on Drake gold and copper field. *Ibid.,* 12.

ANDREWS, E. C., 1910—The Forbes-Parkes Goldfield. *Ibid.,* 13.

ANDREWS, E. C., 1916—The molybdenum industry in New South Wales. *Ibid.,* 24.

ANON, 1961—Reconnaissance of the Granites-Tanami area. In *Bur. Miner. Resour. Aust. Rec.* 1961/38 (unpubl.).

ANON, 1968—Geological Map of the Broken Hill district. *Aust. Inst. Min. Metall.*

ARRIENS, P. A., 1971—The Archaean geochronology of Australia. *Geol. Soc. Aust. spec. Publ.* 3, 11-24.

BARAGWANATH, W. M., 1906—The Walhalla or Thompson River copper mine. *Geol. Surv. Vic. Bull.* 20.

BARAGWANATH, W. M., 1953—The Ballarat Goldfield. *Geol. Aust. Ore Deps.* 986-1002.

BENNETT, E. M., 1965—Lead-zinc-silver and copper ore deposits of Mount Isa. *Geol. Aust. Ore Deps.,* 2nd, 233-46.

BERKMAN, D. A., 1968—The geology of the Rum Jungle uranium deposits; *in* Uranium in Australia. *Aust. Inst. Min. Metall., Rum Jungle Br., Symp.,* 12-31.

BLAKE, D. H., 1972—Regional and economic geology of the Herberton/Mount Garnet area, Herberton Tinfield, north Queensland. *Bur. Miner. Resour. Aust. Bull.* 124.

BLAKE, D. H., and MIEZITIS, Y., 1967—Geology of Bougainville and Buka Islands, New Guinea. *Bur. Miner. Resour. Aust. Bull.* 93.

BLATCHFORD, A., 1953—Charters Towers Goldfield. *Geol. Aust. Ore Deps.,* 796-806.

BLISSETT, A. H., and WARNE, K. R., 1967—Molybdenum and tungsten in the south-eastern portion of Spilsby Island (Sir Joseph Banks Group). *S. Aust. Min. Rev.,* 121, 70-7.

BLOCKLEY, J. G., 1968—Diamond drilling at the Thaduna copper mine, Peak Hill Goldfield. *Geol. Surv. W. Aust. ann. Rep.* 1967, 53-7.

BOTH, R. A., and WILLIAMS, K. L., 1968—Mineralogical zoning in the lead-zinc ores of the Zeehan Field, Tasmania. Part I: Introduction and review; Part 2: Paragenetic and zonal relationship. *J. geol. Soc. Aust.,* 15(1), 121-38; 15(2), 217-44.

BRANCH, C. D., 1966—Volcanic cauldrons, ring complexes, and associated granites of the Georgetown Inlier, Queensland. *Bur. Miner. Resour. Aust. Bull.* 76.

BRANDT, R. T., 1965—The genesis of the Mount Goldsworthy iron ore deposits of Western Australia. *Econ. Geol.,* 61(6), 999-1009.

BROOKS, J. H., 1963—Galah Creek beryl pegmatites, Mount Isa Mineral Field, north-western Queensland. *Qld Govt Min. J.,* 64(740), 371-81.

BROOKS, J. H., 1964—Manganese deposit at Kunwarara, central Queensland. *Ibid.,* 65, 380.

BROOKS, J. H., 1965a—Minor copper deposits in north-western Queensland. *Geol. Aust. Ore Deps.,* 2nd, 253-5.

BROOKS, J. H., 1965b—Gold deposit of Golden Plateau. *Ibid.,* 361-3.

BROOKS, J. H., 1965c—Manganese deposits of Mary Valley. *Ibid.,* 394-5.

BROOKS, J. H., and SHIPWAY, C. H., 1960—Mica Creek pegmatites, Mount Isa, north-western Queensland. *Qld Govt Min. J.,* 61(708), 511-22.

BROWNE, W. R., 1949—Metallogenic epochs and ore regions in the Commonwealth of Australia. *J. Proc. Roy. Soc. N.S.W.,* 83, 96-113.

BURNS, W. G., and CARRUTHERS, D. S., 1965—Ironstone deposit of Scott River. *Geol. Aust. Ore Deps.,* 2nd, 138-9.

CAMPANA, B., and KING, D., 1958—Regional geology and mineral resources of the Olary province. *Geol. Surv. S. Aust. Bull.* 34.

[1] A large number of papers are cited from the two volumes entitled 'Geology of Australian Ore Deposits' published by the 5th Empire and (2nd edition) 8th Commonwealth Mining and Metallurgical Congresses in 1953 and 1965 respectively. To reduce the tedious repetition of citations, these two volumes are abbreviated here to '*Geol. Aust. Ore Deps.*' and '*Geol. Aust. Ore Deps.,* 2nd'.

CAMPBELL, F. A., 1965—Lead and copper deposits of the Northampton Mineral Field. *Geol. Aust. Ore Deps.*, 2nd, 147-9.

CANAVAN, F., 1965a—Iron ore deposits of Roper Bar. *Geol. Aust. Ore Deps.*, 2nd, 212-5.

CANAVAN, F., 1965b—Iron and manganese deposits of Iron Range. *Ibid.*, 391-3.

CAREY, S. W., 1953—The geological structure of Tasmania in relation to mineralization. *Geol. Aust. Ore Deps.*, 1108-28.

CARNE, J. E., 1908—The copper mining industry and the distribution of copper ores in New South Wales. *Geol. Surv. N.S.W. Miner. Resour. Bull.* 6 (2nd Edn).

CARNE, J. E., 1911—The tin mining industry and the distribution of tin ores in New South Wales. *Ibid.*, 14.

CARNE, J. E., 1912—The tungsten mining industry in New South Wales. *Ibid.*, 15.

CARRUTHERS, D. S., 1965—An environmental view of Broken Hill ore occurrence. *Geol. Aust. Ore Deps.*, 2nd, 399-51.

CARTER, E. K., BROOKS, J. H., and WALKER, K. R., 1961—The Precambrian mineral belt of north-western Queensland. *Bur. Miner. Resour. Aust. Bull.* 51.

CHESNUT, W. S., OFFENBERG, A. C., and BLACKSHAW, F. P., in prep.—Geological map of New England at 1:500 000. *Geol. Surv. N.S.W.*

CLAPPISON, R. J. S., 1940—The tin deposits of the Stanhills area, Croydon Gold and Mineral Field. *Aer. Surv. N. Aust., Qld Rep.* 23.

CLAPPISON, R. J. S., and ZANI, J. A., 1953—The structures of the Southern Cross-Bullfinch Belt, Yilgarn Goldfield. *Geol. Aust. Ore Deps.*, 128-37.

CLARKE, D. E., 1971—Geology of the Ravenswood 1-mile Sheet area, Queensland. *Geol. Surv. Qld Rep.* 53.

COATS, R. P., 1963—Geology of the Blinman Dome diapir. *Dep. Min. S. Aust. Rep. Inv.* 25.

COATS, R. P., and BLISSETT, A. H., 1971—Regional and economic geology of the Mount Painter province. *Geol. Surv. S. Aust. Bull.* 43.

COLDHAM, J. C., 1953—Mount Coolon gold mine. *Geol. Aust. Ore Deps.*, 807-12.

COMPSTON, W., and ARRIENS, P. A., 1968—The Precambrian geochronology of Australia. *Canad. J. Earth Sci.*, 5, 561-83.

COCHRANE, G. W., 1971—Tin deposits of Victoria. *Geol. Surv. Vic. Bull.* 6.

CONNOLLY, R. R., 1959—Iron ores in Western Australia. *Geol. Surv. W. Aust. Miner. Resour. Bull.* 7.

COOK, P. J., 1972—Sedimentological studies on the Stairway Sandstone of central Australia. *Bur. Miner. Resour. Aust. Bull.* 95.

COTTON, R. E., 1965—H.Y.C. lead-zinc-silver deposit, McArthur River. *Geol. Aust. Ore Deps.*, 2nd, 197-200.

CRAWFORD, A. R., 1965—The geology of Yorke Peninsula. *Geol. Surv. S. Aust. Bull.* 39.

CROHN, P. W., 1961—Visit to the Granites Goldfield, October 1960. *Bur. Miner. Resour. Aust. Rec.* 1961/157 (unpubl.).

CROHN, P. W., 1965—Tennant Creek Gold and Copper Field. *Geol. Aust. Ore Deps.*, 2nd, 176-82.

CROHN, P. W., LANGRON, W. J., and PRICHARD, C. E., 1967—The Woodcutters L5 prospect, Rum Jungle area, Northern Territory. *Bur. Miner. Resour. Aust. Rec.* 1967/154 (unpubl.).

CROHN, P. W., and OLDERSHAW, W., 1965—The geology of the Tennant Creek One-mile Sheet area, N.T. *Bur. Miner. Resour. Aust. Rep.* 83.

DANIELS, J. L., 1966a—Southern part of Kooline Goldfield. *Geol. Surv. W. Aust. ann. Rep.* 1965.

DANIELS, J. L., 1966b—The Proterozoic geology of the North-West Division of Western Australia. *Proc. Aust. Inst. Min. Metall.*, 219, 17-26.

DANIELS, J. L., 1969—Explanatory notes on the Talbot 1:250 000 Geological Sheet, Western Australia. *Geol. Surv. W. Aust. Rec.* 1969/14 (unpubl.).

DANIELS, J. L., in prep.—Geology of the Blackstone Range, Western Australia. *Geol. Surv. W. Aust. Bull.* 123.

DANIELS, J. L., and HORWITZ, R. C., 1969—Precambrian tectonic units of Western Australia. *Geol. Surv. W. Aust. ann. Rep.* 1968.

DAVIES, H. L., 1971—Peridotite-gabbro-basalt complex in eastern Papua: an overthrust plate of oceanic mantle and crust. *Bur. Miner. Resour. Aust. Bull.* 128.

DAVIES, H. L., and SMITH, I. E., 1970—Geology of eastern Papua—a synthesis. *Bur. Miner. Resour. Aust. Rec.* 1970/116 (unpubl.).

DE KEYSER, F., 1961—Misima Island—geology and gold mineralization. *Bur. Miner. Resour. Aust. Rep.* 57.

DE KEYSER, F., 1963—The Palmerville Fault—A 'fundamental' structure in north Queensland. *J. geol. Soc. Aust.,* 10(2), 273-8.

DE KEYSER, F., 1965—The Barnard Metamorphics and their relation to the Barrow River Metamorphics and the Hodgkinson Formation, Queensland. *J. geol. Soc. Aust.,* 12(1), 91-104.

DE KEYSER, F., and COOK, P. J., 1972—Geology of the Middle Cambrian phosphorites and associated sediments of northwestern Queensland. *Bur. Miner. Resour. Aust. Bull.* 138 (in press).

DE KEYSER, F., FARDON, R. S. H., and CUTTLER, L. G., 1964—Geology of the Ingham 1:250 000 Geological Sheet area SE/55-19, Queensland. *Bur. Miner. Resour. Aust. Rec.* 1964/78 (unpubl.).

DE KEYSER, F., and LUCAS, K. G., 1968—Geology of the Hodgkinson and Laura Basins, north Queensland. *Bur. Miner. Resour. Aust. Bull.* 84.

DE KEYSER, F., and WOLFF, K. W., 1964—The geology and mineral resources of the Chillagoe area. *Bur. Miner. Resour. Aust. Bull.* 70.

DE LA HUNTY, L. E., 1965—Manganese ore deposits of Western Australia. *Geol. Aust. Ore Deps.,* 2nd, 140-6.

DICKINSON, S. B., and SPRIGG, R. C., 1953—Geological structure of South Australia in relation to mineralization. *Geol. Aust. Ore Deps.,* 426-48.

DOW, D. B., and GEMUTS, I., 1969—Geology of the Kimberley Region Western Australia; the East Kimberley. *Bur. Miner. Resour. Aust. Bull.* 106.

DOW, D. B., SMIT, J. A. J., BAIN, J. H. C., and RYBURN, R. J., 1972—Geology of the South Sepik area, Papua New Guinea. *Bur. Miner. Resour. Aust. Bull.* 133.

DUNN, P. R., 1971—Archaean of northern Australia. *Geol. Soc. Aust. spec. Publ.* 3, 154.

DUNN, P. R., and BROWN, M. C., 1969—North Australian plateau volcanics. *Ibid.,* 2, 117-22.

DUNN, P. R., PLUMB, K. A., and ROBERTS, H. G., 1966—A proposal for time-stratigraphic subdivision of the Australian Precambrian. *J. geol. Soc. Aust.,* 13(2), 593-608.

DUNN, P. R., PLUMB, K. A., and ROBERTS, H. G., in prep.—Geology of the Proterozoic Carpentarian Province, Northern Territory: Roper River to the Queensland border. *Bur. Miner. Resour. Aust. Bull.*

DUNNET, D., and HARDING, R. R., 1967—Geology of the Mount Woodcock 1-mile Sheet area, Tennant Creek, N.T. *Bur. Miner. Resour. Aust. Rep.* 114.

EDWARDS, A. B., 1953a—Gold deposits of Wiluna. *Geol. Aust. Ore Deps.,* 215-23.

EDWARDS, A. B., 1953b—The Croydon Goldfield. *Ibid.,* 783-95.

EDWARDS, A. B., 1953c—Mines of the Walhalla-Woods Point auriferous belt. *Ibid.,* 1061-76.

EDWARDS, A. B., 1953d—The Heemskirk-Zeehan Mineral Field. *Ibid.,* 1166-78.

ELLIS, H. A., 1950—Some economic aspects of the principal tantalum-bearing deposits of the Pilbara Goldfield, North-West Division. *Geol. Surv. W. Aust. Bull.* 104.

ELLIS, H. A., 1953a—Norseman Gold Mines N.L. *Geol. Aust. Ore Deps.,* 150-8.

ELLIS, H. A., 1953b—The Greenbushes tin-tantalite district. *Ibid.,* 182-7.

ELLIS, H. A., 1958—The exploratory diamond drilling of the Koolyanobbing iron deposits for pyrite. *Geol. Surv. W. Aust. Bull.* 111.

ELLIS, H. A., 1967—Columbite-beryl deposit on Mineral Claim 313, Pilbara Goldfield, and its significance. *Geol. Surv. W. Aust. ann. Rep.* 1966.

ELLIS, P. L., 1968—Geology of the Maryborough 1:250 000 Sheet area. *Geol. Surv. Qld Rep.* 26.

ELLISTON, J., 1966—The genesis of the Peko orebody. *Proc. Aust. Inst. Min. Metall.,* 218, 9-18.

EVANS, H. J., 1965—Bauxite deposits of Weipa. *Geol. Aust. Ore Deps.,* 2nd, 396-401.

EVERNDEN, J. F., and RICHARDS, J. R., 1962—Potassium-argon ages in eastern Australia. *J. geol. Soc. Aust.*, 9(1), 1-50.

FINUCANE, K. J., 1938—The King Sound tin-wolfram deposits, West Kimberley district. *Aer. Surv. N. Aust., W. Aust. Rep.* 32.

FINUCANE, K. J., 1939—Mining centres east of Nullagine, Pilbara Goldfield. *Ibid.*, 19.

FINUCANE, K. J., 1965—Geology of the Sons of Gwalia gold mine. *Geol. Aust. Ore Deps.*, 2nd, 80-6.

FINUCANE, K. J., and TELFORD, R. J., 1939—The antimony deposits of the Pilbara Goldfield. *Aer. Surv. N. Aust., W. Aust. Rep.* 47.

FISHER, N. H., and OWEN, H. B., 1952—Mount Chalmers copper and gold mine, Queensland. *Bur. Miner. Resour. Aust. Rep.* 7.

GARDNER, D. E., 1955—Beach sand heavy mineral deposits of eastern Australia. *Bur. Miner. Resour. Aust. Bull.* 28.

GEE, L. C. E., 1908—Record of the mines of South Australia (4th Edn). *Adelaide, Govt Printer.*

GELLATLY, D. C., 1969—Probable carbonatites in the Strangways Range area, Alice Springs 1:250 000 Sheet area, petrography and geochemistry. *Bur. Miner. Resour. Aust. Rec.* 1969/77 (unpubl.).

GELLATLY, D. C., 1970—Textures and genesis of lead-zinc ores from Narlarla, West Kimberley region, Western Australia. *Bur. Miner. Resour. Aust. Rec.* 1970/117 (unpubl.).

GELLATLY, D. C., 1971—Bibliography of recent geological work on the Precambrian of the Kimberley region, W.A. *Ibid.*, 1971/22 (unpubl.).

GELLATLY, D. C., 1972—Problems of provenance of the Yampi iron ores, West Kimberley region, Western Australia. *Bur. Miner. Resour. Aust. Bull.* 125, 191-205.

GELLATLY, D. C., SOFOULIS, J., and DERRICK, G. M., in prep.—Precambrian geology of the Kimberley region: the West Kimberley. *Bur. Miner. Resour. Aust. Bull.*

GIBB-MAITLAND, A., 1900—The mineral wealth of Western Australia. *Geol. Surv. W. Aust. Bull.* 4, 39-42.

GIBBONS, G. S., and LE MESSURIER, P., 1962—Report of the Yalwal Goldfield. *Geol. Surv. N.S.W. geol. Rep.* 46.

GRUBB, P. L. C., 1970—Mineralogy, geochemistry, and genesis of the bauxite deposits on the Gove and Mitchell Plateaux (*sic*), Northern Australia. *Mineral. Deposita (Berl.)*, 5(3), 248-72.

HALL, G., 1953—The Granites Goldfield. *Geol. Aust. Ore Deps.*, 317-21.

HALL, G. M., COTTLE, V. M., ROSENHAIN, P. B. MCGHIE, R. R., and DRUETT, J. G., 1965—Lead-zinc ore deposits of Read-Rosebery. *Geol. Aust. Ore Deps.*, 2nd, 485-9.

HALL, H. E., and BEKKER, C., 1965—Gold deposits of Norseman. *Geol. Aust. Ore Deps.*, 2nd, 101-6.

HALLIGAN, R., 1965—The Narlarla lead-zinc deposit, Barker River area, West Kimberley Goldfield. *Geol. Surv. W. Aust. ann. Rep.* 1964.

HARMS, J. E., 1965—Iron ore deposits of the Constance Range. *Geol. Aust. Ore Deps.*, 2nd, 264-9.

HARRISON, E. J. J., 1952—Port Macquarie iron oxide deposits. *Dep. Min. N.S.W. ann. Rep.* 1952, 71-3.

HARRISON, E. J. J., 1953—Scheelite-antimony deposits of the Hillsgrove district. *Geol. Aust. Ore Deps.*, 930-4.

HAYS, J., 1967—Land surfaces and laterites in the north of the Northern Territory. In LANDFORM STUDIES FROM AUSTRALIA AND NEW GUINEA, ed. JENNINGS, J. N., and MABBUTT, J. A. *Canberra, ANU Press.*

HEIDECKER, E., 1972—Evolution of the Ravenswood-Lolworth block; influence upon Devonian tectonism in north-eastern Queensland. *Geol. Soc. Aust. Spec. Groups Mtg, Feb.* 1972 (abstr.).

HEIER, K. S., and RHODES, J. M., 1966—Thorium, uranium and potassium concentrations in granites and gneisses of the Rum Jungle Complex. *Econ. Geol.*, 61, 563-71.

HILL, D., and DENMEAD, A. K., eds, 1961—The geology of Queensland. *J. geol. Soc. Aust.*, 7.

HILLS, E. S., 1965—Tectonic setting of Australian ore deposits. *Geol. Aust. Ore Deps,* 2nd, 3-12.

HOSSFELD, P. S., 1938—Preliminary report on the Granites Goldfield, central Australia. *Aer. Surv. N. Aust., N.T. Rep.* 30.

HOSSFELD, P. S., 1940—The gold deposits of the Granites-Tanami Goldfield. *Ibid.,* 43.

HUGHES, F. E., and MUNRO, D. L., 1965—Uranium ore deposit at Mary Kathleen. *Geol. Aust. Ore Deps.,* 2nd, 256-63.

JACK, R. L., 1953—The Whipstick molybdenite and bismuth mines. *Geol. Aust. Ore Deps.,* 968-70.

JAQUET, J. B., 1896—Platinum in New South Wales. *Rec. geol. Surv. N.S.W.* 15(1), 33-9.

JAQUET, J. B., 1898—Report on cobalt deposits at Port Macquarie. *Dep. Min. N.S.W. ann Rep.* 1897, 177-80.

JENNINGS, I. B., and WILLIAMS, E., 1967—Geology and mineral resources of Tasmania. *Geol. Surv. Tas. Bull.* 50.

JENSEN, H. I., 1940—The tin deposits of the Stanhills area, Croydon Gold and Mineral Field. *Aer. Surv. N. Aust., Qld Rep.* 51.

JOHNS, R. K., 1961—Geology and mineral resources of southern Eyre Peninsula. *Geol. Surv. S. Aust. Bull.* 37.

JOHNS, R. K., 1965—Copper and manganese ore deposits of Pernatty Lagoon—Mount Gunson district. *Geol. Aust. Ore Deps.,* 2nd, 297-300.

JOHNSON, W., 1965—Copper and lead ore deposits of South Australia. *Geol. Aust. Ore Deps.,* 2nd, 285-96.

JONES, O. A., 1953—Geology of the eastern highland region of Queensland in relation to mineralization. *Geol. Aust. Ore Deps.,* 689-702.

JONES, W. R., and NOLDART, A. J., 1962—The geology of the Northampton Mineral Field and its environs, Western Australia. *Geol. Surv. W. Aust. ann. Rep.* 1961, 36-44.

KAPELLE, K., 1970—Geology of the C.S.A. mine, Cobar. *Proc. Aust. Inst. Min. Metall.,* 233, 79-94.

KING, H. F., 1953—The Thackaringa mines. *Geol. Aust. Ore Deps.,* 685-6.

KIRKEGAARD, A. G., SHAW, R. D., and MURRAY, C. G., 1970—Geology of the Rockhampton and Port Clinton 1:250 000 Sheets. *Geol. Surv. Qld Rep.* 38.

KNIGHT, C. L., 1965—Lead-zinc-lode at Dugald River. *Geol. Aust. Ore Deps.,* 2nd, 247-50.

KNIGHT, C. L., and NYE, P. B., 1965—Scheelite deposit of King Island. *Ibid.,* 515-7.

KNIGHT, C. L., FRASER, R. B., and BAUMER, A., 1972—Geology of the Bougainville copper orebody, New Guinea. *In* FISHER, N. H., ed.—Metallogenic provinces and mineral deposits in the Southwestern Pacific. *Bur. Miner. Resour. Aust. Bull.* 141 (in press).

LAMBERT, I. B., MCANDREW, J., and JONES, H. E., 1971—Geochemical and bacteriological studies of the cupriferous environment at Pernatty Lagoon, South Australia. *Proc. Aust. Inst. Min. Metall.,* 240, 15-24.

LAWRENCE, J. L., 1953—Yerranderie silver-lead field. *Geol. Aust. Ore Deps.,* 921-5.

LEITCH, E. C., NEILSON, M. J., and HOBSON, E., in press—Dorrigo-Coffs Harbour 1:250 000 Geological Series Sheet SH/56—10 and 11. *Geol. Surv. N.S.W.*

LEVINGSTON, K. R., 1971—Mineral deposits and mines of the Townsville 1:250 000 Sheet area, Queensland. *Geol. Surv. Qld Rep.* 61.

LEVINGSTON, K. R., 1972—Ore deposits and mines of the Charters Towers 1:250 000 Sheet area, north Queensland. *Ibid.,* 57.

LEWIS, B. R., FORWARD, P. S., and ROBERTS, J. B., 1965—Geology of the Broken Hill lode, re-interpreted. *Geol. Aust. Ore Deps.,* 2nd, 319-32.

LOW, G. H., 1960—Summary report on the principal beach sand heavy mineral deposits, South West Division, Western Australia. *Geol. Surv. W. Aust. Bull.* 114, 68-86.

LOW, G. H., 1963—Copper deposits of Western Australia. *Geol. Surv. W. Aust. Miner. Resour. Bull.* 8.

LOWRY, D. C., 1967—Busselton and Augusta, W.A., 1:250 000 Geological Series. *Geol. Surv. W. Aust. explan. Notes* SI/50—5,9.

McAndrew, J., 1965—Gold deposits of Victoria. *Geol. Aust. Ore Deps.*, 2nd, 450-6.

McClatchie, L., 1970—Copper mineralization in the Lachlan Geosyncline, New South Wales. *Proc. Aust. Inst. Min. Metall.*, 236, 1-16.

McDougall, I., and Leggo, P. J., 1965—Isotopic age determinations on granitic rocks from Tasmania. *J. geol. Soc. Aust.*, 12(2), 295-332.

MacLeod, W. N., 1965—Ferromanganese, Mount Caudan lode, Yilgarn Goldfield. *Geol. Surv. W. Aust. Rec.* 1965/12 (unpubl.).

MacLeod, W. N., 1966—The geology and iron deposits of the Hamersley Range area, Western Australia. *Geol. Surv. W. Aust. Bull.* 117.

MacLeod, W. N., 1972—Peak Hill, W.A.—1:250 000 Geological Series. *Geol. Surv. W. Aust. explan. Notes* SG/50-8.

Macnamara, P. M., 1968—Rock types and mineralization at Panguna porphyry-copper prospect, upper Kaverong valley, Bougainville Island. *Proc. Aust. Inst. Min. Metall.*, 228, 71-80.

McNeil, R. D., 1966—Mount Angelo copper prospect, East Kimberley, Western Australia. *Proc. Aust. Inst. Min. Metall.*, 218, 1-8.

Malone, E. J., Corbett, D. W. P., and Jensen, A. R., 1964—Geology of the Mount Coolon 1:250 000 Sheet area. *Bur. Miner. Resour. Aust. Rep.* 64.

Matheson, R. S., 1944a—The molybdenite deposits on P.A.s 2323 and 2324, Mount Mulgine. *Dep. Min. W. Aust. ann. Rep.* 1943, 76-8.

Matheson, R. S., 1944—The phosphate deposits of the Dandaragan district, South-west Division. *Ibid.*, 1943.

Matheson, R. S., 1945—Report on MC291.H for beryl, Yinnietharra. *Ibid.*, 1944, 99.

Matheson, R. S., 1953—The Coobina chromite deposits. *Geol. Aust. Ore Deps.*, 251-3.

Mathias, B. J., Clark, G. J., Morris, D., and Russell, R. E., 1972—The Hilton deposit—stratiform silver-lead-zinc mineralization of the Mount Isa type. *In* Fisher, N. H., ed.—Metallogenic provinces and mineral deposits in the southwestern Pacific. *Bur. Miner. Resour. Aust. Bull.* 141 (in press).

Mirams, R. C., 1965—Pyrite-pyrrhotite deposits at Nairne. *Geol. Aust. Ore Deps.*, 2nd, 316-8.

Morgan, D. D., 1965—Uranium ore deposit of Pandanus Creek. *Geol. Aust. Ore Deps.*, 2nd, 210-1.

Morgan, K. H., Horwitz, R. C., and Sanders, C. C., 1968—Structural layering of the rocks of the Archipelago of the Recherche. *Geol. Surv. W. Aust. ann. Rep.* 1967, 44-5.

Morton, C. C., 1943—Mount Martin manganese, Edmonton. *Qld Govt Min. J.*, 44, 92-3.

Murray, C. G., 1969—The petrology of the ultramafic rocks of the Rockhampton district, Queensland. *Geol. Surv. Qld Publ.* 343.

Murray, W. J., 1965—Silver-lead-zinc ore deposits of Lawn Hill. *Geol. Aust. Ore Deps.*, 2nd, 251-2.

Noldart, A. J., and Wyatt, J. D., 1963—The geology of portion of the Pilbara Goldfield covering the Marble Bar and Nullagine 4-mile map sheets. *Geol. Surv. W. Aust. Bull.* 115.

Offler, R., and Fleming, P. D., 1968—A synthesis of folding and metamorphism in the Mount Lofty Ranges, South Australia. *J. geol. Soc. Aust.*, 15(2), 245-65.

Oldershaw, W., 1965—Geological and geochemical survey of the Captains Flat area, New South Wales. *Bur. Miner. Resour. Aust. Rep.* 101.

Olgers, F., and Flood, P. G., in press—Palaeozoic geology of the Warwick and Goondiwindi 1:250 000 Sheet areas, Queensland and New South Wales. *Bur. Miner. Resour. Aust. Rep.* 164.

Ostle, D., 1956—Uranium occurrences in Tasmania. *Bur. Miner. Resour. Aust. Rec.* 1956/97 (unpubl.).

Owen, H. B., 1954—Bauxite in Australia. *Bur. Miner. Resour. Aust. Bull.* 24.

Owen, H. B., and Whitehead, S., 1965—Iron ore deposits of Iron Knob and the Middleback Ranges. *Geol. Aust. Ore Deps.*, 2nd, 301-8.

Packham, G. H., ed., 1969—The geology of New South Wales. *J. geol. Soc. Aust.*, 16(1).

Parkin, L. W., 1957—The Myponga uranium project. *S. Aust. Min. Rev.*, 103, 46-53.

Parkin, L. W., 1965—Radium Hill uranium mine. *Geol. Aust. Ore Deps.*, 2nd, 312-3.

PARKIN, L. W., ed., 1969—Handbook of South Australian geology. *Geol. Surv. S. Aust.*

PATTERSON, G. W., 1965—Lead-zinc deposits of Bulman. *Geol. Aust. Ore Deps.,* 2nd, 194-6.

PLUMB, K. A., in prep. a—The tectonic evolution of Australia. *Bur. Miner. Resour. Aust.*

PLUMB, K. A., in prep. b—Geology of the Kimberley region: the Kimberley Basin. *Bur. Miner. Resour. Aust. Bull.*

POGSON, O. J., and SCHEIBNER, E., 1971—Pre-Upper Cambrian sediments east of Copper Mine Ranges, New South Wales. *Geol. Surv. N.S.W. quart. Notes* 4.

PRATTEN, R. D., 1965—Lead-zinc-silver ore deposits of the Zinc Corporation and New Broken Hill Consolidated mines, Broken Hill. *Geol. Aust. Ore Deps.,* 2nd, 333-5.

PRICHARD, C. E., 1965—Uranium ore deposits of the South Alligator River. *Geol. Aust. Ore Deps.,* 2nd, 207-9.

QUEENSLAND, MINES DEP., 1953a—The Einasleigh copper mine. *Geol. Aust. Ore Deps.,* 751-5.

QUEENSLAND, MINES DEP., 1953b—Peak Downs copper mine, Clermont. *Ibid.,* 756-8.

QUEENSLAND, MINES DEP., 1953c—Glassford Creek Copper deposits. *Ibid.,* 763-7.

QUEENSLAND, MINES DEP., 1953d—Gympie Goldfield. *Ibid.,* 813-6.

QUEENSLAND, MINES DEP., 1953e—The Kilkivan mercury deposits. *Ibid.,* 840-4.

RAGGATT, H. G., 1925—Chromium, cobalt, nickel, zirconium, titanium, thorium, cerium. *Geol. Surv. N.S.W. Miner. Resour. Bull.* 13.

RAYNER, E. O., 1960—The nature and distribution of uranium mineralization in New South Wales. *Dep. Min. N.S.W. tech. Rep.* 5, 63-102.

REID, I. W., 1965—Iron ore deposits of Yampi Sound. *Geol. Aust. Ore Deps.,* 2nd, 126-31.

REYNER, N. L., 1955—The geology of the Peake and Denison region. *Geol. Surv. S. Aust. Rep. Inv.* 6.

RHODES, J. M., 1965—The geological relationships of the Rum Jungle Complex, N. T. *Bur. Miner. Resour. Aust. Rep.* 89.

RICHARDS, G. M., 1972—Proterozoic uraniferous conglomerates, Pilbara, W.A. *Geol. Soc. Aust. Spec. Groups Mtg, Feb.* 1972, Abstr.

RICHARDS, J. R., WHITE, D. A., WEBB, A. W., and BRANCH, C. D., 1966—Isotopic ages of acid igneous rocks in the Cairns Hinterland, north Queensland. *Bur. Miner. Resour. Aust. Bull.* 88.

RIDGWAY, J. E., 1941—Magnesite deposit at Princhester, Marlborough district. *Qld Govt Min. J.,* 42, 139.

RIDGWAY, J. E., 1950—Mount Fitton mine. *S. Aust. Min. Rev.,* 89, 117-8.

RIDGWAY, J. E., 1953—Chromite deposits of the Marlborough-Princhester-Tungamall district. *Geol. Aust. Ore Deps.,* 845-9.

ROBERTS, H. G., PLUMB, K. A., and DUNN, P. R., in prep.—Geology of the Proterozoic Carpentarian province, Northern Territory: Arnhem Land. *Bur. Miner. Resour. Aust. Bull.*

ROBERTS, H. G., RHODES, J. M., and YATES, K. R., 1963—Calvert Hills, N.T.—1:250 000 Geological Series. *Bur. Miner. Resour. Aust. explan. Notes* SE/53-8.

ROBERTSON, A. D., and FLOOD, P. G., in press—Intrusive and economic geology of the Warwick and Goondiwindi 1:250 000 Sheets. *In* OLGERS & FLOOD, in press.

ROBERTSON, W. A., 1959—Jervois Range copper-lead deposits, Northern Territory. *Bur. Miner. Resour. Aust. Rec.* 1959/103 (unpubl.).

ROSE, G., and BRUNKER, R. L., 1969—The Upper Proterozoic and Phanerozoic geology of north-western New South Wales. *Proc. Aust. Inst. Min. Metall.,* 229, 105-20.

RUNNEGAR, B., and FERGUSON, J. A., 1969—Stratigraphy of the Permian and Lower Triassic marine sediments of the Gympie district, Queensland. *Pap. Dep. Geol. Univ. Qld,* 9, 247-81.

RYAN, G. R., 1961—The geology and mineral resources of the Hatches Creek wolfram field, Northern Territory. *Bur. Miner. Resour. Aust. Bull.* 6.

RYAN, G. R., 1964—A re-appraisal of the Archaean of the Pilbara Block. *Geol. Surv. W. Aust. ann. Rep.* 1963.

SAINSBURY, C. L., and HAMILTON, J. C., 1967—GEOLOGY OF LODE TIN DEPOSITS. *Int. Tin. Ccl.*

SAINT-SMITH, E. C., 1914—Geology and mineral resources of the Stanthorpe, Ballandean and Wallangarra districts, southern Queensland, 1913. *Geol. Surv. Qld Publ.* 243.

SAINT-SMITH, E. C., 1922—Woolgar Goldfield. *Qld Govt Min. J.*, 23(261), 51-4; 23(262), 95-8.

SCHEIBNER, E., 1972a—The Kanmantoo precratonic province in New South Wales. *Geol. Surv. N.S.W. quart. Notes* 7.

SCHEIBNER, E., 1972b—A model of the Palaeozoic tectonic history of New South Wales. *Geol. Soc. Aust., Spec. Groups Mtg, Feb.* 1972, *Abstr.*

SCHEIBNER, E., in prep.—Tectonic map of New South Wales. *Geol. Surv. N.S.W.*

SHAW, R. D., STEWART, A. J., YAR KHAN, M., and FUNK, J. L., 1971—Progress report on detailed mapping in the Arltunga Nappe Complex, N.T. *Bur. Miner. Resour. Aust. Rec.* 1971/66 (unpubl.).

SHAW, R. D., and WARREN, R. G., in prep.—Geology of the Alcoota 1:250 000 Sheet, N.T. *Bur. Min. Resour. Aust. Rep.*

SIMPSON, E. S., 1948—MINERALS OF WESTERN AUSTRALIA. *Perth, Govt Printer,* 3 vols.

SINGLETON, O. P., 1965—Geology and mineralization of Victoria. *Geol. Aust. Ore Deps.,* 2nd, 440-9.

SMITH, K. G., 1964—Progress report on the geology of Huckitta 1:250 000 Sheet area, Northern Territory. *Bur. Miner. Resour. Aust. Rep.* 67.

SMITH, K. G., 1972—Geology of the Georgina Basin. *Bur. Miner. Resour. Aust. Bull.* 111.

SMITH, S. E., and WALKER, K. R., 1972—Primary element dispersions associated with mineralization at Mount Isa, Queensland. *Bur. Miner. Resour. Aust. Bull.* 131.

SMITH, W. C., and GEBERT, H. W., 1970—Manganese at Groote Eylandt, Australia. *9th Cwealth Min. metall. Cong.,* 2, 585-604.

SOFOULIS, J., 1958—The geology of the Phillips River Goldfield, W.A. *Geol. Surv. W. Aust. Bull.* 110.

SOFOULIS, J., 1963—Boorabbin, W.A.—1:250 000 Geological Series. *Geol. Surv. W. Aust. explan. Notes* SH/51-13.

SOLOMON, M., 1965a—Geology and mineralization of Tasmania. *Geol. Aust. Ore Deps.,* 2nd, 464-77.

SOLOMON, M., 1965b—Lead-zinc-silver ore deposits at Mt Farrell. *Ibid.,* 490.

SOLOMON, M., 1967—Fossil gossans(?) at Mount Lyell. *Econ. Geol.,* 62, 757-72.

SOLOMON, M., 1969—The copper-clay deposits at Mount Lyell, Tasmania. *Proc. Aust. Inst. Min. Metall.,* 230, 39-48.

SPRATT, R. N., 1965—Uranium ore deposits of Rum Jungle. *Geol. Aust. Ore Deps.,* 2nd, 201-6.

SPRIGG, R. C., 1965—Nickel mineralization in the Blackstone and Tomkinson Ranges. *Geol. Aust. Ore Deps.,* 2nd, 314-5.

STAFF, BIG BELL MINES LTD, 1953—The Big Bell goldmine. *Geol. Aust. Ore Deps.,* 224-30.

STAFF, MOUNT MORGAN LTD, 1965—Copper-gold ore deposit of Mount Morgan. *Geol. Aust. Ore Deps.,* 2nd, 364-9.

STANTON, R. L., 1955—Lower Palaeozoic mineralization near Bathurst, New South Wales. *Econ. Geol.,* 50, 681-710.

STILLWELL, F. L., 1953—The Costerfield gold-antimony mine. *Geol. Aust. Ore Deps.,* 1096-100.

STRUSZ, D. L., 1971—Canberra, A.C.T., and N.S.W.—1:250 000 Geological Series. *Bur. Miner. Resour. Aust. explan. Notes* SI/55-16

SULLIVAN, C. J., 1953a—Wauchope wolfram field. *Geol. Aust. Ore Deps.,* 327-9.

SULLIVAN, C. J., 1953b—The Home of Bullion mine. *Ibid.,* 330-3.

TALENT, J. A., and THOMAS, D. E., 1967—Central Victoria. *Excursions Handbk, Sec. 3, 39th ANZAAS Cong.*

TAYLOR, J., 1968—Origin and controls of uranium mineralization in the South Alligator valley; *in* Uranium in Australia. *Aust. Inst. Min. Metall., Rum Jungle Br., Symp.,* 32-44.

TELFORD, R. J., 1939—The Mallina and Peewah mining centres, Pilbara Goldfield. *Aer. Surv. N. Aust., W. Aust. Rep.* 48.

THIEME, PAMELA, 1971—Australian mineral industry: phosphate deposits. *Bur. Miner. Resour. Aust.*

THOMAS, D. E., 1953—The Bendigo Goldfield. *Geol. Aust. Ore Deps.,* 1011-27.

THOMPSON, J. E., and FISHER, N. H., 1965—Mineral deposits of New Guinea and their tectonic setting. *Geol. Aust. Ore Deps.,* 2nd, 115-47.

THOMPSON, R. B., 1972—Surface expression of mineralization in the Solomon Islands. *In* FISHER, N. H., ed.—Metallogenic provinces and mineral deposits in the southwestern Pacific. *Bur. Miner. Resour. Aust. Bull.* 141 (in press).

THOMSON, B. P., 1965—Geology and mineralization in South Australia. *Geol. Aust. Ore Deps.,* 2nd, 270-84.

THOMSON, L. D., and RUSSELL, R. T., 1971—Discovery, exploration and investigation of phosphate deposits in Queensland. *Proc. Aust. Inst. Min. Metall.,* 240, 1-14.

TOMICH, S. A., 1964—Bauxite in the Darling Range, Western Australia. *Proc. Aust. Inst. Min. Metall.,* 212, 125-35.

TRAIL, D. S., 1967—Geology of Woodlark Island, Papua. *Bur. Miner. Resour. Aust. Rep.* 115.

TRENDALL, A. F., and BLOCKLEY, J. G., 1970—The iron formations of the Precambrian Hamersley Group, Western Australia. *Geol. Surv. W. Aust. Bull.* 119.

TUREK, A., and COMPSTON, W., 1971—Rb-Sr geochronology in the Kalgoorlie region. *Geol. Soc. Aust. spec. Publ.* 3, 72 (abstr.).

URQUHART, G., 1965—Ironstone deposit of Dawsonvale. *Geol. Aust. Ore Deps.,* 2nd, 388-90.

URQUHART, G., 1966—Magnetite deposits of the Savage River-Rocky River Region. *Geol. Surv. Tas. Bull.* 48.

VERNON, R. H., 1969—The Willyama Complex. *J. geol. Soc. Aust.,* 16, 20-55.

VOISEY, A. H., 1965—Geology and mineralization of eastern New South Wales. *Geol. Aust. Ore Deps.,* 2nd, 402-10.

WALPOLE, B. P., CROHN, P. W., DUNN, P. R., and RANDAL, M. A., 1968—Geology of the Katherine-Darwin region, Northern Territory. *Bur. Miner. Resour. Aust. Bull.* 82.

WALPOLE, B. P., ROBERTS, H. G., and FORMAN, D. J., 1965—Geology of the Northern Territory in relation to mineralization. *Geol. Aust. Ore Deps.,* 2nd, 160-7.

WEBB, A. W., 1969—Metallogenic epochs in eastern Queensland. *Proc. Aust. Inst. Min. Metall.,* 230, 29-38.

WELLS, A. T., FORMAN, D. J., RANFORD, L. G., and COOK, P. J., 1971—Geology of the Amadeus Basin, central Australia. *Bur. Miner. Resour. Aust. Bull.* 100.

WHITE, D. A., 1965—The geology of the Georgetown/Clarke River area, North Queensland. *Bur. Miner. Resour. Aust. Bull.* 71.

WHITTEN, G., 1965—Iron ore deposits in South Australia outside the Middleback Ranges. *Geol. Aust. Ore Deps.,* 2nd, 309-11.

WHITWORTH, H. F., 1956—The zircon-rutile deposits of the beaches of the east coast of Australia with special reference to their mode of occurrence and the origin of the mineral. *Dep. Min. N.S.W., tech. Rep.* 4.

WILLIAMS, I., 1970—Explanatory notes on the Kurnalpi 1:250 000 Geological Sheet, W.A. *Geol. Surv. W. Aust. Rec.* 1970/1 (unpubl.).

WILLIAMS, I. R., 1971—A regional synthesis of the Archaean geology of the Eastern Goldfields, Western Australia. *Geol. Soc. Aust. spec. Publ.,* 3, 152 (abstr.).

WILMOTT, W. F., WHITAKER, W. G., PALFREYMAN, W. D., and TRAIL, D. S., in press—Igneous and metamorphic rocks of Cape York Peninsula. *Bur. Miner. Resour. Aust. Bull.* 135.

WILSON, A. F., 1969a—Granulite terrains and their tectonic setting and relationship to associated metamorphic rocks in Australia. *Geol. Soc. Aust. spec. Publ.* 2, 243-58.

WILSON, A. F., 1969b—Problems of exploration for metals in granulite terrains with particular reference to Australian localities. *Ibid.,* 375-6.

WILSON, A. F., 1969c—The mineral potential of granulite terrains. *Aust. Inst. Min. Metall., ann. Conf.* 1969, Sec. D (unpubl.).

WILSON, A. F., 1971—Some geochemical aspects of the sapphirine-bearing rocks and related highly metamorphosed rocks from the Archaean ultramafic belt of South Quairading, Western Australia. *Geol. Soc. Aust. spec. Publ.* 3, 401-12.

WILSON, H. D. B., 1971—Archaean platform metallogenic provinces. *Geol. Soc. Aust. spec. Publ.* 3, 254 (abstr.).

WOODALL, R. W., 1965—Structure of the Kalgoorlie Goldfield. *Geol. Aust. Ore Deps.,* 2nd, 71-86.

WOODALL, R., and TRAVIS, G. A., 1970—The Kambalda nickel deposits Western Australia. *9th Cwealth Min. metall. Cong.,* 2, 517-34.

WYATT, D. H., PAINE, A. G. L., CLARKE, D. E., and HARDING, R. R., 1971—Geology of the Townsville 1:250 000 Sheet area, Queensland. *Bur. Miner. Resour. Aust. Rep.* 127.

WYATT, D. H., PAINE, A. G. L., CLARKE, D. E., GREGORY, C. M., and HARDING, R. R., 1971—Geology of the Charters Towers 1:250 000 Sheet area, Queensland. *Ibid.,* 137.

YATES, K. R., and DE FERRANTI, R. Z., 1967—The Astrolabe Mineral Field, Papua. *Bur. Miner. Resour. Aust. Rep.* 105.

INDEX OF MINES AND DEPOSITS

Note: This index only includes mines and deposits referred to in the text: it is neither an exhaustive list of Australian occurrences, nor a list of the most economically important occurrences.

METALLOGENIC MAP
AUSTRALIA AND PAPUA NEW GUINEA

SCALE 1 : 5,000,000

Lambert Conformal Conic Projection — Standard Parallels 10°S and 30°S

SCALE OF KILOMETRES — SCALE OF MILES

Bathymetric contours in metres

Research and publication by the Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia, in collaboration with the Commission for the Geological Map of the World, Sub-Commission for the Metallogenic Map of the World.

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