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THE PROTEROZOIC BARNEY CREEK FORMATION AND SOME ASSOCIATED CARBONATE UNITS OF THE McARTHUR GROUP, NORTHERN TERRITORY

by

M.C. Brown, C.W. Claxton, & K.A. Plumb

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PART I

Stratigraphy and depositional environments

by

M.C. Brown & K.A. Plumb

PART II

Geochemical investigations

by

C.W. Claxton

CONTENTS

PART 1

PART 2

4

APPENDIX

TABLES

5

PLATES

FIGURES

FOREWORD

Part 1 of this Record was originally completed in 1969, but unforeseen circumstances prevented its release until it was extensively modified. Brown, meanwhile, had resigned from the Bureau and left for overseas, which seriously delayed its completion; but, because the Record had already been quoted in several publications, it was necessary to retain the original number, 1969/145.

Claxton had completed his analyses by this stage, so the decision followed to incorporate his work into the Record, as a complete report of the project. His death in a motor accident, while his text was still in draft form, added further delays.

Interpretations and discussions in Part 1 have been extensively revised to accord with new information which has become available since 1969, but measured sections, text figures, and other such data remain in their original form.

Much of the work is now subject to extensive review during the major new BMR McArthur Basin Project.

J.N. CASEY

Assistant Director (Geology)

1 June 1978

PART I

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

by

M.C. Brown & K.A. Plumb

SUMMARY

Part 1

Near old McArthur River homestead in the Northern Territory, fine-grained galena, and pyrite of the H.Y.C. deposit are interlaminated with potash-rich carbonaceous shale and mudstone, which contain interbeds of carbonate-rich breccia and graded arenites. The sedimentary rocks occur within a mainly dolomite-lutite sequence, the McArthur Group, which is of Precambrian age (between 1400 and 1600 m.y. old). The H.Y.C. deposit occurs in the predominantly shaly Barney Creek Formation, which is underlain by the Teena Dolomite and Emmerugga Dolomite and overlain by the Reward Dolomite. The Emmerugga Dolomite overlies a unit consisting mainly of red siltstone (the Myrtle Shale Member of the Tooganinie Formation).

These units have been studied in detail in several small areas over a total area of about 5000 km^2. Studies indicate that they were deposited during a major cycle of transgression and regression. The Myrtle Shale Member is interpreted as a predominantly subaerial deposit. The Emmerugga Dolomite and Teena Dolomite exhibit an overall vertical succession from predominantly sheltered intertidal carbonates near the base, through exposed intertidal and shallow subtidal carbonates, to mainly subtidal carbonates (uniform clean carbonate mudstones) at the top, although alternations of sediments from varying depositional environments occur throughout. An increase in water depth then produced conditions less favourable for carbonate sedimentation, and the Barney Creek Formation, mainly laminated shaly dolomite and dolomitic shale rich in organic matter, was deposited. A subsequent decrease in water depth was accompanied by deposition of the carbonate-rich Reward Dolomite.

Warping and faulting accompanied deposition. During deposition of the Emmerugga Dolomite and much of the Teena Dolomite, depositional slopes remained very low and sedimentation kept pace with subsidence. Later, steeper depositional slopes developed, resulting in marked lateral changes in thickness and lithology during deposition of the top part of the Teena Dolomite, the Barney Creek Formation, and the Reward Dolomite.

During deposition of the latter two formations the Bulburra Depression, which had its deepest expression at the H.Y.C. deposit and which was terminated abruptly to the east by the Emu Fault zone, was an important structural feature, and turbidites and talus screes were transported into the depression from the uplifted fault blocks to the east.

Interpreting the palaeogeography during deposition of the H.Y.C. deposit is complicated by lack of precise time markers within the sequences. The sulphide-rich sediments of the H.Y.C. deposit were deposited in restricted systems in the deepest part of the Bulburra Depression near its abrupt easterly termination against the Emu Fault, while older strata were exposed and being eroded on the uplifted fault blocks to the east. The Bulburra Depression appears to have shallowed gradually to the west, north, and south, into shallower subtidal and perhaps lagoonal and intertidal environments, in which sediments containing more carbonate were deposited.

Conditions at the bottom of the Bulburra Depression may have been favourable for the accumulation of a pool of hot brine similar to those now depositing sulphides in the Red Sea. Water depth could have been as much as 500 m, in restricted depressions, and a source of brine, from older evaporitic sediments exposed on fault blocks to the east, was available. Fractures in the Emu Fault zone could have provided channelways for the movement of brines into the depression.

Part 2

360 samples have been chemically analysed for Ca, Mg, K, acid insoluble residue, Fe, Mn, P, Zn, Pb, Cu, Ni, and Co. Element compositions have been compared between different units and between different areas, and the data have also been analysed statistically by product-moment correlation matrix and factor analysis programs.

Ca:Mg ratios confirm that dolomite is the major carbonate phase throughout the sequence, but there is generally an excess of Ca, for 1:1 molar ratio pure dolomite.

K has been added to the rocks, because the very high contents in the Barney Creek Formation (up to 10%) and tuff(?) beds in dolomite units (up to 12%) exceed K-values for normal igneous rocks.

c.

Anomalous Pb and Zn contents are only present in mineralised Barney Creek Formation, at or near the H.Y.C. deposit. All other units, and the Barney Creek Formation away from the H.Y.C. deposit, show low and relatively constant abundances of around 15 ppm Zn and 10 ppm Pb.

Phosphorus is generally more abundant near the H.Y.C. deposit in all units.

Most units show different element correlation patterns between 'near-H.Y.C.' and 'outlying sections'. Mineralised units, near the H.Y.C. deposit, show more complex groupings of 'sulphide' elements, and partitioning into 'sulphide' and 'silicate' fractions.

INTRODUCTION

Aims and scope of the project

The H.Y.C. deposit is concordant with the enclosing sedimentary rocks (Cotton, 1965) and shows sedimentary features on a small scale (Croxford, 1968); it is generally regarded as having been deposited as a sediment. The structural simplicity and lack of metamorphism of the beds enclosing the deposit, an unusual feature in the massive sulphide orebodies of Australia, and the nature of the enclosing rocks provided an excellent opportunity to investigate the stratigraphic setting and depositional environment of the massive sulphide deposit, assuming a sedimentary origin. Thus it was decided that the BMR would investigate the stratigraphic relationships and depositional environment of the Barney Creek Formation and the enclosing dolomite units, as an aid to current research on syngenetic deposition of sulphides by the Baas-Becking Geobiological Research Group, and to complement more detailed studies of the sulphide body itself by Mount Isa Mines geologists.

Work on the project began with a three-week visit to the area by Plumb, Brown, and others during September 1967. During this visit Plumb, who had participated in the original 1:250 000 BMR mapping of the area, introduced Brown to the regional geology; and Mr J.A. Shaw of Carpentaria Exploration Company Pty Ltd (C.E.C.) showed the BMR geologists the results of CEC's more detailed mapping in the area. During this visit Plumb and Brown spent a week mapping in the Top Crossing area to solve some problems of stratigraphic interpretation.

Part 1 of this report largely describes the results of detailed field investigations and examination of drill cores by Brown during a three-month visit to the area in 1968 and a two-month visit in 1969. Brown and Plumb re-visited the area in 1977 during the first field season of a major new BMR study of the McArthur Basin; and an earlier draft of the report has been somewhat revised as the result of the 1977 observations and in the light of new interpretations of the geology since 1969 by various workers. The first draft of Part I was written by Brown. Subsequent revisions are by Plumb and Brown.

About 360 specimens collected during the 1968 and 1969 field seasons were chemically analysed by the late Charles Claxton in the BMR laboratories. The results of this work are described in Part 2 of this report based on a draft report by Claxton which has been subsequently edited and revised by Plumb.

Previous investigations

In 1959 a diamond drill hole drilled below a small silicified outcrop containing zinc silicates near the old McArthur River homestead intersected, at depth, dark shales containing zinc and lead sulphides. Subsequent drilling of the deposit, now known as the H.Y.C. prospect, by C.E.C. has delineated a large stratiform body of zinc-lead ore. Company geologists (Shaw, 1967) have since mapped an area about 40 km square to the north, south, and west of the deposit at a scale of 1600' to 1" (1:19 200). Cotton (1965) and Shaw (1967) discuss the geological setting of the deposit as known up to that time. Several smaller stratiform zinc-lead sulphide deposits in similar stratigraphic positions to the H.Y.C. prospect have since been proved by drilling in local structural basins up to 10 km from the main deposit (Murray, 1975). Lambert (1976) has recently reviewed the geology of the H.Y.C. deposit.

The Bauhinia Downs 1:250 000 Sheet area, which contains the area mapped by C.E.C., was first mapped by the Bureau of Mineral Resources in 1960 as part of a survey of the Carpentaria Proterozoic Province (Smith, 1964). Many formations were mapped. The Proterozoic formations were grouped into the Tawallah Group (largely arenaceous clastic sediments and volcanics) at the bottom, the McArthur Group (largely carbonates) in the middle, and the Roper Group (largely clastics) at the top. Isotopic dating has indicated Rb-Sr ages of at least 1390 m.y. for glauconitic sandstone in the Roper Group (McDougall and others, 1965) and about 1575 m.y. for rhyolite and microgranite at the top of the Tawallah Group (A.W. Webb, AMDL Rep. An 2250/74, unpubl.). Overall similarities of stratigraphy and isotopic ages in the two regions have indicated that the beds containing the H.Y.C. prospect and the Mount Isa orebody may be of similar age (Dunn, Plumb & Roberts, 1966; Plumb & Derrick, 1975; Plumb & Sweet, 1974). The H.Y.C. zinc-lead deposit, and associated pyritic and dolomitic shale, shaly dolomite, and breccia, were originally mapped by BMR as the 'Barney

Creek Member', of the 'Amelia Dolomite', a formation in the McArthur Group. The Member was only mapped in an area within some 5 km of the H.Y.C. prospect. The formations overlying the 'Amelia Dolomite' were thought to form a barrier reef complex. The 'reef' ("Top Crossing Dolomite') separated 'back-reef' formations (Bauhinia Downs Subgroup) west of the Tawallah Fault from generally shaly 'fore-reef' formations (the Batten Subgroup) to the east. The underlying 'Amelia Dolomite' was thought to be much thicker on the 'fore-reef' side.

C.E.C. geologists found it possible to subdivide the 'Amelia Dolomite', east of the Tawallah Fault, into several informal members and found outcrops of the 'Barney Creek Member', thinner than in the type area, distributed over most of the area mapped (Shaw, 1967). In 1966-67, they observed that the sequence in the 'Amelia Dolomite' east of the Tawallah Fault was very similar to the whole McArthur Group sequence below the Billengarrah Formation, west of the Tawallah Fault, including the 'back-reef' Bauhinia Downs Subgroup; they also recorded rocks similar to the Barney Creek Member in the west.

1967 investigations by BMR

In September 1967 two of the present authors (MCB, KAP), while being shown over the McArthur River area by Shaw, were impressed by the similarities between the sequences in the two areas noted by C.E.C. If these similarities implied a time correlation, it was obvious that the reef complex interpretation was in error; it was critical to remap the Top Crossing area, the only area where all the rocks of the supposed 'reef complex' were exposed in juxtaposition.

Detailed mapping of the Top Crossing area by Plumb and Brown in 1967 showed conclusively that the Bauhinia Downs Subgroup dipped beneath the 'Top Crossing Dolomite', and did not interfinger with it as earlier suggested. A shaly unit, formerly regarded as Lynott Formation (basal Formation of the 'fore-reef' Batten Subgroup) was identified as Barney Creek Formation and was found to conformably overlie the 'Top Crossing Dolomite'. The 'Top Crossing Dolomite' ('reef') was identified as the Emmerugga Dolomite, a unit cropping out to the west and formerly thought to overlie the reef complex. A sequence mapped as Emmerugga Dolomite east of the Tawallah Fault was found to be a much younger unit.

The stratigraphy of the McArthur Group in the Bauhinia Downs Sheet area has been reinterpreted and the nomenclature revised (Fig. 1); the revisions are outlined by Plumb & Brown (1973).

1968 and 1969 investigations by BMR

In 1968 several sections, in the Barney Creek Formation, the underlying Teena Dolomite, Emmerugga Dolomite and Tooganinie Formation, and the overlying Reward Dolomite were measured and described in detail by Brown; their locations are shown in Plate 1. Most were measured using a 1.5-m staff and Abney Level, but some steep-dipping sections, namely 5, 6, and 14, were measured with a 100-ft (30.48-m) metallic tape. Lithological logs and descriptions of the sections were plotted in the field at a scale of 25' = 1" (1:300) (or 50' = 1" (1:600) for Sections 5 and 6 in the Tooganinie Formation) using the continuous recording device of Veevers & Jackson (1966). Plates 2 to 12 show these logs (except Sections 5 and 6), redrawn at a scale of 1:1200. Some other areas of Barney Creek Formation were visited and mapped, and outcrops around the H.Y.C. prospect were compared with other areas.

Following the 1968 field work, air-photo interpretation was used to delineate outcrops of the Barney Creek Formation, Reward Dolomite, Teena Dolomite, and the Emmerugga Dolomite (Pl. 1), and field work in 1969 checked the photo interpretation and examined other areas of outcrop of interest to the study.

Also in 1969, with the permission of C.E.C., cores from three representative vertical diamond drill holes, drilled by C.E.C. during testing of the H.Y.C. deposit, were examined (Pls. 13, 14, 15). One of the holes, Te 115 (Pl. 14), intersected a thick section of Barney Creek Formation consisting of about 402 m of H.Y.C. Pyritic Shale Member overlying 93 m of W-Fold Shale Member. Hole Ie 115 (Pl. 13), a 760-m-deep hole about 300 m east of Te 115, intersected brecciated dololutite with intervals of pyritic and carbonaceous shale (Cooley Dolomite Member) overlying 21 m of green and red ?tuffaceous mudstone (W-Fold Shale Member), 126 m of Coxco Dolomite Member, and about 10 m of the lower unit of the Teena Dolomite at the base. In Ue 133 (Pl. 15) the sequence from 199.4 m to total depth of 440 m was examined in detail, and consisted of the lower unit of the Teena Dolomite at the base overlain by Coxco Dolomite Member, W-Fold Shale Member, and H.Y.C. Pyritic Shale Member. In the latter hole the H.Y.C. Pyritic Shale Member lacked the interval with galena and sphalerite beds and contained thick intervals of brecciated dolomite and dolomite-rich breccia. Detailed examination of the cores was facilitated by rubbing off the drilling marks of representative pieces, at about 3-m intervals, with an emery stone, followed by polishing with 'wet and dry' emery paper.

Summary of stratigraphy and depositional environments of units studied

The vertical sequence of rock types between the Tooganinie Formation and the Batten Subgroup (or Billengarrah Formation) is rather uniform, apart from some changes in thickness, over much of the Bauhinia Downs 1:250 000 Sheet area, but near the Emu Fault there are some marked lateral changes in lithology and thickness of units and some probable unconformities. The general vertical sequence is shown in Figure 2.

The sequence of sediment types is interpreted as having resulted from a major transgression, followed by regression. The transgression produced the change from predominantly subaerial siltstone (Myrtle Shale Member), through mainly intertidal dolomite (Mara Dolomite Member), and shallow marine carbonates (Mitchell Yard and Coxco Dolomite Members), to deeper water shaly carbonates, tuffaceous mudstones, shales with sulphides, and locally graded arenites and breccias (Barney Creek Formation). Regression resulted in a return to predominantly carbonate sediments (Reward Dolomite), and development of local unconformities. Figure 3 is an interpretation of the probable physiography of depositional environments represented by this sequence.

Lateral changes in lithology and thickness are shown diagrammatically in Figure 4. Some warping and faulting seems to have accompanied sedimentation, so that the lower boundaries of transgressive units are likely to be older in the areas of more rapid subsidence; this is fairly clear in the field at the change from the Coxco Dolomite Member to the Barney Creek Formation, and is likely for the change from W-Fold Shale Member to the H.Y.C. Pyritic Shale Member. The boundary between the H.Y.C. Pyritic Shale

17

STRATIGRAPHIC RELATIONSHIPS AND NOMENCLATURE, Mc.ARTHUR GROUP, BAUHINIA DOWNS SHEET AREA

Fig. 1.

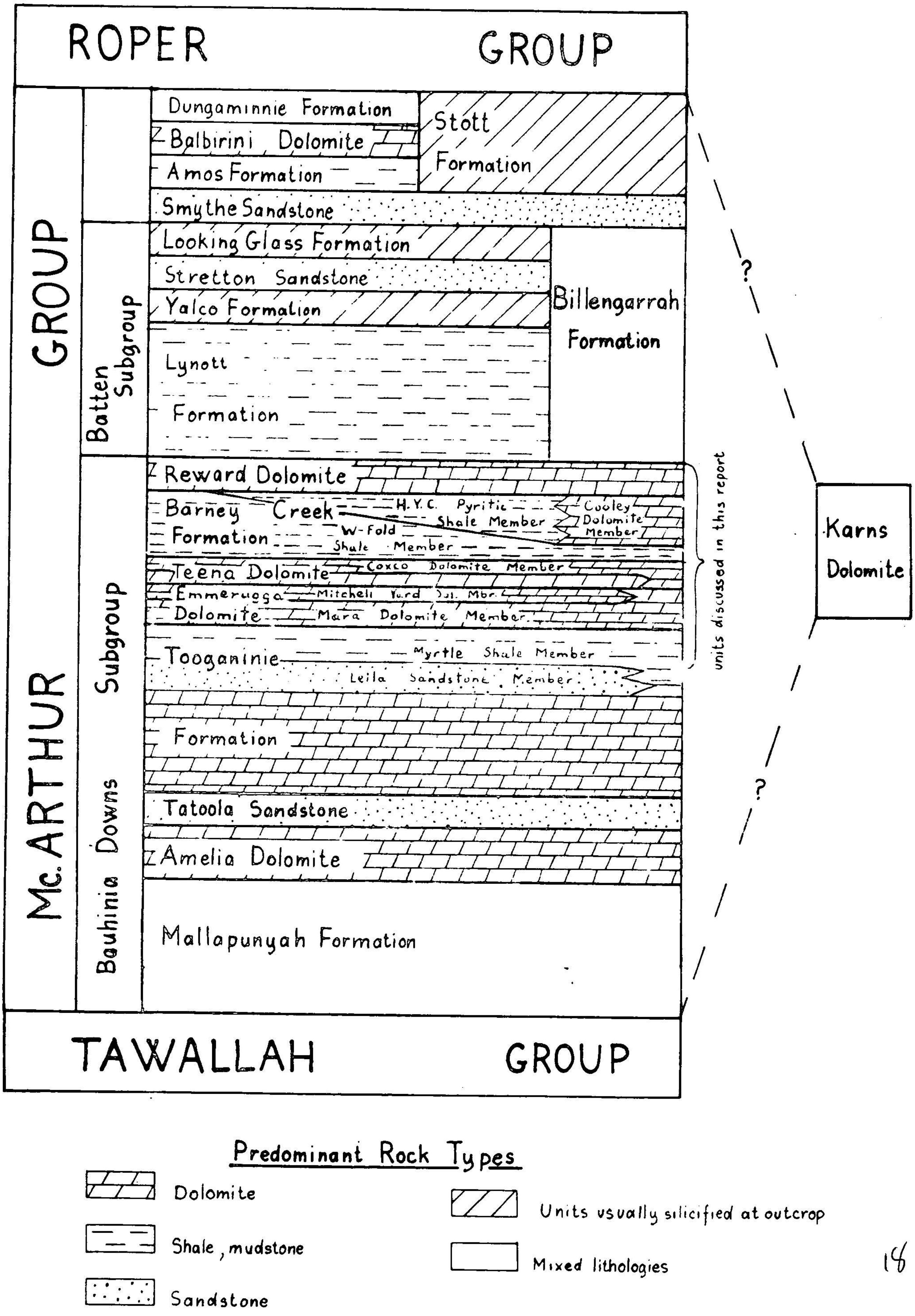


Fig. 2. GENERALIZED VERTICAL SEQUENCE, MYRTLE SHALE MEMBER TO REWARD DOLOMITE

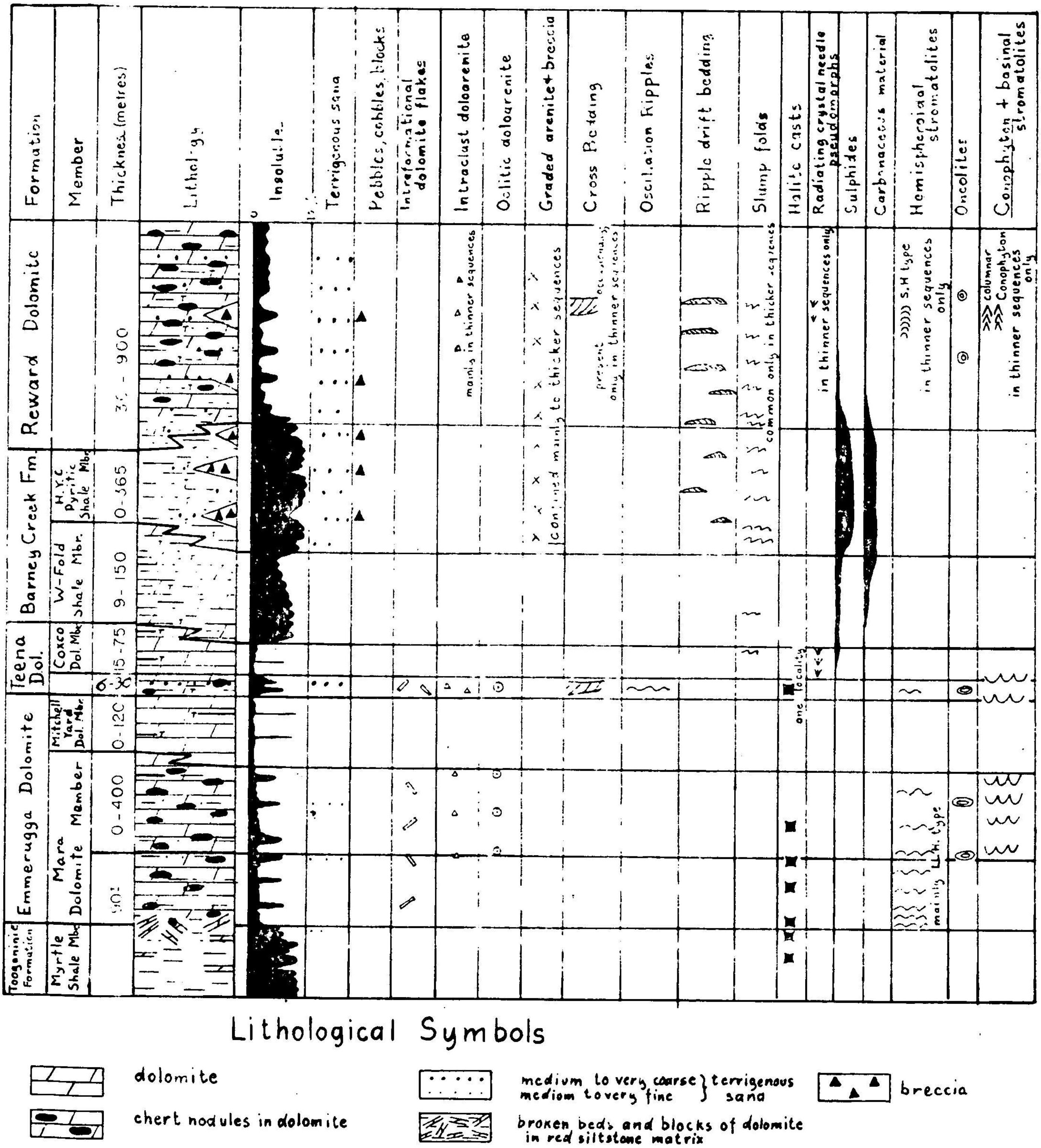
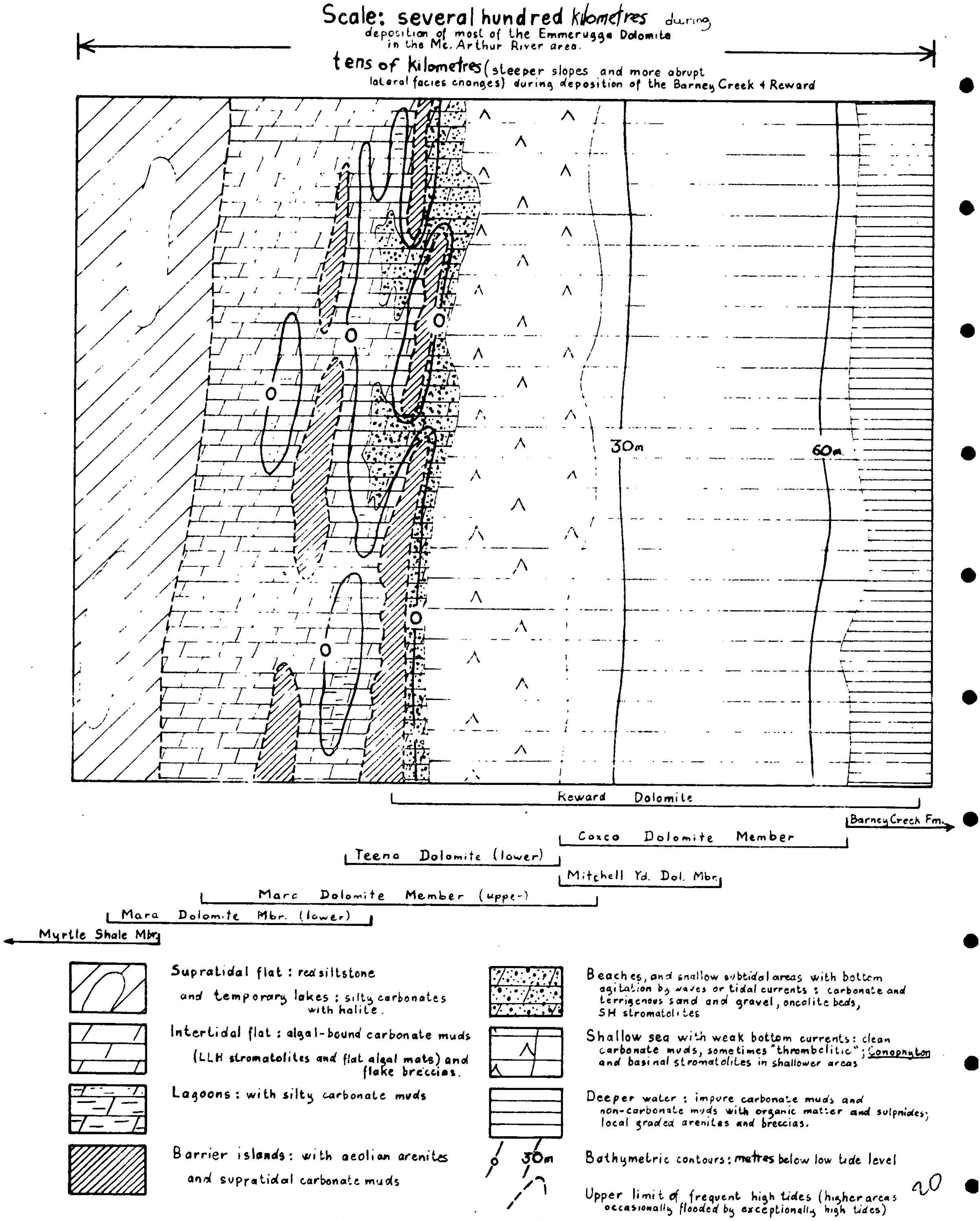


FIG. 3

PHYSIOGRAPHIC PLAN (DIAGRAMMATIC) OF DEPOSITIONAL ENVIRONMENTS

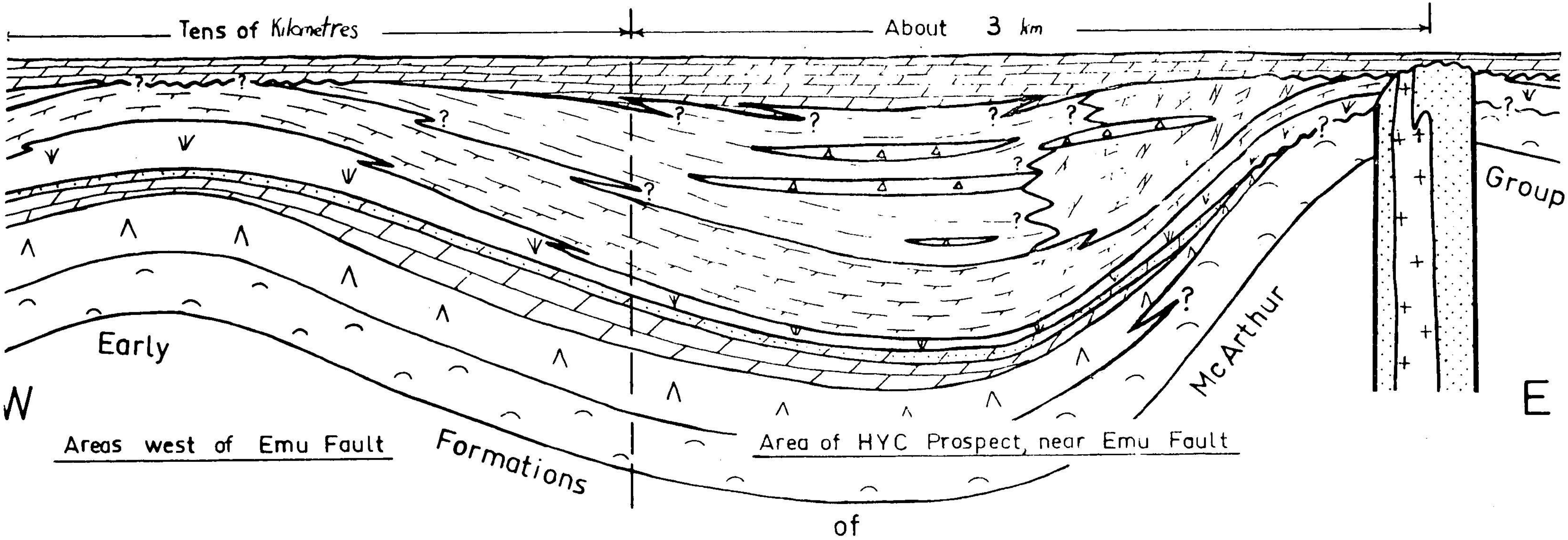


20

To accompany Record 1962/145

STRATIGRAPHIC RELATIONSHIPS of EMMERUGGA DOLOMITE, TEENA DOLOMITE, BARNEY CREEK FORMATION, & REWARD DOLOMITE

DIAGRAMMATIC E-W STRATIGRAPHIC CROSS SECTION — LATER FOLDING REMOVED



Reward Dolomite		▨	Dolomite, generally cherty; in places sandy or ?tuffaceous; some algal balls; stacked hemispheroidal and conical stromatolites in thinner sections
Barney Creek Formation	H.Y.C Pyritic Shale Member	▤	Shales, ?tuffs, and ?tuffaceous shales with pyrite (also Pb, Zn, Cu sulphides near base) doloarenite and dolomite breccia interbeds.
	Cooley Dolomite Member	▨	Brecciated dolomitite and shale
	W Fold Shale Member	▤	Laminated ?tuffaceous and shaly dolomite; dolomitic ?tuff, and bituminous shale; green and red high-potassium ?tuffaceous mudstone near H.Y.C.
Teena Dolomite	Coxco Dolomite Member	Ѱ	Thick and thin bedded clean dolomite with small radiating crystal needle pseudomorphs; pink ?tuff interbeds common.
		▨	Dolomite with some stromatolites; silty, sandy, and ?tuffaceous dolomite; oolite; sandstone; rare halite casts.
Emmerugga Dolomite	Mitchell Yard Dolomite Member	▨	Thick-bedded clean dolomite, with wisps and tubules of dolomite spar.
	Mara Dolomite Member	Λ	Dolomite, with hemispheroidal, conical, and basinal stromatolites and oncolites; some oolite, silty dolomite, and dolomitic siltstone; halite casts.
		⌢	Dolomite, generally cherty, with hemispheroidal stromatolites; siltstone and silty dolomite interbeds; halite casts
Tawallah Group		▨	Silica-cemented quartz sandstone; microsyenite intrusions

〰 Local unconformity

▌ Fault. (Emu Fault Zone)

Δ Coarse breccias with blocks derived from Mara Dolomite Member, Tawallah Group sandstone, and microsyenite intrusions

FIG. 4.

To accompany Record [illegible]

E53/A3/3'

Member and the Reward Dolomite, interpreted as being a result of regression, is probably younger in more strongly downwarped areas than in structurally higher areas.

SOME FEATURES OF THE SEDIMENTS AND THEIR SIGNIFICANCE

CARBONATE MINERALOGY

Tests on many outcrop samples with dilute acid, and to a lesser extent with weakly acid Alizarin Red S solution, indicate that the carbonate in the rocks is predominantly dolomite with some iron-bearing carbonate in places; the predominance of dolomite has been substantially verified by chemical analyses. Limestone has been found only in drill cores through carbonate pebbles and blocks in breccias at the base of the H.Y.C. Pyritic Shale Member; some of these fragments have been identified, from characteristic radiating acicular crystal, as undolomitised Coxco Dolomite Member. There are two main possibilities for the near absence of limestone:

(a) The carbonate was originally calcium carbonate and has been subsequently dolomitised, either soon after deposition, or much later by processes unrelated to the depositional environment, or

(b) the carbonate was initially deposited as protodolomite or dolomite.

If the compositions of the atmosphere and sea water during deposition were the same as in modern areas of carbonate deposition, (a) is the most likely. Other features of the sediments (discussed later) suggest that the physical conditions during deposition of some units (particularly the Mitchell Yard Member, much of the upper part of the Mara Dolomite Member, and probably the Barney Creek Formation and Reward Dolomite) would have resulted in calcium carbonate deposition from normal present-day sea water. It could also be inferred that the carbonates which were deposited in shallow water of restricted circulation and raised salinity (e.g. lower part of the Mara Dolomite Member) would probably have been deposited as dolomite, or, more likely, precipitated as calcium carbonate and dolomitised during early diagenesis.

During the long period since the deposition of the McArthur Group, late diagenetic dolomitisation of the bulk of any calcium carbonate originally in the sequence could have been accomplished by reaction with Mg-rich groundwater. The limestone-bearing breccias at the base of the H.Y.C. Pyritic Shale Member are enclosed in carbonaceous shale and have a carbonaceous shale matrix; this has apparently prevented access of dolomitising solutions.

IRON CONTENT

The carbonate minerals all contain varying amounts of $FeCO_3$ in solid solution. The amount of iron carbonate in carbonate rocks is an important indicator of oxidation potential during deposition or diagenesis, since iron in the oxidised (ferric) state cannot enter carbonate lattices. The total iron content has been determined for all samples chemically analysed, and its distribution within the rocks checked by staining thin sections and cut surfaces with a dilute weakly acid solution of potassium ferricyanide and Alizarin Red S. This stains iron-rich dolomite blue, while low-iron dolomite remains unstained; iron-rich calcite stains mauve, while low-iron calcite stains red.

Samples from the Mara Dolomite Member, especially the lower part, have a low total Fe content (generally < 0.5%); the Mitchell Yard Dolomite Member and the Teena Dolomite have a similarly low Fe content over most of their outcrop. This probably indicates an oxidising environment during deposition, and little or no introduction of iron during diagenesis. Some of the red dolomitic mudstones of the Myrtle Shale Member have a high total Fe content (up to 4%), occuring as finely divided hematite rather than in the carbonate lattice.

The W-Fold Shale Member and H.Y.C. Pyritic Shale Member of the Barney Creek Formation generally contain organic material and the total iron content is frequently high (0.5% to 4.6%), occurring, except for red sediments in the W-fold Shale Member near the H.Y.C. deposit, as iron-rich dolomite. Both deposition and diagenesis of these organic-rich sediments would have been

23

under reducing conditions. Detrital dolomite and limestone fragments in arenites and breccias in the H.Y.C. Pyritic Shale Member usually have a low iron content, except for a thin rim of iron-rich carbonate produced during diagenesis in a reducing environment.

Within a semi-circular area extending approximately 14 km west, north, and south from the H.Y.C. deposit, the Teena Dolomite, the Mitchell Yard Dolomite Member, samples from near the top of the Mara Dolomite Member, and the Cooley Dolomite Member all have unusually high iron contents (2% to 4%); in all other respects the Emmerugga and Teena Dolomites resemble their outcrops in the other areas where the iron contents are much lower. There is no indication that the depositional environment of these particular units was any different near the H.Y.C., hence the iron was probably introduced during diagenesis, perhaps during dolomitisation of original calcium carbonate. This is further supported by the low-iron fragments of undolomitised Coxco Dolomite Member in the H.Y.C. drill cores.

On the other hand, the zinc-lead mineralisation in the Barney Creek Formation and the iron-rich dolomites in the underlying carbonates seem to have the same areal distribution: within the area of iron-rich dolomites boreholes in several outliers of Barney Creek Formation have encountered sphalerite and less commonly galena, while elsewhere the Barney Creek Formation seems to be 'barren'. Dr. I. B. Lambert (personal communication, 1969) suggested that the iron-rich dolomites may be related to the genesis of the H.Y.C. zinc-lead deposit; if the sulphides were deposited on the sea floor from hot-brine solutions coming from below, then these solutions would permeate unconsolidated carbonate sediments beneath the sea floor, and any ferrous iron in solution could be readily incorporated into the carbonate.

The iron-rich dolomites are particularly striking in outcrop: while fresh rocks are grey to dull grey on broken surfaces, weathered surfaces have a buff to red skin of limonite and hematite. Weathered surfaces of low-iron rocks elsewhere are typically greyish. The iron-rich dolomites are easily recognisable in the field and may be useful prospecting guides. They are so far not known anywhere away from the known H.Y.C.-type mineralisation.

CHERT

Chert occurs as thin laminae, tabular masses, and ellipsoidal to irregular nodules in the carbonate rocks. The outlines of chert nodules transgress sedimentary laminae, and the silica appears to have migrated into its present situation and replaced pre-existing carbonate. It is particularly abundant in stromatolite-bearing Mara Dolomite Member, and is generally abundant in the Reward Dolomite. It is usually absent from silty dolomites, and is not abundant in thick intervals of clean dololutite such as the Mitchell Yard and Coxco Dolomite Members. In stromatolite-bearing dolomite, chert usually preferentially replaces the domed laminae of LLH-type stromatolites and the upper parts of cones of Conophyton, and the intervening depressions are usually unsilicified or less strongly silicified (Fig. 8C).

The abundance of chert is closely related to the lithology and the stratigraphic position of the enclosing dolomite. It seems most reasonable to assume that the silica was derived from the sediments, and, during diagenesis, migrated over small distances and became concentrated in favourable situations as nodules or laminae. It formed relatively soon after deposition of the sediments because some units (e.g. Reward Dolomite and H.Y.C. Pyritic Shale Member) contain pebbles and grains of chert and cherty dolomite, apparently derived from earlier formations of the McArthur Group.

GRAINSIZE

The grainsize of the sediments can be used as an indication of the energy of the depositional environment, and in general the sizes of carbonate and terrigenous grains in any one specimen are similar. Most of the rocks have been deposited as silt or clay-size grains, capable of being carried in suspension in air or water.

Sand-size and coarser sediments are fairly abundant in the upper part of the Mara Dolomite Member and the lower unit of the Teena Dolomite, locally in the H.Y.C. Pyritic Shale Member, and commonly in the Reward Dolomite. In the Emmerugga Dolomite and parts of the Reward Dolomite, sedimentary structures in the sand-size sediments include cross-bedding, oscillation ripples, flat lamination with primary current lineation, and ripple-drift lamination; the latter is especially common in the Reward Dolomite. These structures, especially the first three, indicate movement of sediment by bottom traction, probably caused by wave action and tidal currents. Graded bedding occurs in rudites and arenites in the H.Y.C. Pyritic Shale Member and parts of the Reward Dolomite.

The grainsize of the sediments in the Emmerugga Dolomite and parts of the Reward Dolomite can be related to the environments illustrated in Figure 3. Sands and coarser sediments are related to areas of shallow water near the open sea, to beaches, and to shallow straits between islands. Silt and clay-size sediments occur on the floor of the sea at depths below wave base and in areas of weak tidal currents, or on intertidal and supratidal flats and in shallow lagoons behind barrier islands and shallow sand shoals.

Arenities and rudites which are locally interbedded with the silt and clay-size sediments of the Barney Creek Formation, and some of the arenites and rudites in the Reward Dolomite, are interpreted as turbidity-current deposits; those in the mineralised part of the H.Y.C. Pyritic Shale Member are discussed by Croxford (1968).

OOLITHS

Dolomite consisting dominantly of well sorted sand-size ooliths, or a mixture of ooliths and intraclasts set in sparry dolomite, is present in the upper part of the Mara Dolomite Member and in the lower Teena Dolomite. Well-sorted oolitic carbonate sands at present form in environments whose limits are well defined: in general they form in water shallower than six metres, in areas of strong tidal currents or wave agitation. They are usually deposited from warm water with salinity higher than that of the open sea. They are also known from the near-shore sediments of salt lakes.

STROMATOLITES

LLH types and flat algal mats

The dominant stromatolites in dolomite of the lower part of the Mara Dolomite Member of the Emmerugga Dolomite belong to the LLH type of Logan, Rezak, and Ginsburg (1964) - stromatolites consisting of domed laminae, with laminae generally continuing across the surrounding depressions into adjacent domes. Adjacent domes are usually close together (type LLH-C). The domes are generally less than 2 cm high near the base of the Emmerugga Dolomite, but increase in size higher in the section. In larger specimens the domes have a 'squashed' appearance - rather flat on top, with overhanging sides. The enclosing rock is laminated dolomite which appears identical to the dolomite of the stromatolites, except that the laminae are flat or only slightly undulating: it seems probable that the LLH stromatolites and the enclosing laminated dolomite were both produced by precipitation and binding of carbonate by mats of algae on the sediment surface. According to Logan and others (1964), such flat algal mats and laterally linked hemispheroidal stromatolites are characteristic of intertidal flats sheltered from wave attack, and they also occur on the floors of temporary saline lakes.

SH types

Columnar stromatolites formed of stacked hemispheroidal laminae, with intervening poorly laminated or unlaminated sediment (type SH of Logan and others, 1964), are locally abundant in the Reward Dolomite and rarely in the Emmerugga Dolomite. In the Reward Dolomite they are abundant in thinner than normal sections, which overlie condensed sections of Barney Creek Formation, and they form columns generally 2.5 cm to 25 cm in diameter and up to 50 cm high. In the Emmerugga Dolomite miniature SH stromatolites with columns about 2 mm in diameter, in places branching, occur in a dolomite about 120 m above the base of the Mara Dolomite Member in Section 9 (Pl.7). Larger SH stromatolites, with columns about 1 cm in diameter, were found in the Mara Dolomite Member about 10 km west of Top Springs homestead in the Wallhallow 1:250 000 Sheet area.

Logan and others (1964) consider that SH stromatolites are formed in the intertidal zone in areas of moderate wave attack. In Shark Bay, Western Australia the height of modern stromatolites of this type is close to the local tidal range.

However, Playford and Cockbain (1969) have reported SH stromatolites, in Devonian fore-reef limestones with marine fossils, down to a vertical distance of about 45 m below the top of the fore-reef slope.

SS types (oncolites)

Stromatolites which have grown around a nucleus and are not attached to the bottom (type SS of Logan and others, 1964), occur in the upper part of the Mara Dolomite Member, at one locality in the lower unit of the Teena Dolomite, and probably also in the Reward Dolomite. Those in the Emmerugga Dolomite are generally ellipsoidal in shape and are built up of continuous laminae wrapped around a dolomite flake nucleus.

The building of continuous laminae around a nucleus has previously been interpreted as requiring frequent rolling-over of the structure while it is growing, and hence agitated water (e.g. Logan and others 1964), but more recently present-day examples have been found in several quiet marsh and supratidal lagoon environments (M. R. Walter. personal c1977).

Conophyton and giant dome-shaped stromatolites

Stromatolites composed of successive conical laminae (Conophyton) are characteristic of the upper part of the Mara Dolomite Member, and are also commonly present at the bottom and top of the lower unit of the Teena Dolomite; they also occur in the Reward Dolomite where the unit consists mainly of clean dolomite containing SH stromatolites. At some localities conical stromatolites have grown up from a substrate of flat laminated dololutite, and the laminae of adjacent stromatolites. are continuous across the intervening depressions (Fig. 5). At other places adjacent stromatolites are packed close together and form columns of stacked cones, the columns having polygonal cross-sections as in columnar basalt and dolerite (Figs. 6a, b). The cones are up to 45 cm in diameter at the base, and the apical angle is usually acute (about 60°). At several localities the heads of large conical stromatolites are overlain by giant closely packed, laterally linked dome-shaped stromatolites up to 60 cm across (Fig. 7).

In the upper part of the Mara Dolomite Member close, laterally linked conical stromatolites (as in Fig. 5) grade into a 'basinal' variety of Conophyton (Figs 8a, b, c) in which shallow cuspate 'basins' separate widely-spaced polygonal to ridge-shaped columns, with low relief of laminae (Fig. 8). Figure 9 shows the geometrical relationships between the two types of Conophyton.

Conophyton appears to be fundamentally different from the stromatolites discussed previously, and from known Phanerozoic and most present-day algal stromatolite structures. According to Cloud (1968) the regular cone shape of Conophyton is restricted to the Precambrian.*

The cone, basin, and regular giant dome shapes are difficult to interpret merely as sedimentary structures controlled by the interaction of a sediment-trapping algal mat with the physical environment; they seem to be primarily controlled by the organisms themselves, and are probably characteristic of the organisms themselves rather than the passive response of the organisms to their environment. Their regular shape and even laminations, without desiccation features, are difficult to reconcile with the very variable physical conditions of an intertidal carbonate mud flat.

An indication of the environment of deposition of the dolomites containing Conophyton is provided by their position in the Emmerugga Dolomite, relative to rock types whose environment can be interpreted more readily. In general they are characteristic of the upper part of the Mara Dolomite Member, where the associated sediments are of shallow subtidal to sheltered intertidal origin, and they occur between dolomites of predominantly sheltered intertidal origin below and the overlying mainly uniform clean dololutites of the Mitchell Yard Dolomite Member, which are probably shallow marine. They also commonly occur at the transition between the mainly shallow subtidal

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*Recent Conophyton stromatolites are now known from hot springs in Yellowstone National Park (Walter, Bauld, & Brock, 1976).

Fig. 5. Vertical section of large Conophyton with laminae of adjacent conical heads continuing across intervening depressions. Locality; about 1.5km SSW of Top Crossing. Upper part of Mara Dolomite Member, about 115m above base of Section 4.

B.M.R. Neg. No. M/822/2.

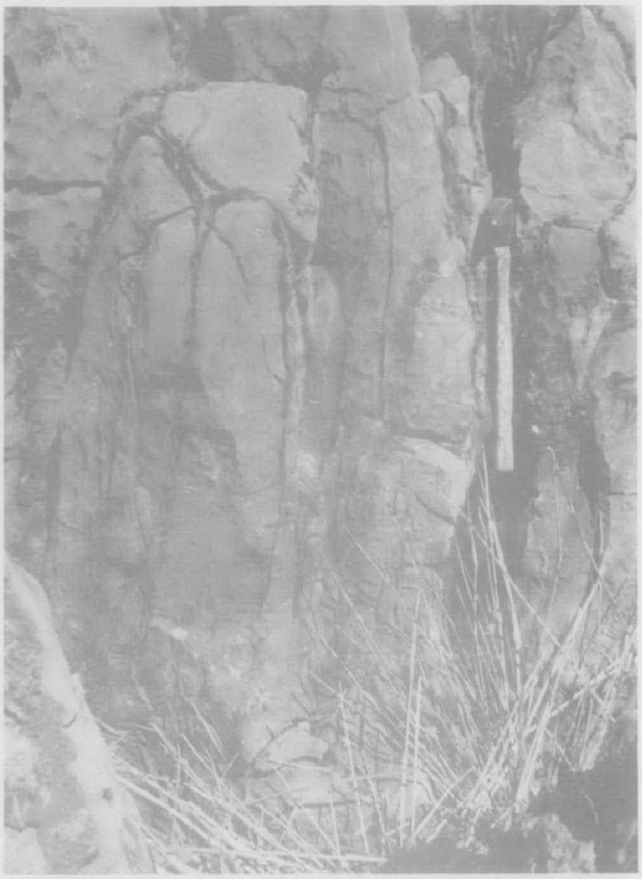


Fig. 6a. Vertical section of bed of dolomite consisting of closely stacked cones of Conophyton. Bedding is sub-horizontal, and cones are in vertical stacks. Locality; about 6.5km SE of "Bauhinia Downs". Upper part of Mara Dolomite Member, about 150m above base of Section 7.

B.M.R. Neg. No. M/822/15.

Fig. 6b. Same bed as above, looking down on a surface parallel to the bedding, showing cross sections of closely-packed vertically stacked cones

B.M.R. Neg. No. M/522/16.

Fig. 7. Conical stromatolite head (Conophyton)in centre of photograph; later laminae above it change progressively from conical to hemispheroidal (at level of hammer head). Locality; 2.5 km SW of Top Crossing. Upper part of Mara Dolomite Member.

B.M.R. Neg. No. M/822/17.

Fig. 8a. Vertical section of bed of dolomite consisting of basinal stromatolites. Locality; about 4km WSW of junction of Daly Waters road with new road from Anthony Lagoon to Borroloola. Upper part of Mara Dolomite Member.

B.M.R. Neg. No. M/544/34.

Fig. 8b. Same bed as above, looking down on surface parallel to bedding.

B.M.R. Neg. No. M/544/35.

Fig. 8c. Dolomite with stromatolites transitional between Conophyton and basinal types, looking down on surface parallel to bedding. Ridges between basins are in places silicified and stand out on weathered surface; peaks at junctions of three or more basins have mainly cuspate cross sections, but in places (e.g. just above centre of photograph) have circular cross sections at the centre. Scale is in inches. Locality; 1 km SW of Amelia No. 1 diamond drill hole. Base of Teena Dolomite, about 115m above the base of Section 12.

B.M.R. Neg. No. M/822/30.

to intertidal sediments of the lower unit of the Teena Dolomite and the uniform clean dololutites of the overlying Coxco Dolomite Member or underlying Mitchell Yard Dolomite Member. The simplest explanation of these relationships is that Conophyton-bearing dolomites are probably subtidal, deposited at a depth shallow enough for prolific growth of algae. Figure 3 shows their probable physiographic setting during deposition.

HALITE

Moulds and casts of cubic crystals, usually with the hollow-faced 'hopper' shape characteristic of halite, are common in some sediments. They usually occur in laminated dolomitic siltstone and silty dolomite, but have been found in flat-laminated very fine dolomitic sandstone at about 70 m above the base of Section 4(Pl.4). The casts are generally filled by sediment differing from that in which the crystals were embedded, but examples have been found in dololutite where no sediment has entered the cast, and it is now partly filled with clear dolomite crystals which have grown inward from the walls. Pseudomorphs are preserved as casts when the infilling sediment is the less resistant, or as moulds when the infilling sediment is the more resistant. At one locality near the base of the Emmerugga dolomite, 9 km north of Bauhinia Downs homestead, silica boxworks in dolomite have cubic crystal symmetry and apparently represent silica replacements of skeletal halite.

Halite casts and moulds are particularly abundant towards the top of the Myrtle Shale Member, as moulds on thin interbeds of laminated pale green dololutite. They can nearly always be found by careful search of silty dololutite or dolomitic siltstone intervals in the overlying Mara Dolomite Member. They have been found at two places in the lower unit of the Teena Dolomite in weathered (probably formerly dolomitic) buff mudstone Section 8, Plate 6, around 180 m above the base of the section, and at a locality about 1 km to the south). They have not been found in the Mitchell Yard or Coxco Dolomite Members, the Barney Creek Formation, or the Reward Dolomite. Silica replacements of halite have only been found in dolomites at the base of the Emmerugga Dolomite.

Halite casts indicate that the sediments in which they occur were probably deposited from saline lakes or shallow lagoons with restricted access to the sea, in a climate in which evaporation exceeded precipitation. It is not yet clear whether the crystals grew at a sediment-water interface due to evaporation from the water surface, or within soft sediments due to evaporation of interstitial water from an exposed sediment surface above a shallow saline water table; in the latter case the environment of deposition of the enclosing sediments need not necessarily be the same as that which caused precipitation of halite. It still seems valid nonetheless to infer that the presence of halite casts at intervals within a stratigraphic unit implies the periodic existence of saline lake or restricted lagoonal environments during its deposition.

TERRIGENOUS SILT AND CLAY

Terrigenous silt and clay is most abundant in the Myrtle Shale Member, and generally decreases in abundance from the base to the top of the Mara Dolomite Member. It is virtually absent from the thick-bedded dolomite of the Mitchell Yard Dolomite Member, increases in the lower part of the Teena Dolomite, and decreases with the incoming of the Coxco Dolomite Member. It gradually increases towards the top of the Coxco Dolomite Member and is an important constituent of the Barney Creek Formation. It is a minor constituent of the Reward Dolomite.

Two main factors control the ration of carbonate to terrigenous silt or clay - firstly the distance from the source of terrigenous sediment, and secondly the rate of deposition of carbonate sediment. The first probably explains most of the variation of silt and clay content of the Myrtle Shale Member, Emmerugga Dolomite, and Teena Dolomite, but the high clay and silt content of the Barney Creek Formation may reflect an environment unfavourable for carbonate precipitation (?deep water) and a slow rate of sedimentation.

Silt and clay may be carried in suspension by both air and water. During the deposition of the McArthur Group wind transport was probably an important mechanism: land plants were absent, and the climate was probably dry (ubiquitous halite casts). The silt and clay of the

36

subaerial(?) Myrtle Shale Member could have been transported to the depositional site largely by wind, and the silt and clay of other lacustrine, intertidal, lagoonal, and marine sediments could have been transported by both wind and water.

TERRIGENOUS SAND AND COARSER DETRITUS

Quartz sand, much of it coarse grained, is fairly abundant in the lower unit of the Teena Dolomite and locally abundant in the H.Y.C. Pyritic Shale Member and the Reward Dolomite; some sand is present locally in the Mara Dolomite Member, mainly in the south near the boundary between the Bauhinia Downs and Wallhallow Sheet areas. In the H.Y.C. Pyritic Shale Member and Reward Dolomite the quartz sand is usually accompanied by sand-size grains of dolomite and, in places, by pebbles of chert and dolomite and cobbles and boulders of cherty dolomite, sandstone, and microsyenite; the carbonate and chert clasts are probably derived from lithified McArthur Group, and the sandstone and microsyenite from the Tawallah Group.

The incoming of coarse terrigenous detritus after long periods of mud deposition is interpreted as due to tectonic movements increasing topographic relief and bringing sources of coarse terrigenous detritus closer to the depositional site. Sand and pebbles may have been transported many tens, or possibly hundreds, of kilometres, by streams, longshore drift, and tidal currents, but local sources are required for cobbles and boulders.

The terrigenous detritus was deposited in a variety of environments by a variety of mechanisms. Sand and pebbles accumulated as beach deposits and probably in shallow tidal channels. Sand and coarser detritus were locally carried down slopes by turbidity flows and boulder slides and deposited in deep water below the influence of waves and tidal currents.

OXIDATION STATE OF SEDIMENTS

In all exposures, the Myrtle Shale Member and Mallapunyah Formation are mostly red or, in places, red-brown and purple, indicating that iron is

37

present mainly as primary hematite. These red beds indicate an oxidising atmosphere during deposition of the McArthur Group.

In the Emmerugga Dolomite, Teena Dolomite, Barney Creek Formation, and Reward Dolomite the iron is mostly reduced. The main colours are green-grey and grey, and the iron occurs in carbonates, clay minerals, and, in the Barney Creek Formation, in sulphide; pale brown and brown-grey colours in parts of the Emmerugga Dolomite may indicate small amounts of hematite. The iron was probably reduced by organic matter soon after deposition. The pyrite and other sulphides in the Barney Creek Formation appear to be part of the sedimentary sequence (Cotton, 1965), and may have been precipitated by biochemical reduction of sulphate ions in sea water.

In some areas of outcrop (west of Mallapunyah homestead, the Amelia Creek area, and the area near Section 11) the Emmerugga Dolomite, Teena Dolomite, Barney Creek Formation, and Reward Dolomite are mainly red, purple, and pink. Here the McArthur Group is exposed just below regional unconformities beneath Cambrian carbonates and sandstone; secondary oxidation apparently occurred during Adelaidean or early Cambrian weathering.

TUFFS AND POTASSIUM CONTENT

In the upper part of the Mara Dolomite Member, the Mitchell Yard Dolomite Member, and the Coxco Dolomite Member, sections of predominantly near-uniform dololutite are abruptly interrupted in places by beds of fine-grained non-carbonate rock, varying from about 2 cm up to several metres thick. The beds are structureless to well-laminated, and buff to pink in colour. They commonly contain rhombs of iron-rich carbonate (ankerite). They have previously been referred to as 'sideritic chert' in field notes. The beds often pinch and swell, intrude cracks in dolomite, and have a strongly-contorted laminae - although now hard, they appear to have been soft and plastic early in their history. They are characterised by a very high potassium content (up to 12%) and are composed mainly of microcrystalline orthoclase.

Apparently identical rocks also occur in the Barney Creek Formation, Reward Dolomite, and younger formations of the McArthur Group (e.g. Yalco Formation, Stretton Sandstone, Amos Formation, and Dungaminnie Formation).

In the Barney Creek Formation and Reward Dolomite the potassium-rich beds are between a few millimetres and several metres thick. They are pale grey to green and generally stand out on weathered surfaces. Insoluble residues of specimens from the Barney Creek Formation contain between 3.5% and 10% potassium (Croxford, 1968; Claxton, Part 2 of this report). One specimen from near the base of the Reward Dolomite has an insoluble residue with 8.5% potassium.

Thin sections of Barney Creek Formation, from outcrop and boreholes, show clear outlines of abundant former glass shards, and Croxford and Jephcott (1972) recognise outlines of glass shards in potassium-rich beds in the mineralised H.Y.C. Pyritic Shale Member. C.E.C. geologists regard the high-potassium rocks of the McArthur River area as tuffs, and the present study tends to confirm this interpretation.

Remnants of glass shards have not been seen in the potash-rich beds of the Emmerugga Dolomite or Coxco Dolomite Member, but their occurrence as thin interbeds in otherwise uniform clean carbonates, suggesting sudden rapid deposition, is consistent with a volcanic ash fall.

Ash falls alone do not account for the high potassium content which exceeds that of all but a few rare igneous rock types; the potassium has probably been introduced. Swett (1968), in discussing high-potassium mudstone associated with dolomitised carbonates in the Cambrian of northwestern Scotland, has suggested that the potassium could have come from replacement of illitic limestones by dolomite; this would suggest that at least some of the McArthur Group dolomite has replaced limestone. Lambert and Scott (1973) have more recently suggested that the high potassium content is due to formation of illite and potassium felspar by reaction between unstable tuffaceous material and saline pore waters.

DESCRIPTION AND INTERPRETATION OF INDIVIDUAL ROCK UNITS

MYRTLE SHALE MEMBER OF THE TOOGANINIE FORMATION

The upper part of the Tooganinie Formation consists mainly of red dolomitic silstone. Thin interbeds of dololutite and silty dololutite, often with halite casts, increase in abundance near the top. The appearance of cherty dololutite with stromatolites marks the boundary between the Myrtle Shale Member and overlying Emmerugga Dolomite, but interbeds of red dolomitic silstone continue into the Emmerugga Dolomite above this boundary; red dolomitic siltstone, silty dololutite, and cherty dololutite with stromatolites, are usually interbedded in a transition zone about 30 m thick. The transition zone is commonly brecciated: the dolomite is broken into blocks from several metres to a few millimetres across, and red dolomitic siltstone matrix fills the fractures.

The red dolomitic siltstone is interpreted as a subaerial deposit, composed largely of wind-transported dust. The incoming of dololutite interbeds at the top of the Myrtle Shale Member indicates the early stages of a transgression; shallow incursions of sea water or salt lakes occasionally flooded the surface and deposited carbonate. Evaporation raised the salinity of the interstitial and surface water, sufficiently to precepitate halite; later incursions sometimes dissolved the halite crystals, and sediment filled the cavities.

Because of the wide range of sizes of blocks and lack of evidence for their transport, the brecciated zone at the base of the Emmerugga Dolomite seems best explained by solution collapse. The sediments at the top of the Myrtle Shale Member probably built up high concentrations of halite, which then slowly dissolved as incursions of seawater became more frequent during deposition of the lower Emmerugga Dolomite. The reduction in volume caused the more competent carbonates to fracture, and softer silt and clay (probably in part an insoluble residue of the halite-rich sediments) squeezed between the blocks. Examples of similar solution collapse breccias, where aeolian siltstones were covered by incursions of the sea, are described from back-reef sediments of the Permian of West Texas (C.G. St C. Kendall, pers. comm.), the Devonian of Canada (Beales & Oldershaw, 1969), and the Cretaceous of Guatemala (Blount & Moore, 1969).

MARA DOLOMITE MEMBER OF THE EMMERUGGA DOLOMITE

The lower member of the Emmerugga Dolomite, the Mara Dolomite Member, is at least 500 m thick near Mara Hill, 6.5 km south of the H.Y.C. deposit, and is probably of similar thickness at the H.Y.C. Elsewhere it is thinner (e.g. 229 m in Section 4 (Pl. 4) near Top Crossing, 183 m in Section 7 (Pl. 5) near Bauhinia Downs homestead). It consists mainly of cherty dololutite containing abundant stromatolites, some interbeds of dolomitic siltstone and silty dololutite with halite casts, and minor very fine to fine-grained dolomitic sandstone. Intraformational dolomite-flake breccias and intraclast doloarenites are fairly common in the upper part of the unit, which also contains some intervals of oolitic doloarenite. Occasional intervals of chert-free thick-bedded to unbedded clean dololutite in the upper part of the unit increase in importance upward in the section. The upper boundary of the Mara Dolomite Member is arbitrarily placed where stromatolites disappear, and thick-bedded clean dololutites become the only rocks in the section.

The stromatolite types in the Mara Dolomite Member change fairly systematically from the base to the top of the unit. The lower part contains mainly small, laterally linked hemispheroidal types (type LLH of Logan and others, 1964) and flat-laminated algal-mat carbonates. The LLH stromatolites become larger in the upper part of the unit, and beds of <u>Conophyton</u> appear. Oncolites also occur in the upper part of the unit. The lower part of the member, with the small LLH stromatolites, is generally about 90 m thick; the main variations in thickness occur in the upper part.

If the stromatolites were formed in similar environments to present-day stromatolites, as outlined by Logan and others (1964), then the common LLH stromatolites and the flat-laminated algal-mat sediments were deposited in the intertidal zone of areas sheltered from wave attack, with water of high salinity and restricted access

41

to the open sea, or in ephemeral salt lakes not connected with the sea. The common halite casts in dolomitic siltstone, fine sandstone, and silty dololutite interbeds were probably deposited when access to the open sea was more restricted than during deposition of the stromatolitic carbonates, and salinity was raised sufficiently to precipitate halite; it is not certain whether the sediment surface was mainly subaqueous or subaerial. The very fine to fine-grained dolomitic sandstone at about 97.5 m in Section 4 (Pl. 4) is flat-laminated, with primary current lineation on bedding surfaces, and was probably deposited at the shore of a lagoon or saline lake.

The upper part of the Mara Dolomite Member, as well as containing some intervals of sediments deposited in sheltered tidal flats, lagoons, or salt lakes, also contains sediments probably deposited from water with more open access to the open sea, and mainly below low-tide level. The oolitic doloarenites are the main indicators of shallow marine conditions, and beds of Conophyton and clean massive to thickly laminated dololutite, are also thought to have been deposited below wave and low tide base.

Two hypotheses can explain alternations of more marine and less marine sediments superimposed on the overall transgressive character of the Mara Dolomite Member: firstly, the alternations could have resulted from relative rises and falls of mean sea level or, alternatively, the area may have subsided at a fairly steady rate, the alternations being controlled by sedimentary processes. As an example of the latter, Figure 3 shows open-marine conditions separated from tidal-flats and lagoons by barriers built up where a gently-sloping marine shelf rises to the shallow depth favourable for rapid carbonate deposition. With steady, slow subsidence the barrier crests could migrate seaward while the increasingly large restricted areas behind fell below sea level, until the system became unstable, the barriers broke down, and there was an influx of sea water over the formerly restricted areas. The process would be repeated as new barriers grew and migrated seaward.

MITCHELL YARD DOLOMITE MEMBER OF THE EMMERUGGA DOLOMITE

The Mitchell Yard Dolomite Member is nearly 120 m thick in the type area, 3.2 km southwest of old McArthur River homestead, but elsewhere is generally between 15 and 45 m thick. It is absent from sections near the Emu Fault zone. It is typically thick-bedded, the beds in places appearing to consist of thick overlapping lenses. It lacks the stromatolites and abundant chert of the Mara Dolomite Member. The dolomite varies in texture from uniform dololutite with occasional wisps of clear dolomite spar, to various types of breccia or pseudobreccia, consisting of abundant flakes of dololutite (apparently broken laminae), blocks of thin-bedded dololutite, or flake-shaped patches of sparry dolomite, set in a matrix of unlaminated dololutite. The textures are sometimes accentuated in placed by the partial or complete silicification of the 'clasts'.

The presence of a dololutite matrix suggests that the brecciation is not due to strong current or wave action. Possible mechanisms could involve collapse, resulting either from solution of evaporite minerals or decomposition of algal filaments within carbonate mud; more petrographic work is necessary to confirm this.

The uniform nature of the Mitchell Yard Dolomite Member and lack of chert suggests a subtidal environment of deposition, either shallow marine (as in Figure 3) or subtidal lagoons.

TEENA DOLOMITE

The Teena Dolomite can be divided into two units. The Coxco Dolomite Member at the top has some similarities with the Mitchell Yard Dolomite Member, and the underlying unnamed unit (lower Teena Dolomite) resembles parts of the Mara Dolomite Member.

The lower Teena Dolomite consists of between 6 m and 30 m of cherty dololutite (in places containing stromatolites), shaly beds (rarely with halite casts), oolitic and intraclastic doloarenties, dolomite-flake breccias, cross-bedded coarse sandy doloarenite and dolomitic sandstone, and some fine-grained dolomitic sandstone and sandy doloarenite with oscillation ripple marks and primary current lineations. Conophyton occurs at the top and bottom of the unit at several localities. The unit comprises mainly clean dolomite in the Top Crossing and Bauhinia Downs areas, and the content of terrigenous sand, silt, and clay increases towards the McArthur River area.

The sediments are probably of shallow subtidal and intertidal origin (indicated by the presence of oolitic carbonate, dolomite flake breccias, and flat laminated sandstone with primary current lineation). The dolomite with Conophyton, at the base and top of the unit, is interpreted as a shallow subtidal facies.

The lower Teena Dolomite is a valuable stratigraphic marker, being thin and marking a single short-lived cycle of regression and transgression. This suggests that it probably represents an approximate time marker, and synchronous deposition of such a uniform shallow-water facies over such a wide area in turn implies very shallow to flat depositional slopes.

The Coxco Dolomite Member comprises clean dololutite, similar to the Mitchell Yard Dolomite Member, but the Coxco Dolomite Member is generally thinner bedded and contains frequent thin interbeds of buff to pink potash-rich mudstone. It is characterised by the presence, in places in great abundance, of radiating aggregates of small acicular crystal casts which have grown upward from points on bedding surfaces. The needles are mostly about 50 mm long and 1 mm thick, they are now composed of clear crystalline dolomite, and cross-sections are nearly regular hexagons. They grew before compaction and lithification since laminae now drape over them; it is not certain whether they grew in soft sediment, entirely below the sediment-water interface, or whether they grew upward from the sediment surface. From their shape, habit of growth, and presence in a carbonate rock, they were originally interpreted by the authors as aragonite pseudomorps. More recently, Walker and others (1977) have identified them as pseudomorphs after acicular needles of gypsum, and pointed out analogies with modern examples growing in shallow brine pools on the sabkhas of the Trucial Coast. We now concur with this conclusion. During 1977, geologists participating in a BMR reconnaissance tour of the McArthur Basin found cuspate gypsum pseudomorphs in the Coxco Dolomite Member in Barney Creek, underlying the H.Y.C. deposit.

Small columnar Conophyton occur in the lower few metres of the unit. During 1977 Plumb and others identified abundant stratiform stromatolites in the unit, but Brown considers they may be normal bedding, deformed by differential compaction over gypsum or by soft sediment sliding.

The thickness of the Coxco Dolomite Member ranges from about 22 to 100 m; the thinner sections are thinner bedded and contain more impurities. Locally the Coxco Dolomite Member has behaved incompetently and is fairly tightly folded. In many outcrops it is brecciated, blocks of bedded dololutite being enclosed in a matrix of unbedded dololutite.

The authors are not in complete agreement on the interpretation of the environment of deposition of the Coxco Dolomite Member. A restricted hypersaline environment is clearly indicated by the ubiquitous gypsum, and clean dololutites indicate a subtidal environment without strong currents. Because of the gypsum and the shallow environment indicated by stromatolites, Plumb favours brine pools and lagoons, in a larger sabkha complex. Because the Coxco Dolomite Member is part of a broad transgressive cycle, from lower Teena Dolomite to Barney Creek Formation, Brown favours deposition on the floor of a large hypersaline water body (sea or lake), with restricted access to the open ocean.

BARNEY CREEK FORMATION

The Barney Creek Formation contains much more non-carbonate material than the underlying dolomites; the principal non-carbonate components are microcrystalline potash feldspar, terrigenous silt and clay, locally abundant sulphides, and carbonaceous and bituminous material. Locally at the H.Y.C. deposit arenite and breccia interbeds occur in the upper member of the formation. The detritus in the arenites and breccias is derived from older carbonate rocks, sandstone, and igneous rocks, and includes blocks several tens of metres across.

The contact with the underlying Coxco Dolomite Member is gradational over a few metres of section, and locally carbonate-rich and carbonate-poor sediments alternate in a zone up to 10 m thick.

Within the area of the Bulburra Depression (Murray, 1975), where the Barney Creek Formation is thickest the Coxco Dolomite Member is notably thinner than elsewhere, suggesting that downwarping and deposition of the Barney Creek Formation began sooner in this area, while cleaner carbonates continued to accumulate in the surrounding shallow-water areas.

The Barney Creek Formation is divided into a lower W-Fold Shale Member, an upper H.Y.C. Pyritic Shale Member, and, east of the H.Y.C. deposit, a Cooley Dolomite Member.

W-Fold Shale Member

The W-fold Shale Member is the lower and most laterally-persistent member of the Barney Creek Formation; it varies in thickness from about 5 m to 150 m. Near the H.Y.C. deposit it consists of green and red, probably tuffaceous, mudstone and dolomitic mudstone; away from the H.Y.C. deposit it is generally grey. The dolomite content is variable: both regionally and locally, thinner sections consist mainly of shaly laminated dolomite, rather than dolomitic shale which characterises thick sections.

H.Y.C. Pyritic Shale Member

The H.Y.C. Pyritic Shale Member is characterised by a high content of carbonaceous material and sulphides. The sulphides are mainly pyrite, but also include the bedded sphalerite and galena of the H.Y.C. deposit. The member is thickest (about 400 m) at the H.Y.C. deposit, abuts against the Cooley Dolomite Member to the east, and thins gradually to the south and west, to 30 m or less within 25 km.

At the H.Y.C. deposit the member consists of interbedded and interlaminated fine sulphide and carbonaceous shale, interrupted by beds of graded doloarenite and graded pebble breccias, thick intervals of dolomite boulder breccia, and some beds of grey-green tuff. Beds of sphalerite/galena (about 30 m thick) occur near the base of the member, separated from the W-Fold Shale Member by about 20 m of carbonaceous shale with limestone and dolomite breccia interbeds ('lower dolomitic shales'). Outcrops are sparse and the pyrite has weathered to iron oxides in outcrop. Apart from limited exposures in Barney Creek, the member is known mainly from drill cores from which C.E.C. geologists have worked out a detailed stratigraphy (Murray, 1975).

Borehole Te 115 (Pl. 14), which intersected one of the thickest sections of H.Y.C. Pyritic Shale Member, illustrates the main features of the member, except that the thickness of ore beds is exaggerated (probably by slumping). In Ue 133 (Pl. 15), at the northeastern edge of the orebody, the ore beds are missing and intervals of dolomite breccia are much more important. In measured Sections 2, 7, and 11, small thicknesses (6 m to 11 m) of thin-laminated bleached or ferruginous shale, probably originally pyritic, have been interpreted as possible H.Y.C. Pyritic Shale Member.

Cooley Dolomite Member

The Cooley Dolomite Member, known only from boreholes, overlies the W-Fold Shale Member and passes laterally into and interfingers with the H.Y.C. Pyritic Shale Member (Murray, 1975). Murray describes it as a brecciated dolomite with fine-grained, sometimes sulphide-rich, dolomite filling the spaces between the fragments; carbonaceous intervals are also recorded.

Brown has studied the type section of the member - diamond drillcore Ie 115 (Pl. 13). A thick section of Cooley Dolomite Member overlies a thinner than usual section of W-Fold Shale Member, and the hole bottomed in Coxco Dolomite Member and about 10.6 m of the lower Teena Dolomite. In this core the Cooley Dolomite Member shows the brecciation and fine-grained dark dolomite void-fillings noted by Murray. The individual breccia fragments are of a thin-bedded to laminated grey, grey-green, and green dololutite resembling rock types of the underlying Emmerugga and Teena Dolomites; staining reveals that the dolomite is iron-rich. An important feature is the presence of clusters of radiating acicular gypsum pseudomorphs, identical to those in the Coxco Dolomite Member.

Murray (1975) interpreted the Cooley Dolomite Member as a reef complex, developed on a fault block associated with the Emu Fault zone and adjacent to the H.Y.C. orebody.

Most recently, Walker, Logan & Binnekamp (in press) have shown that most of the dolomites lying on top of the fault block (shown diagrammatically in Figs. 1 and 4 in this report and in Murray's (1975) Fig. 4) are in fact Teena and Emmerugga Dolomites, overlying Tooganinie Formation. They restrict the Cooley Dolomite Member to the area immediately adjacent to the H.Y.C. orebody (as in Ie 115), where they interpret it as a talus slope breccia on the scarp of the concealed 'Western Fault', derived from the underlying Teena and to a lesser extent Emmerugga Dolomites, and emplaced penecontemporaneously with the H.Y.C. Pyritic Shale Member.

Interpretations

The fine grain size and persistent laminations indicate that the W-Fold Shale Member and H.Y.C. Pyritic Shale Member were deposited below wave-base, in water deep enough to inhibit growth of algae and precipitation of abundant carbonate; carbonaceous material and sulphides indicate reducing conditions. Sea-floor gradients were steep enough to cause development of ubiquitous small slump folds and, locally near the H.Y.C. deposit, turbidity current transport of sand and gravel and boulder slides of coarser detritus. These slopes partly reflected deposition of varying thickness of the underlying dolomite unit and, probably more importantly, tectonic subsidence, particularly near the H.Y.C. deposit. The minimum water depth during deposition is largely a matter of conjecture, but it was too deep for sunlight to penetrate the water column and hence probably greater than 50 m.

Estimates of water depths for deposition of the H.Y.C. Pyritic Shale Member in the Bulburra Depression (Murray, 1975), based on reconstructions of palaeotopography and depositional slopes, are complicated by the presence of syndepositional fault scarps. A maximum conceivable depth may be derived from the vertical thickness - 550 m - of Cooley Dolomite Member, assuming that it was all deposited in one brief interval so that its thickness equalled approximately the fault scarp down which it slid. These assumptions are probably not valid: the talus deposit probably accumulated slowly as the depression subsided, and the true water depth at any time was less.

REWARD DOLOMITE

The Reward Dolomite contains mainly carbonate and subordinate dolomitic shale, dolomitic coarse sandstone and breccia, and potash-rich mudstone, and occurs between the shaly Barney Creek Formation and the sandy and shaly Batten Subgroup or Billengarrah Formation. The dolomite is mainly dololutite or pelletal or intraclastic doloarenite, and usually contains abundant chert nodules; a characteristic of the unit is small silica-rich spheroids, generally a few millimetres to a centimetre in diameter and of uncertain origin, which occur commonly in beds of impure dololutite.

The formation contains a variety of sedimentary structures and stromatolites. A characteristic feature of the unit is the marked lateral changes in thickness and rock-type which occur. These, in general, mirror the facies of the underlying Barney Creek Formation: the thinner sections generally consist mainly of dolomite and overlie thin sections of dolomitic Barney Creek Formation; thick shaly sections overlie thick shaly Barney Creek Formation.

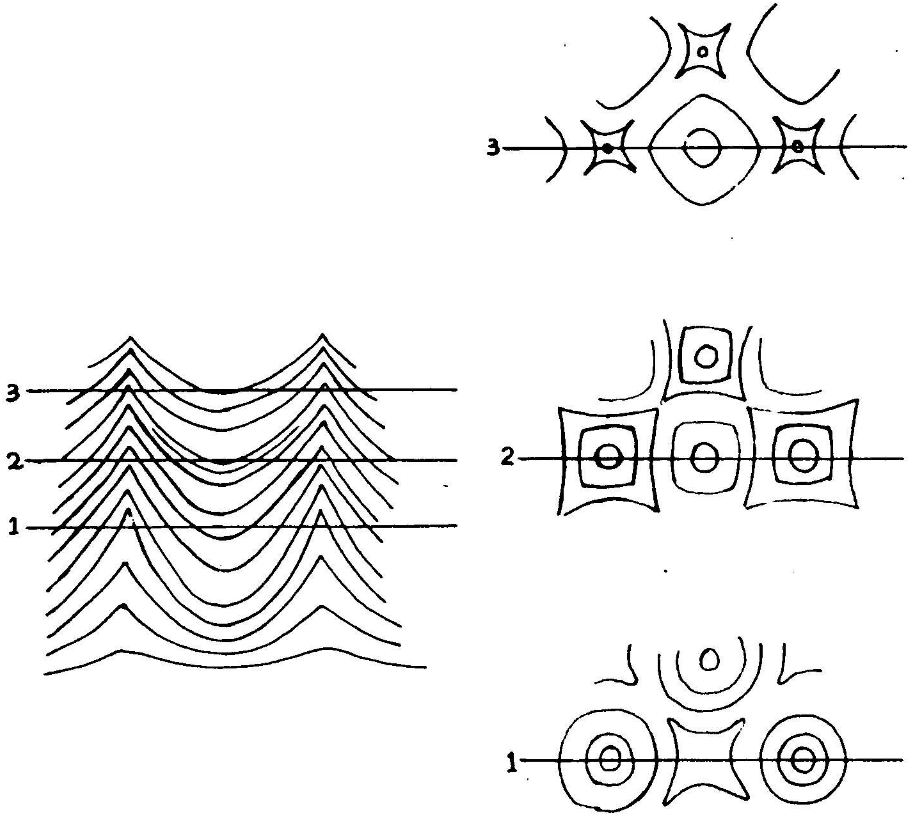
Some of the thinner sequences, such as 8 km west of Mallapunyah homestead, 4 km NNW of Balbirini homestead, near the junction of Amelia Creek and the Clyde River (Sections 9, 10; Pls. 8, 7), and in the vicinity of Cook's and Cox's lead prospects*, consist mainly of chert-free dolomite and generally contain abundant columnar (SH type) stromatolites and some <u>Conophyton</u>. During 1977 Brown and D.E. Large found clusters of radiating acicular gypsum pseudomorphs, similar to those of the Coxco Dolomite Member, cutting across the stromatolitic laminae in these dolomites. Locally these stromatolitic dolomites are inter-bedded with or overlain by coarse to very coarse sandy intraclastic doloarenite or coarse to very coarse dolomitic sandstone containing common pebbles of stromatolitic dolomite or chert. The coarse dolomitic sandstone and doloarenite generally show only vague traces of flat bedding, but in places show sets of large-scale cross-beds.

* C.E.C. geologists had mapped outcrops of stromatolite-rich Reward Dolomite near Cox's prospect as Mitchell Yard Dolomite Member or Teena Dolomite.

49

85

Fig. 9.



Vertical section and three horizontal sections of a bed of laterally-linked "Conophyton" which grade upward into basinal stromatolites.

To accompany Record 1969/145

E53/A3/32

Fig. 10. Thin-bedded dololutite with impersistent thin beds and lenses (darker tone on photograph) of fine impure pelletal doloarenite showing small-scale (ripple-drift) cross laminations. Locality; 13.5km NE of new homestead of McArthur River station. Reward Dolomite, about 150m above base. Coin is about 2.9 cm in diameter.

B.M.R. Neg. No. M/822-32.

Other sequences, somewhat thicker than the above, contain a variety of rock types and sedimentary structures: laminated and thin-bedded grey and brown dololutite with abundant small nodules and thin bands of chert, and with variable potash content, grading into potash-rich mudstone, is most characteristic; fine sandy and pelletal (?) doloarenite, in isolated ripple lenses and thin beds with current ripple laminations, are common (Fig. 10), particularly in Section 8. The laminae frequently show small recumbent folds and low-angle overthrusts, resembling those produced experiementally by shearing laminated mud by differential movement of more competent strata above and below (McKee & Goldberg, 1969), Within individual localities the direction of shearing is fairly constant.

Arenites and rudites, generally with abundant coarse to very coarse quartz sand, are interbedded with these fine-grined sediments in places, e.g., Section 8, in outcrops just south of Amelia No. 1 diamond-drill hole, in outcrops to the west of the H.Y.C. deposit, and in the subsurface north of the H.Y.C. deposit (boreholes Emu No. 1 and Emu No. 2). In Section 8 the interbeds vary from small lenses of sandy doloarenite and dolomitic sandstone, generally with erosional bases, to 3m thick beds of coarse and very coarse sandy doloarenite containing scattered pebbles and blocks of the interbedded strongly contorted fine-grained dolomite and potash-rich mudstone, and grading into coarse poorly-sorted intraformational breccias. South of Amelia No. 1 diamond-drill hole thin lenticular beds of coarse and very coarse sandy doloarenite and sandstone occur, together with an erosion-channel fill of weathered very coarse dolomitic pebbly sandstone and conglomerate, about 10 m thick and 45 m wide, in the underlying dololutite and potash-rich mudstone.

Some sections (Section 8, and 1.2 km ESE of the junction of the Kilgour and McArthur Rivers) contain intervals of grey dololutite spheres about 2 cm in diameter, set in paler dololutite with patches of dolomite spar and resembling the Girvanella nodules of the early Middle Cambrian limestones of the Georgina Basin; they are interpreted as algal balls or oncolites. Grey mottled dolomites in Section 8 resemble the Palaeozoic 'thrombolitic' carbonates of Aitken (1967).

The sequences in Section 2 and in outcrops 8 km southwest of Leila First Crossing are intermediate in character between the types discussed above: they grade upward from interbedded laminated dololutite and potash-rich mudstone (often contorted and with thin interbeds and lenses of coarse doloarenite and fine breccia), through clean dolomite with chert nodules (locally 'thrombolitic'), to interbeds of well-sorted coarse sandy doloarenite and dolomite with columnar (SH) stromatolites (the stromatolites were not found in Section 2).

A variety of depositional environments can be inferred for the Reward Dolomite. The columnar stromatolitic and Conophyton dolomites probably represent a shallow subtidal facies, the acicular gypsum needles suggesting restricted pools, such as lagoons, with the associated cross-bedded arenite perhaps representing tidal channels. The 'intermediate facies' oncolitic and 'thrombolitic' dolomites may have been deposited in more open-marine conditions, but in water less than about 60m deep to allow penetration of sunlight. The dololutite and potash-rich mudstone facies could have accumulated at greater depths, but probably of the order of tens rather than hundreds of metres because some sequences contain intervals of oncolite-bearing or 'thrombolitic' carbonates. Current-rippled fine dolarenite could have been transported by either weak traction currents or turbidity currents. The interbeds of coarser arenites and breccias, especially those containing quartz sand, are interpreted as turbidites, butssome poorly-sorted coarse breccias in Section 8 show little transport. The small-scale overfolds in the finer sediments indicate appreciable depositional slopes.

The lateral variations in the Reward Dolomite reflect the palaeogeography of the underlying Barney Creek Formation, and indicate a continuation of the general topography established during deposition of the Barney Creek Formation. The thin shallow-water sequences, containing land-derived sand grains, around the margins of the basin were reworked to provide the thicker sequences of muddy sediments and interbedded turbidites in the deeper water areas, which remained permanently below sea level throughout the deposition of both the Barney Creek Formation and Reward Dolomite.

SOME PROBLEMS OF TIME CORRELATION AND PALAEOGEOGRAPHY OF THE BARNEY CREEK FORMATION

CORRELATIONS

There are no easily recognised regionally persistent marker horizons, suitable for precise time correlation, between the Teena Dolomite and the top of the Reward Dolomite. The boundaries between rock units are based largely on criteria which are sensitive to environment, and thus are almost certainly diachronous.

Interpretation of the depositional environment and palaeogeography of the H.Y.C. Pyritic Shale Member depends upon its time correlation at the H.Y.C. deposit with sequences in other areas. Figure 11 shows four possible time correlations. Correlation 1 - direct time correlation of the H.Y.C. Pyritic Shale Member with thin weathered pyritic(?) shale at the top of the Barney Creek Formation in other areas - is unlikely; diachronous boundaries are more likely. The choice between the remaining three possibilities depends on the relative importance and timing of regional marine transgressions and regressions and tectonic warping during sedimentation.

In correlation 2 the H.Y.C. Pyritic Shale Member interfingers with both the W-Fold Shale Member and the Reward Dolomite, implying continuous warping and maintenance of a depositional slope towards the H.Y.C. deposit throughout deposition of the Barney Creek Formation and Reward Dolomite. In correlation 3 the main warping and facies changes occur low in the Barney Creek Formation, and the surface was subsequently substantially levelled off by sedimentation before the onset of regional regression. Correlation 4 is the reverse; the W-Fold Shale Member was deposited over a near-flat surface, after which warping accompanied the regression which followed regional transgression, so that intertidal or shallow subtidal stromatolitic and arenitic sediments of the Reward Dolomite passed laterally into deep-water sulphide-bearing shales and turbidites of the H.Y.C. Pyritic Shale Member.

Both the H.Y.C. Pyritic Shale Member and the Reward Dolomite show a deepening of water, and hence downwarping, towards the Bulburra Depression.

Combining this with the application of Walther's Law to the transgressive-regressive cycle of the Emmerugga Dolomite-Barney Creek Formation-Reward Dolomite, correlation 2 (essentially a combination of 3 and 4, and perhaps some synchronous rock marker units as in 1) becomes the most likely.

PALAEOGEOGRAPHY

Regardless of the precise details of the time correlations between the H.Y.C. Pyritic Shale Member and other units, the Barney Creek Formation and Reward Dolomite both show similar distributions and facies changes, and both give a guide to the palaeogeography of the H.Y.C. Deposit.

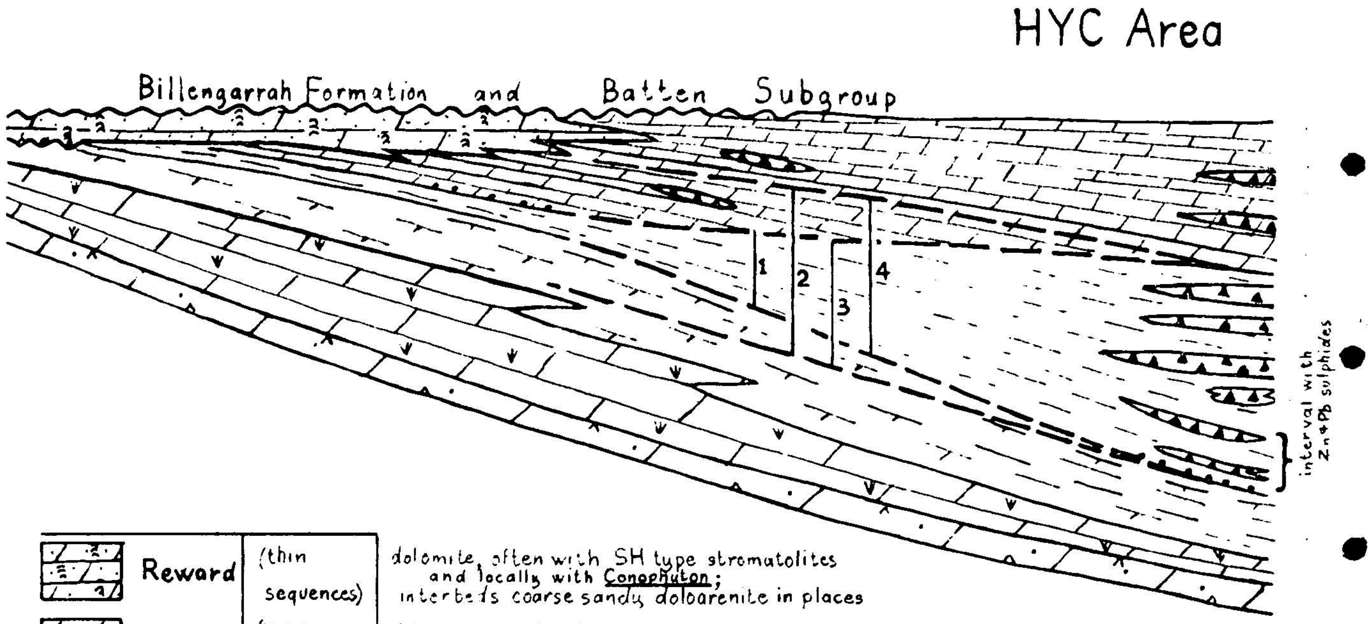
The Barney Creek Formation and Reward Dolomite are exposed over an area of about 6000 km^2 through the central north-south belt of the Bauhinia Downs Sheet area, between the Emu Fault and Billengarrah Creek. Farther to the south (Wallhallow Sheet), north (Mount Young Sheet), and west (western Bauhinia Downs Sheet) the Emmerugga Dolomite is unconformably overlain by either Roper Group or younger McArthur Group rocks, and it is not known whether the Barney Creek Formation and Reward Dolomite were not deposited there or eroded after depostion. Drilling by C.E.C. at the H.Y.C. deposit shows that the Barney Creek Formation dies out suddenly against the Emu Fault zone and, since its equivalent has so far not been found farther to the east, on the Wearyan Shelf, is inferred that the Emu Fault marked the approximate eastern depositional limit of the Barney Creek Formation.

Independent evidence of the significance of the Emu Fault is found farther south around Amelia Creek (Sections 9, 12) where the total section, and most individual units, thin markedly eastwards onto the Emu Fault zone. Around the lower Kilgour River, slump breccias and turbidites, presumably derived from the east, characterise the Reward Dolomite and lower part of the overlying Lynott Formation.

The H.Y.C. Pyritic Shale Member accumulated within the Bulburra Depression (Murray, 1975), which extended for some 25 km southwestwards from the H.Y.C. deposit. The economically interesting lead and zinc sulphides occur at the base of the thickest sections of the member, and accumulated in a number of small deeper depressions within the overall

Fig. 11.

POSSIBLE TIME CORRELATIONS IN BARNEY CREEK FORMATION AND REWARD DOLOMITE BETWEEN HYC AREA AND AREAS ELSEWHERE



▨	**Reward**	(thin sequences)	dolomite, often with SH type stromatolites and locally with Conophyton; interbeds coarse sandy doloarenite in places
▨	**Dolomite**	(thicker sequences)	dolomite; mostly cherty dololutite, generally shaly or ?tuffaceous; some algal balls; sandy doloarenite and breccia interbeds in places.
▤	**Barney Creek Fm.**	H.Y.C Pyritic Shale Mbr	shale, ?tuff, and ?tuffaceous shale with bituminous material and sulphides; local sandy doloarenite and breccia interbeds
▤		W-Fold Sh. Mbr. (Other areas)	laminated ?tuffaceous and shaly dololutite; dolomitic ?tuff and shale
▤		W-Fold Sh. Mbr. (HYC area)	green and red potash-rich ?tuffaceous mudstone
▨	**Teena**	Coxco Dol. Mbr.	thick and thin bedded clean dololutite with crystal needle pseudomorphs; thin ?tuff interbeds.
▨	**Dolomite**		dolomite, in places cherty; also sandy, silty, and ?tuffaceous dolomite; rare halite casts; Conophyton and basinal stromatolites at top and bottom in places.

〰	possible local unconformity
— — —	possible time planes
▲▲	breccia interbeds.
• • • • •	first incoming of coarse quartz sand above sandy interval in Teena Member
1,2,3,4	alternative time correlations discussed in text

To accompany Record 1969/145

E53/A3/33

56

Bulburra Depression (Walker and others in press). The Bulburra Depression shallowed gently to the west, north, and south, but terminated abruptly to the east against the Emu Fault zone.

Assuming diachronous boundaries between rock units, the depression passed gradually westwards into shallower subtidal, lagoonal, and perhaps intertidal areas in which either the W-Fold Shale Member and underlying units (Correlation3), the Reward Dolomite (Correlation 4), or both (Correlation 2) were being deposited. These areas were probably stable and provided little sediment to the depressions. The Emu Fault zone to the east, however, was an area of active erosion and shed terrigenous and carbonate material, turbidites, and talus scree material into the depressions.

Within the broad area of generally shallow-water sedimentation, deeper-water restricted systems developed within the tectonically-controlled Bulburra Depresssion. Water depths were sufficient to restrict growth of algae and to allow adequate slopes for influx of turbidites and talus screes. Restricted circulation on the floor of the depressions may have allowed the development of closed chemical systems, in which metal accumulation, sulphate reduction, and preservation of organic carbon were enhanced, although data so far available cannot resolve whether these processes operated at the time of deposition or during diagenesis.

SOME IDEAS ON THE DEPOSITIONAL ENVIRONMENT OF THE ZINC AND LEAD SULPHIDES

At the present day, sulphides of iron, zinc, and lead are being deposited from pools of hot concentrated brine in restricted depressions on the floor of the Red Sea (White, 1968). The overlying Red Sea water has salinity only slightly higher than that of the open ocean, and the brine remains in pools on the sea floor because of its high specific gravity, despite its high temperature which is preserved because of the low conductivity of the sea water. White suggests that the brine is derived from the solution of Tertiary evaporites. The source of the heat is not known, but the Red Sea generally has a high heat flow.

Some analogies can be drawn between the geological setting of the Red Sea sulphides and those of the H.Y.C. deposit:

(a) the H.Y.C. sulphides accumulated in local restricted depressions on the sea floor;
(b) older evaporitic sediments occur in the sequence.

The presence of thick evaporites in the sequence, not very far below the sulphides, is inferred from the ubiquitous solution-collapse breccias at the transition between the Myrtle Shale Member and the Mara Member. These occurred at or near the surface, in fault blocks of the Emu Fault zone, and at levels above the floor of the Bulburra Depression, during deposition of the sulphides (Walker and others, in press), providing hydraulic gradients and channelways for movement of brines into the depression.

The main differences from the Red Sea are, firstly, that the water was probably shallower at the H.Y.C. (less than 500 m), and secondly, that a shoreline with sources of coarse terrigenous detritus was much closer. These factors would have little influence on the chemical environment at the sea floor, but the terrigenous sediments diluted the sulphides in the deposits (Cotton, 1965; Croxford, 1968).

The potassium-rich tuffs(?) associated with the H.Y.C. sulphides might suggest a volcanic source for the metals. Although this is possible, the potassium-rich tuffs are not restricted to the H.Y.C. or to the mineralised part of the section; they occur at intervals throughout the McArthur Group sequence and over most of the McArthur Basin.

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PART 2

GEOCHEMICAL INVESTIGATIONS

by

C.W. Claxton

INTRODUCTION

Aims and scope of the project

All samples (360 in number), which Brown collected for petrographic study, have been chemically analysed for Ca, Mg, acid-insoluble residue (A.I.), K, Fe, Mn, P, Zn, Pb, Cu, Ni, and Co. This part of the report presents the analytical data, and discusses their significance to interpreting sedimentary environments and exploration indicators.

The results are tabulated in Appendix 1; sample localities and rock types are shown in the stratigraphic sections (Plates 1-12). In the discussion, samples are separated into those from near the area of mineralization ('Outlying Sections'; Sections 1-7). Sections 8, 9, 10, and 12 lie close to, but outside the known limits of significant Pb-Zn mineralisation, and therefore are transitional in character between the extremes.

It should be stressed that the stratigraphic sections were only selectively sampled by Brown for petrographic study of representative samples of all the rock-types present, and thus do not represent a true statistical sample of the bulk composition of the formations. This must be kept in mind when interpreting the average compositions of the sampled formations without reference to the individual rock-types collected, although the broad conclusions are probably valid.

Analytical Methods

Each sample was reduced to a fine powder by crushing in a jaw crusher and grinding in a Sieb-Technik mill. Four aliquots were split from each sample so that the following determinations could be made:

1. Acid-insoluble, calcium, and magnesium,
2. Trace elements (Fe, Mn, Ni, Co, Cu, Pb, and Zn),
3. Phosphate,
4. Potassium.

The first three were transferred to 'Pyrex' beakers and the last to a platinum dish. All weighings were acid digested.

To determine the acid-insoluble content (A.I.) of each sample, the carbonate fraction was dissolved by adding hydrochloric acid (2N) and allowing the reaction to proceed overnight at room temperature; siliceous and sulphide materials are virtually inert under these conditions. The residue was collected on a filter paper, washed, ignited to 800°C, cooled, and weighed. The filtrate was preserved for the determination of calcium and magnesium.

An aliquot of the filtrate was treated with ammonium chloride and ammonia solution (1:1) to precipitate iron, aluminium, and some manganese, which were then removed by filtration and discarded; complete manganese separation is not necessary prior to oxalate precipitation (Mellor & Thompson, 1938). The ammonia filtrate was acidified and calcium precipitated, after buffering the solution with oxalic acid and ammonia and the addition of ammonium oxalate. Because magnesium in large amounts is partly precipitated with the calcium, the precipitate was collected, dissolved, and reprecipitated to free it of the occluded magnesium before final filtering. The calcium oxalate was then ignited to 1000°C to form calcium oxide, which was weighed.

Magnesium was determined on the combined filtrate from the oxalate separation, which was evaporated to dryness and baked to volatilise the ammonium salts, before redissolving in water. The solution was buffered with ammonia/ammonium chloride solution to prevent interference by any remaining manganese. Excess ethylenediammine-tetraacetic acid (EDTA) was added and the solution back-titrated with standard magnesium solution, using eriochrome black T to indicate the equivalence point. Only traces of strontium and barium interfere, and are determined simultaneously. Iron has been previously removed (Schwartzenbach, 1957).

Extraction of the trace elements was not complete but was found to be adequate. The sample was treated with hydrochloric acid (5N) and evaporated to dryness. This was repeated before the final solution was prepared. The hydrochloric acid extraction was supplemented by the addition of nitric acid (15N) if the first residue was markedly discoloured. The nitric acid addition necessitated an additional evaporation. The residue remaining after the extraction was white to light grey and was assumed to be mainly sandy material.

The trace elements were determined by atomic absorption spectrophotometry on a Techtron model AA4 spectrophotometer. Non-atomic absorption corrections were made to small readings.

For the determination of phosphate, perchloric acid (21% W/V), was used for digesting the sample. After the digestion, excess perchloric acid was removed by evaporation on a hot plate. The extract was made up to a volume and an aliquot taken. Ammonium vanadate (4.68 g/1, 66 ml 70% $HC10_{44}$/1) and ammonium molybdate (70.6 g/1) reagents were added and colorimetry performed at a wavelength of 460 nm in a Unicam SP500 spectrophotometer after allowing 30 minutes for colour development. The ferric iron interference was removed by the formation of colourless ferric perchlorate. Manganese was precipitated. All other interferences were too small to have any appreciable effect. The method, according to Charlot (1964), is 'accurate to within 0.1% with natural phosphates'.

For the determination of potassium, the sample was treated with hydrofluoric and perchloric acids and placed on a water bath, where the siliceous material volatilised as SiF_4. Afterwards, the sample was placed on a hot plate to remove the excess perchloric acid. Finally the sample was dissolved in hydrochloric acid (5N). The atomic absorption was measured at a wavelength of 404.4 nm, which enabled potassium contents down to 0.05% to be evaluated.

Statistical analysis of the results

All analytical results are tabulated in Appendix 1. Chemical data were punched on 80-column cards for statistical computations on the CSIOR CDC 3600 computer. Two programmes were used: GESTAT (Garrett, 1967) and FACTORAN (Brown, 1965), for general data screening and factor analysis respectively.

GESTAT is a general purpose data-screening programme which computes summary statistics for each variable (mean, standard deviation, skewness, and kurtosis), as well as a product-moment correlation matrix (containing coefficients of correlation between every pair of variables). The significance level for each correlation coefficient is indicated by a 'Student' t test; in the present study, correlations with less than 95 percent probability of significance were rejected.

The factor analysis programme (FACTORAN), which uses methods outlined by Harman (1967), was employed to clarify relationships among the variables; ideally this method reduces a large number of observed variables, by linear transformation, to a smaller number of hypothetical variables (factors); rotation of the resulting matrix to 'Simple Structure' (Harman, 1967), giving the best fit to the original variables, allows one to give the factors physical interpretations.

Several separate statistical analyses were carried out: initially individual stratigraphic sections were studied; the total population of samples was analysed; and then each stratigraphic unit was analysed separately. Figure 12 diagrammatically illustrates the statistical correlations obtained between the elements.

The small number of samples available for some of these studies limits the statistical reliability of the numerical results, so most of the discussion of the results will be limited to a qualitative assessment of the statistical parameters.

DISCUSSION OF INDIVIDUAL ELEMENTS

Calcium and Magnesium

As one would expect from samples of impure dolomites, strong positive correlations are present between calcium and magnesium, whilst both show negative relationships with the acid-insoluble fraction. The close association between calcium and magnesium in carbonates justifies discussing them together.

An average Ca:Mg ration of 1.8 (Table 1) was obtained for the area, which is the same as published values for the Precambrian carbonate rocks of the Russian Platform (Vinogradov and others, (1952), cited by Ingerson (1962)). This is slightly higher than the expected ratio of 1.65, in pure dolomite with a 1:1 Ca:Mg molar ratio. Staining of thin sections does not indicate the presence of a separate calcium carbonate phase in the rocks.

The excess calcium can be partly accounted for by substitution of iron for magnesium in the dolomite lattice. The Tooganinie Formation, Reward Dolomite, and Barney Creek Formation have generally higher Ca:Mg ratios than the Emmerugga and Teena Dolomites (Table 2), and they also have a higher iron content over most of the region (Table 3). However, many of the rocks with excess calcium still have too little iron to account for all of the excess in this way, so that the carbonate phase must contain, in many cases, excess calcium in the dolomite lattice.

In the immediate area of the H.Y.C. mineralisation (Sections 13,14), the *Emmerugga* and *Teena Dolomites* show an anomalous deficiency in calcium.

TABLE 1. AVERAGE CALCIUM-MAGNESIUM RATIOS IN THE MEASURED SECTIONS

Section No.	Ca:Mg
2	2.0
3	1.8
4	1.8
5	1.85
6	2.0
7	1.8
8	1.8
9	1.85
10	2.0
11	2.1
12	1.55
13	1.6
14	1.75
Average (all samples)	1.8

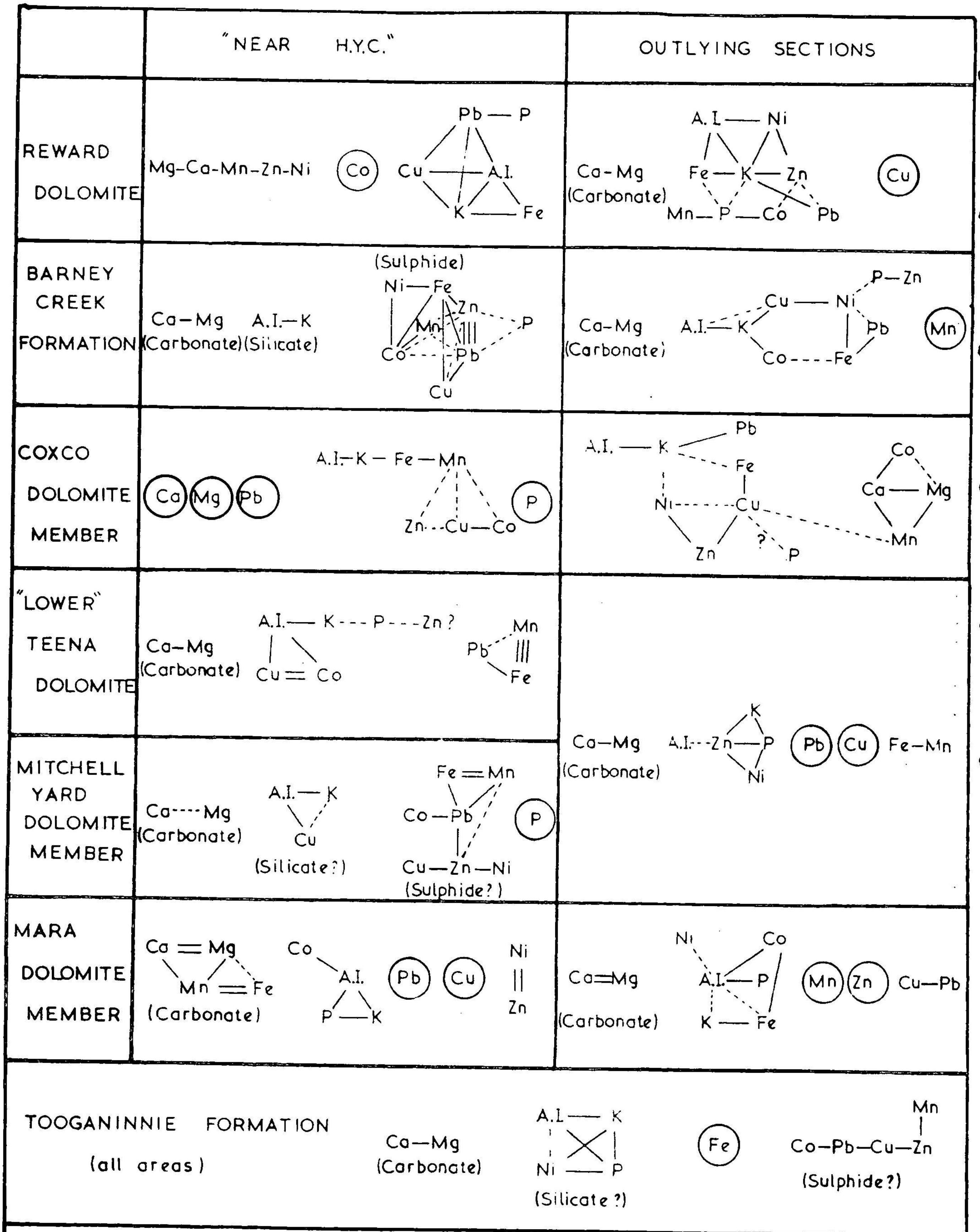

FIGURE 12 Diagrammatic representation of statistical correlations between elements.

To Accompany Record No. 1969/145

TABLE 2. AVERAGE CALCIUM-MAGNESIUM RATIOS OF ROCK UNITS

Outlying sections

Reward Dolomite		2.15
Barney Creek Formation		1.85
Teena Dolomite	Coxco Dolomite Member	1.8
	Lower unit	
Emmerugga Dolomite		1.7
	Mitchell Yard Dolomite Member	
	Mara Dolomite Member	1.8

Sections near H.Y.C.

Reward Dolomite		1.9
Barney Creek Formation		2.0
Teena Dolomite	Coxco Dolomite Member	
	Lower unit	1.75
Emmerugga Dolomite	Mitchell Yard Dolomite Member	1.65
	Mara Dolomite Member	1.7

Average Ca:Mg ratios, of 1.6 and 1.75 respectively, are closer to a 1:1 molar ratio than the average for the area as a whole. The rocks in these sections (particularly upper Mara Dolomite Member, Mitchell Yard Dolomite Member, and Coxco Dolomite Member) have iron contents (1%-4%) which are about five times the content elsewhere in the area. Calculations for five speciments (14/1, 14/2, 14/4, 14/10, 14/16) showed molar ratios between 0.973 and 1.14 for Ca:Mg, and 0.933 and 0.970 for Ca:Mg+Fe. This calcium deficiency could be due either to substitution of calcium by magnesium and/or iron in the dolomite lattice, or the presence of separate iron or magnesium carbonate phases.

In Section 12, near the limit of known anomalous zinc values in the Barney Creek Formation, the Emmerugga and Teena Dolomites again have a low average Ca:Mg ratio of 1.55 (molar ratio 0.94); iron contents here are intermediate between Sections 13, 14 and the outlying areas.

Iron

Values range from 0.11 percent to 5.5 percent; the highest individual value was found in a sample of red subaerial siltstone containing hematite-stained terrigenous material, from the Myrtle Shale Member. Other values greater than 4 percent were found in samples of Barney Creek Formation throughout the area, and from the Mitchell Yard Dolomite Member near the H.Y.C. deposit.

Near H.Y.C: The Emmerugga and Teena Dolomites and the Barney Creek Formation all have higher average iron contents than in outlying sections (Table 3), particularly in Sections 13 and 14; this is confirmed by Lambert & Scott (1973). This clearly reflects the abundance of pyrite in the Barney Creek Formation, but in the carbonate-rich units an absence of H_2S gas during dissolution of samples shows that the rocks did not contain appreciable amounts of sulphide. The fresh dolomites show no red pigmentation (Fe_2O_3), and most contain too little insoluble residue for the iron to occur as silicates. The iron appears to occur in the carbonate fraction as ferroan dolomite. When weathered, the iron-rich dolomites develop a distinctive red-brown colour.

Product-moment correlation matrices from the Teena and Emmerugga Dolomites show a strong Fe-Mn relationship, suggesting that manganese may also have been deposited as carbonate. Fe-Pb correlation is shown by the Mitchell Yard Dolomite Member and lower Teena Dolomite. The Coxco Dolomite Member shows a Fe-K relationship, which probably derives from iron in K-rich tuffs (?) which comprise a significant proportion of the samples from this unit.

Iron, particularly the oxide but also the sulphide, has the ability to scavenge other ions from solution (Krauskopf, 1957). The relationships inferred in the product-moment correlation matrix for the Barney Creek Formation show that deposition of Ni, Co, Cu, Pb, and Zn is related to the iron content.

In the Reward Dolomite, Fe-A.I. and Fe-K correlations reflect the abundance of tuffaceous material in the unit near the H.Y.C. deposit.

Outlying Sections: The Mara Dolomite Member shows Fe-K correlation, which probably reflects samples of terrigenous beds, and Fe-P and Fe-Co correlations also exist. The Coxco Dolomite Member shows correlations between Fe, Cu, and Pb.

TABLE 3. AVERAGE IRON CONTENTS OF ROCK UNITS

Rock Unit		% Fe
Reward Dolomite	Outlying	1.05
	Near H.Y.C.*	0.78
Barney Creek Formation	Outlying	1.24
	Near H.Y.C.	1.62
Coxco Dolomite Member	Outlying	0.36
	Near H.Y.C.	1.46
Mitchell Yard Dolomite Member and lower unit of Teena Dolomite Member	Outlying	0.29
Lower unit of Teena Dolomite Member	Near H.Y.C.	1.44
Mitchell Yard Member	Near H.Y.C.	1.55
Mara Dolomite Member	Outlying	0.52
	Near H.Y.C.	0.69
Tooganinie Formation and Tatoola Sandstone	All samples	1.33

* The Reward Dolomite is not exposed in the immediate vicinity of the H.Y.C. deposit. The 'near-H.Y.C.' samples are from sections 8, 9, and 10, about 20 km from the deposit.

The Reward Dolomite shows correlation of Fe with K and acid insolubles, and weak correlation with P, again reflecting iron oxides in the terrigenous component.

Manganese

The manganese content of the sediments varies from less than 50 ppm to more than 1.2 percent; the average value (1030 ppm Mn; 1330 ppm MnO) compares favourably with an extrapolation of the trend determined by Ronov & Erminshkina (1959) for carbonate rocks on the Russian Platform. If these trends are valid in the McArthur Basin sediments, then the rate of manganese deposition in carbonate rock appears to have been almost constant for 1000 million years.

Manganese oxides, like iron, have the ability to scavenge ions from solution by absorption. Deposition usually occurs as a hydrated oxide after migration in suspension, as adsorbed cations on colloidal particles such as clay minerals, and partly in solution from the breakdown of igneous and metamorphic rocks by chemical weathering.

There is a widespread correlation of Mn with Ca and Mg and sometimes with Zn and Fe, in the carbonates of most units, suggesting that Mn, as well as Fe and probably Zn, have substituted for Ca and possibly Mg in the dolomite crystal lattices.

Near H.Y.C.: Strong Fe-Mn correlation was found throughout the Fe-rich carbonates of the Emmerugga and Teena Dolomites. The Mitchell Yard Dolomite Member also shows Mn-Pb correlation and weaker Mn-Zn correlation, while the lower Teena Dolomite shows only weak Mn-Pb correlation.

Outlying Sections: The Fe-Mn correlation decreases to only weak correlation in the Mitchell Yard Dolomite Member and lower Teena Dolomite. This perhaps reflects different pH and Eh conditions away from the mineralised area, allowing geochemical differentation of manganese and iron as proposed by Krauskopf (1957).

In the Myrtle Shale Member, Mn was found to correlate with Zn, most likely due to Mn-oxides adsorbing Zn in the Fe-rich terrigenous siltstones.

Cobalt

The values obtained for cobalt are significantly lower than has been reported for carbonates elsewhere. Graf (1962) determined an average value of 4.3 ppm Co for Scottish, Russian, and New Zealand rocks. At McArthur River the rocks average 3.1 ppm Co, although some samples are as high as 43 ppm. In the Coxco Dolomite Member, none of the thirty-four samples analysed have values above the detection limit (2.5 ppm).

In all other units, apart from the Barney Creek Formation, the number of values which lie above the detection limit is too small for reliable inferences. However, from a statistical evaluation of the entire sample population, an Fe-Co correlation can be inferred. In the Barney Creek Formation, which shows the highest cobalt values, the relationship weakens with distance from the H.Y.C. deposit (Students t-test values decreasing). This probably indicates that the cobalt either occurs in the sediments as sulphide, or is adsorbed onto pyrite or iron oxides: this inference is supported by correlations with other elements, particularly nickel, which commonly occur as sulphides.

The generally low cobalt values in the rocks are consistent with their deposition in a marine environment (Keith & Degens, 1959).

Nickel

Statistical analysis failed to establish any general correlations between nickel and other elements. Each unit or area tends to show different correlations, suggesting that nickel was introduced independently into the sediments.

Near H.Y.C.: Ni-Zn correlations were found in the Emmerugga and Reward Dolomites and, in the latter, appear to be related to the carbonate fraction. The Barney Creek Formation shows correlations of Ni with Fe, Mn, and Co, and these elements, in turn, are associated with the economic metals of the sulphide deposit, Pb-Zn.

Around Amelia Creek (Sections 10, 11) only the Mara Dolomite Member is of significance, as all other units either exhibit no nickel correlations or their nickel contents lie below the detection limits. Here nickel is associated with copper and, to a lesser degree, zinc, possibly in sulphides.

Outlying Sections: Ni-Zn correlations here show up in the Mitchell Yard Dolomite Member, lower Teena Dolomite, Coxco Dolomite Member, and Reward Dolomite, but here they appear to be associated more with the non-carbonate fraction of the rocks. An interrelationship is inferred between Ni, acid insolubles, and K in the Tooganinie Formation, Reward Dolomite, and (weak) Coxco Dolomite Member, while an ill-defined relationship between Ni and acid insolubles is inferred in the Mara Dolomite Member. These associations suggest transport and precipitation of nickel with terrigenous material, perhaps by adsorption on clays etc.

In the Top Crossing area the Reward Dolomite and Barney Creek Formation show correlations of Ni with Fe, K, and Zn. Lower in the sequence, the Coxco Dolomite Member retains its strong Ni-Zn correlation, but Ni-Fe and Ni-K correlations weaken whilst new associations develop between Ni-A.I. and Ni-P. In the Mara Dolomite Member (Section 4) Ni is associated with the sulphide cations, Cu and Co, the Ni-Fe correlation is re-established (perhaps due to adsorption effects in the non-carbonate rocks), the phosphate and acid insoluble residue relationships remain, but the Ni-Zn correlation is weaker. The upper half of the Tooganinie Formation (Section 5) shows Ni associated with P, K, A.I., and Zn, but these do not continue into the lower Tooganinie (Section 6), where Ni correlates with Pb, and weakly with Fe and Co.

In the Bauhinia Downs area (Section 7), the only significant relationship established is a weak Ni-P correlation.

Lead and Zinc

Lead and zinc are the major economic metals in the sulphide ore bodies of the H.Y.C. Pyritic Shale Member. Although a general correlation was found between these elements throughout the area, it is only in the mineralised parts of the H.Y.C. Pyritic Shale Member that strong Pb-Zn associations occur. Significant, but weaker correlations also occur in the Mitchell Yard Dolomite Member and lower Teena Dolomite near the mineralised area.

Lead and zinc show distinctly different associations, for most formations, between the 'near H.Y.C.' and 'outlying' sections.

The average values for all units are 110 ppm Zn and 20 ppm Pb; averages of individual units are shown in Table 4. The only major anomalies found were in the mineralised parts of the Barney Creek Formation, at or near the H.Y.C. deposit. If these anomalous results are removed from the overall averages, the averages reduce to 15 ppm Zn and 10 ppm Pb. The average values for the Barney Creek Formation in the outlying sections are only 20 ppm Zn and 10 ppm Pb, comparable with the values of the other units. The lead and zinc contents of all units are relatively constant throughout the section, except for a slight enrichment of zinc in those units immediately underlying and overlying the Barney Creek Formation in outlying sections.

These latter results tend to support the suggestion in Part 1 that the H.Y.C. Pyritic Shale Member was penecontemporaneous with units above and below it in outlying areas; this is particularly shown by the stromatolitic Reward Dolomite in Sections 9 and 10, where zinc anomalies are about 10x the overall average.

Near H.Y.C.: There was a strong Zn-Ni correlation in the Mara Dolomite Member, but associations are more complex in the Mitchell Yard Member, where the Pb-Zn shows interrelated correlations with the (sulphide?) elements Cu, Ni, Co, Fe, and Mn.

In the lower Teena Dolomite, a correlation is inferred only between Pb-Fe and Pb-Mn (weak), while the Coxco Dolomite Member shows weak relationships between Zn, Mn, Cu, and Co. These associations may reflect adsorption of trace elements on Mn and Fe oxides.

Complex associations appear again in the Barney Creek Formation, where the strongly interrelated Pb and Zn are related to the sulphide elements Fe and Cu, and show a weak correlation with Cu, Mn, and P.

In the Reward Dolomite, Pb and Zn are again independent. Zn is correlated with Mn and Ni, and, through them, with Ca and Mg; Pb is related to the terrigenous component, being correlated with K, insoluble residue, Fe, Cu, and P, perhaps reflecting adsorption of the trace elements on clays.

TABLE 4: AVERAGE LEAD AND ZINC CONTENTS OF ROCK UNITS

Rock unit		Zn(ppm)	Pb(ppm)
Reward Dolomite	Near-H.Y.C.	30	10
	Outlying	10	10
Barney Creek Formation	Near-H.Y.C.	1890	320
	Outlying	20	10
Coxco Dolomite Member	Near-H.Y.C.	20	10
	Outlying	20	10
Lower unit of Teena Dolomite	Near-H.Y.C.	10	10
Mitchell Yard Dolomite Member	Near-H.Y.C.	10	10
Mitchell Yard Dolomite Member and Lower unit of Teena Dolomite	Outlying	10	10
Mara Dolomite Member	Near-H.Y.C.	10	10
	Outlying	10	10
Tooganinie Formation and Tatoola Sandstone		20	10

Outlying Sections: In the Tooganinie Formation, scavenging of trace elements by Mn oxides apparently explains the complex associations which are inferred of Zn with Mn and Cu, Pb with Cu and Co, and indirectly through Cu of Pb with Zn and Mn.

The Mara Dolomite Member shows correlation only between Pb and Zn. In the Mitchell Yard Dolomite Member and lower Teena Dolomite a Zn-K-P-Ni interrelationship, and weak Zn-acid insoluble correlation, apparently reflects transport and deposition with terrigenous material, while Pb appears to have been adsorbed onto hydrated Fe and Mn oxides.

Transport of terrigenous material is again reflected in the complex relationships of the Coxco Dolomite Member with direct Zn-Ni, Zn-Cu, and Pb-K correlations, indirect correlations through K of Pb and A.I., and indirect correlations of Zn with Pb through Cu, Fe, and K.

The Barney Creek Formation shows independent correlations of Zn with P, and Pb with Fe; these appear to occur in the non-carbonate fraction of the rocks.

The Reward Dolomite again shows weak but direct Pb-Zn correlation, direct correlation of Zn with Ni and K, and then, through them, tenuous relationships of Zn with all the non-carbonate elements of the rock.

Copper

Copper, like nickel, does not show any general correlations. The overall average is about 10 ppm, with relatively little variation between the rock units. The highest average - 20 ppm - is from the Tooganinie Formation; four mineralised samples of Barney Creek Formation from near the H.Y.C. deposit (Section 15) averaged 26 ppm. An ascending series could be constructed through the near-H.Y.C. samples, and through the outlying samples, although there are variations between the two areas.

Near H.Y.C.: No significant correlations were observed in the Mara Dolomite Member, but the Mitchell Yard Dolomite Member shows weak correlations of Cu with insoluble residues and K. In the lower Teena Dolomite Cu maintains its correlation with insoluble residue, and through it, with K, and develops a strong Co correlation. The Co correlation continued into the Coxco Dolomite Member, where there are also weak correlations of Cu with Mn and Zn.

In the Barney Creek Formation new Cu-Fe, Cu-Pb, and weak Cu-Zn correlations appear. The Cu-Pb correlation continues into the Reward Dolomite, and correlations again appear between Cu and K and acid insolubles.

In this area, copper therefore exhibits two general types of association:

(a) with acid insolubles and potassium in the carbonate-rich units, reflecting introduction of copper with the terrigenous components;

(b) with the principal sulphide components in the Barney Creek Formation, and to a lesser extent Coxco Dolomite Member, reflecting a swamping of the terrigenous association by the introduction of copper with the mineralisation.

Outlying Sections: No significant correlations can be found in the Mitchell Yard Dolomite Member, lower Teena Dolomite, or Reward Dolomite The Tooganinie Formation shows significant Cu-Pb and Cu-Zn correlations. The Mara Dolomite Member shows a Cu-Pb correlation. The Coxco Dolomite Member still maintained oxide or sulphide metal associations, this time Cu-Fe, Cu-Zn, and weak Cu-Ni and Cu-Mn. In the Barney Creek Formation the outlying sections showed completely different correlations from the mineralised area, with correlation of Cu with K, A.I., and Ni.

The copper in this area therefore seems to be dominated by the association with the terrigenous fraction. The significant association with lead and zinc in the Tooganinie Formation may reflect the favourable facies for primary copper sulphide mineralisation indicated by the abundant redbeds in this unit.

Potassium

The potassium is contained in the non-carbonate materials of the sediments, and correlates strongly with insoluble residue and phosphorus. The upper parts of the Emmerugga Dolomite and the Teena Dolomite, Barney Creek Formation, and Reward Dolomite contain beds of fine-grained buff to pink non-carbonate rocks with abnormally high potassium contents, which Brown and Plumb interpret as tuffs. Inclusion of samples of these beds in calculations of average potassium contents have probably produced results which are too high, particularly in the Coxco Dolomite Member, because of sample bias.

TABLE 5: AVERAGE POTASSIUM CONTENTS OF ROCK UNITS

Outlying Sections

Rock Unit	% K
Reward Dolomite	1.4
Barney Creek Formation	3.79
Coxco Dolomite Member	1.9
Lower unit of Teena Dolomite and Mitchell Yard Dolomite Member	0.18
Mara Dolomite Member	0.50

Sections near H.Y.C

Rock Unit	% K	
Reward Dolomite	1.24	
Barney Creek Formation	2.94	
Coxco Dolomite Member	0.89	
Lower unit of Teena Dolomite	1.65	0.92
Mitchell Yard Dolomite Member	0.29	
Tooganinie Formation and Tatoola Sandstone	1.62	

Fresh rocks from the Barney Creek Formation yielded values ranging from 0.8 to 10% K, the lower values mainly in dolomite-rich samples; the K content, expressed as a percentage of the insoluble residue fraction, has a range of about 3-11 percent. One thin tuff(?) bed in the Coxco Dolomite Member contains 12% K, and one sample from the Reward Dolomite (2/32) has a value of 6% K. These values are higher than those normally found in igneous rocks, so, if they are tuffs, additional potassium must have been added from some other source.

Individual units show considerable differences in average potassium contents between 'near-H.Y.C.' and outlying sections, but the variation is not systematic and simply reflects sample bias (Table 5).

K almost invariably correlates strongly with A.I., and less commonly with P in a three-way relationship. Some sections (e.g. Section 3) show strong K-Fe-A.I. correlations, mostly in place of K-P correlations. Potassium correlates with a variety of trace elements, particularly where sulphide mineralisation is absent, indicating that the metal ions are incorporated in the normal rock minerals rather than in distinct sulphide phases in these areas.

Acid Insoluble Residue (A.I.

The samples show an almost complete range of compositions, from almost pure carbonates to rocks composed almost entirely of insoluble residue; the overall average content of insoluble residue is 28 percent. The insoluble residue comprises terrigenous silt, clay, sand, and pebbles, and authigenic minerals such as chert, K-felspar, and sulphides.

As described previously, the insoluble residue always correlates with potassium, and less commonly with phosphate or iron. No other significant correlations are apparent.

Away from the H.Y.C. deposit, the trace element associations within the insoluble residue component of the rock are diffuse and complex; most of the non-carbonate elements show common complex groupings in all units. Near the H.Y.C. deposit associations in the carbonate-rich units become more divergent, with groupings into distinct silicate (?) and sulphide(?) fractions.

Phosphorus

The overall average phosphorus content is 520 ppm. In general, 'near-H.Y.C.' samples have higher P-contents than samples from 'outlying sections', perhaps reflecting additional phosphate in solution due to decomposition of P-bearing organic material (Ronov & Korzina, 1960).

The Coxco Dolomite Member and part of the Barney Creek Formation have P-contents approximately 2-4 times the overall average. In the upper parts of the Coxco Dolomite Member some samples with low insoluble residues have phosphorus contents of up to 4700 ppm - about 8 times the overall average. This suggests association with the carbonate fraction, by precipitation of apatite from sea water. Ames (1959) showed that apatite precipitation requires a pH greater than 7, presence of calcareous material, and a system which is saturated in calcium relative to bicarbonate.

CONCLUSIONS

The principal result of the chemical analyses, with significance either to interpretation of the origin of the rocks, or as exploration indicators, are:

(1) Ca:Mg ratios confirm that dolomite is the major carbonate phase throughout the sequence, but there are significant departures from the 1:1 molar ratio of pure dolomite. In most cases Ca:Mg ratios indicate a significant Ca excess, but locally there are anomalous Ca deficiencies. Substitution of Fe or Mn for Mg in the dolomite lattice can not, alone, explain the Ca excess.

(2) The Emmerugga and Teena Dolomites show the following significant compositional differences near the H.Y.C. deposit, compared with outlying areas:
   (i) Fe and Mn contents are much greater
   (ii) Ca:Mg+Fe molar ratios are less than 1; this Ca deficiency may be explained by substitution of Fe or Mg for Ca in the lattice, or by the presence of separate Fe or Mg carbonate phases.

(3) Potassium contents are generally high, particularly in the Barney Creek Formation (up to 10% K) and in tuff(?) beds in dolomite units (up to 12% K). These exceed values for normal igneous rocks, indicating addition of potassium from other sources.

(4) Anomalous Pb and Zn contents are only present in the mineralised part of the Barney Creek Formation, at or near the H.Y.C. deposit. All other units, and the Barney Creek Formation away from the H.Y.C., show low and relatively constant abundances of around 15 ppm Zn and 10 ppm Pb.

(5) Phosphorus is nowhere in economically interesting concentrations. P contents are generally higher near the H.Y.C. deposit in all units. Concentrations of about 8x average in the upper Coxco Dolomite Member may indicate chemical precipitation of apatite during sedimentation.

(6) Most units show different element correlation patterns between 'near-H.Y.C.' and 'outlying sections' samples, but there is no consistent or significant pattern.

(7) Mineralised units, near the H.Y.C. deposit, tend to show more complex groupings of 'sulphide' elements, and partitioning into sulphide and silicate fractions, than in outlying sections, where the various trace elements are presumably absorbed into mineral lattices, rather than associated with sulphides.

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85 x

APPENDIX 1

Results of chemical analyses.

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   -LEGEND-
NO=SAMPLE NUMBER
1501=SECTION 15 SAMPLE 1,ETC,
FM=FORMATION/MEMBER
TA=TATOOLA SANDSTONE
TL=TOOGANINIE FORMATION,LEILA SANDSTONE
TU=TOOGANINIE UNDIFFERENTIATED
TM=TOOGANINIE FORMATION,MYRTLE SHALE
EM=EMMERUGGA DOLOMITE,MARA MEMBER
EY=EMMERUGGA DOLOMITE,MITCHELL YARD MEMBER
TD=TEENA DOLOMITE
TC=TEENA DOLOMITE,COXCO MEMBER
BW=BARNEY CREEK FORMATION,W-FOLD MEMBER
BH=BARNEY CREEK FORMATION,HYC MEMBER
RD=REWARD DOLOMITE
LI=LITHOLOGY
BD=DOLOMITE BRECCIA
 C=CHERT
CD=CHERTY DOLOMITE
DA=DOLOARENITE
DL=DOLOLUTITE
DT=DOLOMITIC TUFF
PS=EX-PYRITIC SHALE(WEATHERED)
 S=SHALE
SD=SHALEY,SILTY OR SANDY DOLOMITE
SL=SILTSTONE
 T=TUFF BAND
TD=TUFFACEOUS DOLOMITE
TS=TUFFACEOUS SHALE OR SILTSTONE
CA=CALCIUM,PERCENT
MG=MAGNESIUM,PERCENT
AI=PERCENT RESIDUE AFTER ACID TREATMENT
K=POTASSIUM,PERCENT
FE=IRON PERCENT*
MN=MANGANESE,PERCENT*
P=PHOSPHORUS,PPM
ZN=ZINC,PPM*
PB=LEAD,PPM*
CU=COPPER,PPM*
NI=NICKEL,PPM*
CO=COBALT,PPM*
*=EXTRACTED BY HOT 5N HYDROCHLORIC ACID
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NO	FM	LI	CA	MG	AI	K	FE	MN	P	ZN	PB	CU	NI	CO
1501	BW	TD	11,60	5,35	48,20	2,85	1,76	0,25	1690	118	18	49	3	6
1502	BW	DT	4,90	0,41	92,00	4,10	1,89	0,20	2630	175	43	5	10	5
1503	BW	PS	12,80	0,93	52,00	1,30	4,64	1,21	240	4690	1045	35	30	5
1504	BW	DT	0,40	0,30	95,10	3,10	0,55	0,03	590	1095	41	17	20	40
1401	EM	DL	19,20	11,30	6,45	0.35	2,14	0,19	580	6	10	4	3	1
1402	EM	CD	18,60	11,60	8,25	0.35	1,13	0,11	350	16	16	345	3	1
1403	EM	CD	12,60	7,80	37,50	1,05	0,71	0,07	310	9	7	50	3	1
1404	EM	CD	19,20	11,20	4,95	0,08	2,75	0,22	370	5	4	18	3	1
1405	EM	CD	16,80	10,60	17,20	0,24	0,89	0,10	310	6	27	3	3	1
1406	EM	CD	18,90	11,80	6,85	0,35	1,28	0,14	800	112	13	9	9	1
1407	EM	DL	18,80	11,50	3,65	0,10	3,00	0,30	350	10	10	6	3	1
1408	EY	DL	19,20	11.50	2,90	0.06	2,75	0,30	390	13	6	4	3	1
1409	EY	DL	20,10	12.00	2,90	0,07	3,10	0,34	80	4	21	3	3	1
1410	EY	DL	20,00	11,20	1,00	0,07	4,13	0,46	50	6	22	3	3	1
1411	TD	CD	19,30	9,40	10,80	0,50	3,43	0,40	50	8	71	5	3	1
1412	TD	CD	13,40	7,00	40,80	0,65	0,91	0,09	580	6	8	4	3	1
1413	TD	DA	12,50	6,10	44,30	0,43	1,30	0,13	50	5	2	4	3	1
1414	TD	CD	18,60	9,25	15,50	0,90	2,35	0,29	50	9	6	3	3	1
1415	TD	CD	19,50	10.90	7,75	0,65	3,48	0,45	350	43	7	4	3	1
1416	TC	DL	17,20	9.15	7,00	1,50	3,70	0,50	380	23	2	5	20	1
1417	TC	DL	18,00	10,20	12,30	1.15	2,75	0,37	580	15	7	3	3	1
1418	BW	TD	15,20	9.15	26,40	1,95	1,59	0.24	950	8	2	3	3	1
1419	BW	TD	15,60	9,50	26,30	1,95	1,38	0,23	1190	7	2	3	3	1
1301	EM	SD	18,90	12,00	9,80	0,58	0,51	0,07	340	19	2	4	3	1
1302	EM	DL	20,90	12,80	1,50	0,07	1,50	0.24	220	3	2	3	3	1
1303	EM	DL	17,00	10,50	21,20	1,45	0,91	0,12	780	3	12	7	3	1
1304	EM	DL	18,40	11,70	13,10	0,22	1,18	0,14	490	6	30	8	10	1
1305	EY	BD	16,30	9,80	21,00	1,45	1,89	0.23	260	13	21	7	3	1
1306	EY	DL	18,90	12,60	1,65	0.20	1,69	0,21	680	5	2	3	3	1
1307	EY	DL	19,30	12,20	1.00	0.10	2,19	0,29	600	4	4	3	3	1
1308	EY	DL	19,70	12,00	1,60	0,20	2,21	0,32	1550	4	8	3	3	1
1309	EY	DL	20,00	12,90	1,25	0.10	1,91	0,26	350	4	4	3	3	1
1310	EY	DL	20,70	12,60	0,60	0,05	1,53	0,17	120	5	6	3	3	1
1311	EY	DL	19,60	12,60	1,05	0.05	1,85	0,21	450	7	6	3	3	1
1312	EY	DL	20,30	12,80	0,55	0,05	1,69	0,19	610	5	4	3	3	1
1313	EY	DL	19,30	12.00	2,90	0,32	2,21	0,28	300	7	6	3	3	1
1314	EY	DL	19,30	11.80	3,75	0,42	2,26	0,29	610	19	24	4	5	4
1315	EY	BD	18,30	10,70	7,65	0,83	2,86	0,37	230	35	15	6	5	1
1316	TD	DL	17,40	11,80	3,10	0,28	2,78	0,37	230	15	19	3	5	1
1317	TD	TD	11,90	7.40	40,50	2.15	0,86	0,12	490	8	2	3	5	1
1318	TD	CD	11,80	8,25	30,20	2,20	1,33	0,17	600	169	38	14	4	4
1319	TD	DL	17,20	11,40	7,90	0.53	2,53	0,41	270	17	7	7	3	1
1320	TD	TD	11,40	6,95	40,20	3,65	1,58	0,22	820	14	5	3	3	1
1321	TC	TD	16,20	10,90	12,70	1.20	1,71	0,33	360	10	2	4	3	1
1322	TC	DL	16,00	9.80	14,60	0,90	2,65	0,47	380	39	14	6	3	1
1323	TC	DL	16,00	9,95	15,50	1,50	2,40	0,58	700	48	6	9	3	4
1324	BW	TD	13,00	7,90	33,00	2,80	2,19	0,41	1450	45	2	10	4	4
1325	BW	TS	0,30	0,50	85,60	8,60	0,76	0,14	260	68	30	10	4	1
1326	BW	TD	14,70	8,90	21,50	1,35	3,10	0,62	1200	42	280	27	10	1
1327	BW	TD	11,10	4,40	48,70	3,15	3,56	0,59	2790	27500	4200	38	10	20
1201	EM	SD	15,20	9,95	23,70	1,15	0,79	0,06	280	13	2	3	3	1
1202	EM	DL	20,50	14,00	0,68	0,05	0,51	0,06	250	15	2	3	3	1
1203	EM	CD	18,90	12,60	8,60	0,38	0,69	0,09	250	6	2	3	3	1
1204	EM	DL	18,80	12,40	8,60	0.35	1,26	0,12	310	4	5	3	3	1
1205	EM	CD	21,30	13,60	1,80	0,05	0,96	0,18	100	13	2	3	3	1
1207	EM	DL	20,60	14,00	1,50	0.05	0,87	0,09	110	3	2	3	3	1

95

NO	FM	LI	CA	MG	AI	K	FE	MN	P	ZN	PB	CU	NI	CO
1208	EM	DL	19,20	11,60	5,85	0,05	0,72	0,14	80	12	2	3	3	1
1209	EM	DL	20,20	11,80	2,10	0,05	1,49	0,15	270	15	2	3	4	1
1210	EM	DL	19,80	11,70	2,55	0,05	1,70	0,15	1100	11	5	3	3	1
1211	EM	DL	21,70	11,90	1,15	0,05	0,96	0,13	140	7	2	3	4	1
1212	EY	CD	20,20	11,60	4,60	0,10	0,43	0,08	260	5	2	3	7	1
1213	EY	DL	20,20	11,90	1,85	0,13	0,75	0,11	150	10	2	3	3	1
1215	EY	DL	21,30	14,00	2,00	0,13	0,54	0,09	80	3	2	3	3	1
1216	EY	CD	15,40	12,00	15,20	0,37	0,55	0,06	120	4	14	3	3	1
1217	TD	CD	14,00	10,50	21,50	1,20	0,60	0,05	60	3	4	3	3	1
1218	TD	TD	9,30	6,90	49,70	1,65	0,90	0,04	200	4	9	11	3	1
1219	TD	CD	13,60	9,85	30,70	0,75	1,09	0,06	170	4	14	13	5	1
1220	TD	DL	18,40	12,90	4,65	0,17	0,32	0,04	110	3	2	5	3	1
1221	TC	DL	18,10	12,70	7,70	0,42	0,53	0,07	80	3	5	3	3	1
1222	TC	TD	16,70	11,60	15,50	0,86	0,51	0,07	340	4	16	3	3	1
1223	TC	TD	15,30	11,00	11,00	0,67	0,58	0,07	330	4	5	3	3	1
1101	TC	TD	19,60	9,50	13,90	1,60	0,50	0,08	4380	4	2	13	3	1
1102	TC	TD	18,70	9,50	15,70	1,75	0,59	0,09	250	5	2	10	3	1
1103	BW	TD	10,80	5,25	52,50	2,35	0,55	0,11	1640	13	2	8	5	1
1104	BW	TD	14,00	6,65	38,20	2,60	1,78	0,08	650	12	2	7	8	1
1105	RD	DS	12,20	5,25	46,50	2,70	1,22	0,11	940	12	2	20	3	1
1105	RD	DL	13,70	6,65	38,50	2,50	0,87	0,17	1000	5	2	5	3	1
1106	RD	SD	17,40	9,10	21,80	1,05	0,97	0,16	450	4	2	5	5	1
1107	RD	SD	21,90	2,10	38,30	1,35	0,72	0,25	450	8	2	20	5	1
1108	RD	SD	15,60	6,85	34,20	1,45	1,30	0,19	500	5	2	5	7	1
1109	RD	S	0,43	0,14	96,70	1,75	2,75	0,01	590	3	2	13	3	1
1110	RD	DS	11,40	5,90	49,40	2,10	2,35	0,14	600	5	2	7	3	1
1111	RD	DS	13,70	5,10	38,60	1,55	1,19	0,16	750	7	2	8	3	1
1112	RD	CD	19,30	9,90	21,40	0,66	0,96	0,29	1190	49	7	6	5	1
1113	RD	CD	18,50	11,30	10,60	0,24	0,88	0,18	290	15	2	3	3	1
1114	RD	CD	18,30	11,50	12,00	0,30	0,94	0,15	270	5	2	5	3	1
1115	RD	CD	14,00	9,70	26,90	1,46	0,71	0,11	450	5	2	6	4	1
1002	TC	DL	15,90	7,75	18,90	1,35	1,80	0,10	2530	40	2	3	8	1
1003	TC	DL	20,50	10,40	7,25	0,75	0,68	0,12	250	30	2	3	3	1
1004	BW	SD	17,10	8,75	21,40	1,20	0,68	0,11	350	30	2	3	3	1
1005	BW	SD	19,20	10,00	11,40	1,10	0,68	0,13	50	23	2	3	7	1
1006	BW	SD	13,70	6,90	26,80	2,20	1,28	0,15	1440	18	2	3	3	1
1007	BW	SD	19,60	9,80	11,80	0,75	0,75	0,12	300	45	2	5	3	1
1008	RD	DL	17,20	8,60	23,10	1,35	1,40	0,12	150	50	2	3	5	1
1009	RD	DA	16,60	8,50	25,00	0,40	0,94	0,12	1150	20	2	3	3	1
1010	RD	DA	18,30	9,20	16,60	0,25	0,94	0,10	250	28	2	5	3	1
1012	RD	DL	18,90	9,65	14,60	0,60	0,37	0,08	150	88	2	10	5	1
1013	RD	DL	21,30	11,10	1,55	0,10	0,64	0,10	50	150	2	5	5	1
901	TL	SD	15,40	7,95	22,50	0,85	1,13	0,83	500	80	13	3	3	1
902	TM	SL	6,20	2,75	72,60	2,55	5,50	0,04	600	23	13	3	5	1
903	TM	SD	19,80	9,65	13,10	0,05	1,19	0,10	50	9	18	3	7	5
904	EM	DL	21,50	9,90	6,55	0,10	1,09	0,08	50	1	23	13	20	1
905	EM	CD	7,70	3,60	67,90	0,05	0,31	0,02	50	6	13	8	10	1
906	EM	DL	21,90	10,50	4,05	0,05	0,53	0,07	50	13	23	3	10	1
907	EM	DL	19,00	11,10	9,25	0,05	0,31	0,04	50	8	23	3	5	1
908	EM	DL	19,40	11,30	6,15	0,10	0,46	0,08	50	10	23	3	5	1
909	EM	DL	19,40	12,00	4,60	0,05	0,41	0,07	50	6	18	3	8	1
910	EM	DL	18,50	10,70	9,75	0,03	0,50	0,10	50	3	23	3	10	1
911	EM	DL	20,60	12,40	2,00	0,05	0,27	0,05	50	22	23	3	5	1
912	EM	DL	19,80	12,00	5,70	0,05	0,25	0,05	50	3	18	3	5	5
913	EM	DL	18,10	10,30	12,40	0,10	0,25	0,05	50	5	23	3	3	1
914	EM	DL	19,60	12,00	5,70	0,05	0,23	0,05	50	7	18	3	3	1

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NO   FM LI   CA    MG     AI     K      FE    MN     P      ZN    PB   CU  NI   CO
915  EM DL 19,40 11,60   7,60  0,15   0,47 0,10    50     93     2   50 500    1
916  EM CD 16,70 10,20  18,10  0,05   0,30 0,05    50    103     2   65 300    1
917  EM DL 19,70 11,80   6,65  0,05   0,35 0,07    50     38     2   23  70    1
918  EM DL 18,40 11,20  10,90  0.10   0,60 0,08    50     23     2   10  30    1
919  EM DL 20,40 10,30   6,95  0,25   0,66 0,13   150     25     2    7  10    1
920  TC DL 20,00 10,00   9,65  0,30   0,40 0,08   850     20     2    3   3    1
921  TC DL 20,50 10,40   6,05  0,10   1,25 0,13  4710     38     2    3   5    1
922  TC DL 20,70 10,30   6,60  0,40   0,68 0,12  2640     23     2    5   3    1
923  RD DL 21,10 10,80   3,70  0,25   0,93 0,17   200     28     2    5   5    1
924  RD DA 16,90  8,75  22,70  0,15   1,10 0,09   550     15     2    5   3    1
925  RD DL 17,60  9,05  19,60  0,50   0,68 0,12   400    218     2    5  10    1
801  EM DB 19,40 11,50  13,40  0,23   0,30 0,03    50      3    11    5   3    1
802  EM  C  2,70  1,25  68,00  0,10   0,49 0,04   900     10    21    9   8    3
803  EM CD 14,80  8,10  34,00  0,85   0,48 0,03   250      5    30    8   3    3
804  EM DL 19,10 11,80  14,30  0,65   0,40 0,03    50      4     3    4   3    1
805  EM DL 21,30 12,50   5,50  0,10   0,26 0,02  1000      5     2    3   3    1
806  EM  C  8,25  4,20  65,00  4,00   0,19 0,02  1700      6     2    5   3    1
807  EM DL 20,90 12,00   7,50  0,25   0,23 0,03   400      4     2    3   3    1
808  EM  C  8,45  4,65  63,00  0,10   0,26 0,03  1000      6     2    3   4    1
809  EM DL 20,80 11,90   7,70  0,23   0,22 0,03    50      3     2    3   3    1
810  EM CD 15,30  9,95  20,20  0,85   0,31 0,03   250      3    19    4   5    1
811  EM DA 19,50 10,70  14,30  0,40   0,31 0,03   750      2     2    4   5    6
812  EM CD 10,00  4,80  56,20  0,23   0,27 0,03  1100     11     2    3   3    1
813  EM CD 15,90  8,90  25,50  0,80   0,42 0,02   250      5     6    6   3    9
814  EM DL 21,00 11,80   4,40  0,10   0,39 0,05    50      2     2    3   3    1
815  EM SD 14,40  7,70  33,20  2,20   0,63 0,04    50      4    13    9   5    3
816  EY DL 20,00 11,30   7,05  0,10   0,42 0,04   500      9     5    8   3    1
817  EY DL 21,30 12,00   2,65  0,10   0,30 0,04    50      2     2    3   3    1
818  EY DL 21,30 12,30   2,35  0,20   0,48 0,06   500      2     2    3   3    1
819  EY DL 21,40 12,00   2,30  0,30   0,57 0,06    50      2     2    3   3    1
820  EY DL 21,30 11,80   3,00  1,40   0,57 0,06   100      2     2    3   3    1
821  EY DL 19,10 10,60  13,40  0,20   0,30 0,03    50      3     2    3   3    1
822  TD SD 15,90  8,60  26,20  1,85   0,45 0,03   250      9     2    4   5    1
823  TD DL 19,40 10,20   1,70  0,50   0,57 0,04    50      2     2    5   3    1
823  TD DS 13,80  7,10  38,60  0,75   0,62 0,03   250      2     2    3   5    1
824  TD DL 19,10 10,20  13,40  0,45   1,00 0,06    50      8     8    4   5    1
825  TD TS  0,21  0,48  96,30  5,35   2,47 0,17   450      3    18   58   4   30
826  TD SD 14,30  7,60  35,60  2,75   0,95 0,05   350      3     8   16   3    1
827  TD TS  0,17  0,06  97,30  7,60   0,06 0,09   250     55     5   16   3    1
828  BW TS  5,70  2,50  73,70  4,85   0,85 0,38  1350     18    18   15   5    1
829  BW TS  0,30  0,09  96,90  4,50   0,87 0,05   870      4     8    6   5    1
830  BW TS  3,95  1,55  81,60  4,40   0,87 0,11  1140     71    10    8   5    1
831  BW TD 12,20  6,40  43,40  2,00   1,55 0,10  1740      6    40   10  20   10
832  BW TD 14,00  7,20  37,20  2,20   1,00 0,09   650     23     2    9   4    1
832  BW DL 19,40 10,80  12,00  0,50   0,64 0,10   400     21    13    3   3    1
833  RD TD 11,30  6,00  49,40  3,60   0,70 0,07   700     30     8    8   3    1
834  RD TD 12,00  6,20  45,80  3,10   0,73 0,07   550      5     2    5   3    1
835  RD TS  0,09  0,03  98,40  3,55   1,58 0,04   500      5    30    9   6    1
836  RD TD 12,30  7,40  45,20  3,45   0,80 0,05   800      3    13   10   5    3
837  RD DL 19,40 10,50  13,80  0,60   0,54 0,05    50      2     5    6   3    3
839  RD DL 16,30 10,00  28,30  1,25   0,90 0,07   500      3    13   10   5    3
840  RD DA 18,90 11,80  17,30  0,65   0,47 0,05  3100      2    13    3   3    1
841  RD CD 17,20 11,50  24,40  0,35   0,45 0,05    50      1     2    3   3    3
842  RD SD 15,40 10,10  32,10  1,65   0,53 0,05   150      3     2    3   3    1
844  RD SD 13,00  7,83  40,30  2,70   0,95 0,05  2730     75    53   11   3    1
845  RD TD 16,00 10,20  30,00  2,05   1,28 0,07   700     23     8    8   5    1
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NO	FM	LI	CA	MG	AI	K	FE	MN	P	ZN	PB	CU	NI	CO
846	RD	DL	19,30	11.70	14,60	0,45	0,73	0,07	1540	2	13	4	3	1
847	RD	DL	19,20	11,60	15,00	0,50	0,63	0,07	200	3	2	4	9	1
848	RD	DA	16,30	8,30	28,70	1.60	0,63	0,05	300	3	18	8	5	1
849	RD	DL	22,00	10,90	3,35	0.05	0,40	0,07	400	3	18	5	3	1
850	RD	DL	19,20	12.30	13,40	0.05	0,44	0,06	450	5	5	5	3	1
851	RD	DB	15,20	7,85	3,48	1.00	0,75	0,08	1150	4	23	7	3	1
852	RD	TD	11,50	5.05	50,50	1.40	0,63	0,05	1250	2	13	8	3	1
853	RD	SD	12,20	5.65	48,10	1.30	0,68	0,05	1930	3	13	7	5	1
854	RD	SD	12,60	6.15	46,40	2.40	1,16	0,07	700	4	35	13	3	1
701	EM	SD	14,90	7,70	33,30	1,05	0,80	0,05	200	9	2	7	5	5
702	EM	DL	20,90	11,50	7,00	0.17	0,69	0,05	50	10	7	5	5	5
703	EM	C	6,10	3,05	72,30	0.00	0,28	0,03	50	11	2	5	10	1
704	EM	DS	8,60	4,70	59,80	3.65	2,19	0,03	700	21	8	5	5	5
705	EM	SD	14,30	7.20	35,30	2.10	0,76	0,04	1840	20	5	2	7	5
707	EM	DL	21,00	12,20	0,86	0.21	0,88	0,06	50	9	7	5	5	1
708	EM	CD	17,90	10,40	20,30	0.00	0,54	0,03	100	22	25	8	8	1
710	EM	DL	22,50	12.10	2,90	0.10	0,60	0,06	150	25	38	18	7	5
711	EM	DL	20,80	12.30	6,10	0.17	0,40	0,04	200	44	20	7	5	5
713	EM	DL	21,90	13.00	2,10	0.14	0,78	0,09	150	10	2	10	10	1
715	EM	CD	19,20	11.30	13,70	0.22	0,41	0,04	150	8	2	15	10	1
716	EM	DL	22,20	12.60	0,91	0.00	0,40	0,05	50	6	2	7	10	1
717	EM	DL	22,20	11.20	1,20	0.10	0,56	0,08	140	181	2	5	10	1
718	EM	DL	21,70	12,20	2,65	0.17	0,28	0,04	250	10	2	5	10	1
719	EM	DL	22,20	12,20	1,65	0.13	0,37	0,05	50	5	2	3	8	1
720	EM	DL	21,30	12.50	1,60	0.05	0,28	0,04	100	10	2	3	10	1
721	EM	DL	21,60	11.90	4,10	0.05	0,87	0,09	1110	17	2	3	10	1
723	EM	DL	21,80	12.20	3,15	0.13	0,42	0,06	150	24	2	3	10	1
724	EY	DL	22,30	12.60	1,45	0.13	0,00	0,04	390	7	2	3	10	1
725	EY	DL	20,90	11.60	7,10	0.70	0,00	0,05	1360	20	2	3	10	1
726	TC	DL	20,30	11.40	9,95	0.45	0,00	0,05	1080	9	2	5	10	1
727	TC	DL	20,80	12.00	7,20	0.60	0,00	0,06	1150	12	2	5	10	1
728	TC	DL	20,50	11.50	6,45	0.53	0,00	0,06	780	20	2	3	10	1
729	TC	DL	21,10	11.10	8,85	0.45	0,47	0,06	1790	18	2	3	10	1
730	TC	TS	3,95	1.80	83,40	6.70	0,13	0,02	1090	6	2	3	8	1
731	TC	DL	21,70	11.90	4,60	0.25	0,46	0,07	390	134	2	15	10	1
732	BW	TD	9,40	4.55	57,40	4.80	0,53	0,04	2190	49	2	15	10	1
733	BW	TD	9,35	5.40	59,80	4.95	1,45	0,05	1960	18	2	18	20	1
734	BW	TD	13,90	5,90	39,70	3.25	0,68	0,05	2400	43	13	25	20	1
737	BW	TS	6,70	4.10	68,30	5,75	0,69	0,04	1740	43	8	5	5	1
738	BW	TD	12,70	7,20	44,30	3,38	0,58	0,06	700	39	7	5	3	1
739	BW	TS	3,40	1.65	86,90	9.40	0,18	0,02	980	10	2	3	5	1
740	BW	TD	12,50	6.55	44,80	2.65	0,68	0,13	940	19	2	5	3	1
741	BW	TS	0,25	0.12	97,80	4.35	0.11	0,00	400	6	2	10	5	1
742	BW	TS	0,57	0.30	95,60	10.00	2,38	0,03	290	15	28	58	20	20
743	BW	TD	12,50	5,90	44,30	2.60	1,50	0,06	750	7	13	18	10	1
744	BW	TD	12,10	6.00	45,70	2.35	1,31	0,04	900	9	13	10	5	10
601	TA	SL	1,65	0.57	93,70	3.00	0,94	0,04	250	8	2	25	8	3
602	TA	SL	6,00	2.15	72,00	4,65	1,83	0,04	790	4	45	18	20	3
603	TU	DL	18,20	8,85	19,40	0.80	1,28	0,10	300	10	2	43	3	3
604	TU	DA	18,00	10.00	15,50	0.37	1,31	0,11	100	65	68	375	10	5
605	TU	CD	16,20	8,75	25,90	0.46	1,89	0,09	100	9	45	60	10	30
606	TU	SD	14,30	7.70	33,40	0.40	0,89	0,06	100	6	20	10	5	1
607.	TU	SD	10,70	6,20	46,50	2,60	1,23	0,05	700	15	2	7	7	1
608	TU	SD	16,80	9.00	20,70	1.20	1,16	0,05	150	9	2	18	5	5
609	TU	DA	18,20	10.10	14,60	0,45	0,90	0,05	100	6	18	8	8	1
610	TU	SD	15,40	8,05	28,50	1.50	1,50	0,06	250	13	25	40	7	10

NO	FM	LI	CA	MG	AI	K	FE	MN	P	ZN	PB	CU	NI	CD
611	TU	CD	17,50	9,05	19,50	0,27	1,23	0,06	50	7	2	23	3	1
501	TU	SL	8,60	5,70	57,40	2,55	2,10	0,05	500	19	10	10	6	4
502	TU	DS	10,30	5,55	51,00	2,45	2,20	0,05	790	19	3	5	10	4
503	TU	DS	9,60	4,90	54,90	3,30	1,53	0,05	550	14	13	15	9	3
504	TU	DS	7,70	3,30	63,10	3,20	1,65	0,03	750	16	9	19	10	3
505	TU	DL	19,10	10,50	11,50	0.17	1,90	0,07	250	14	2	4	3	3
506	TU	SD	15,80	8,50	28,30	0.40	1,78	0,07	100	11	10	29	3	1
507	TU	SD	16,80	8,85	22,20	0,80	1,90	0,07	250	8	3	6	3	4
508	TU	DS	8,60	4,60	59,40	2,55	1,50	0,03	700	13	5	68	3	3
509	TU	DL	20,10	10,60	7,80	0,25	1,50	0,05	550	14	2	8	3	3
510	TU	C	3,80	1,90	81,20	0,00	1,15	0,04	250	15	5	9	9	1
511	TU	DS	10,10	5,10	52,10	3,65	1,58	0,03	700	13	3	18	9	1
512	TU	DL	20,80	11,30	6,25	0,00	1,80	0,07	50	9	5	4	3	1
513	TU	SD	12,90	6,95	40,90	2,30	1,73	0,04	700	12	2	13	10	1
514	TU	DL	20,80	11,10	5,05	0,06	1,50	0,07	100	14	2	10	3	1
515	TU	C	2,75	0.47	87,80	0,09	0,80	0,03	150	9	5	44	10	6
516	TU	SD	15,30	8,15	28,50	1,05	1,45	0,05	350	11	5	8	3	1
517	TU	SD	16,50	8,80	24,00	1.15	1,24	0,06	150	20	23	28	4	8
518	TU	DL	18,20	9,60	16,20	0,32	1,24	0,06	50	11	18	3	3	3
519	TU	SL	3,90	1,25	78,70	4,45	2,22	0,03	840	23	10	5	9	4
520	TU	SD	16,30	8,70	23,50	0,28	1,24	0,07	50	6	23	7	3	1
521	TU	C	6,45	3,05	70,70	0,15	0,58	0,03	100	10	10	5	3	4
523	TL	SD	17,90	8,55	19,30	0,28	1,89	0,11	300	5	55	8	3	10
524	TL	SD	13,30	10,30	37,60	0,25	0,85	0,07	150	5	18	15	3	3
525	TL	SD	10,90	8,05	48,10	1,90	1,20	0,06	750	12	28	33	6	10
526	TL	SD	17,70	14,20	19,10	0,80	0,10	0,08	1050	6	33	7	4	10
527	TM	CD	15,70	7,60	29,60	0,73	0,10	0,07	300	13	8	8	3	8
528	TM	DS	8,30	3,40	61,70	3,00	0,11	0,06	700	12	23	10	9	10
529	TM	SL	6,10	2,35	70,80	4,10	0,20	0,05	1000	29	10	3	10	10
530	TM	DS	7,80	3,30	62,80	3,75	0,10	0,05	800	27	10	3	10	10
531	TM	SL	5,30	1,90	75,50	4,45	0,20	0,03	950	27	5	3	10	10
532	EM	DS	8,55	3,25	61,50	3,80	0,11	0,07	700	17	10	3	6	4
533	EM	C	4,90	2,25	77,10	0,05	0,00	0,03	300	8	10	3	3	9
534	EM	DL	21,30	11,20	5,80	0,12	0,00	0,05	50	10	23	3	3	3
535	EM	TD	14,80	7,10	34,70	2,75	0,00	0,03	200	42	33	3	4	10
401	TM	SL	9,30	5,20	56,50	3,25	1,73	0,02	700	18	2	3	8	1
402	EM	CD	12,50	7,30	34,70	0,15	0,58	0,02	200	6	2	4	6	1
403	EM	CD	15,50	8,20	31,80	0,76	0,65	0,03	50	5	2	5	4	1
404	EM	SD	13,60	7,10	40,10	0,83	1,28	0,03	450	8	2	3	4	1
405	EM	SD	8,50	4,60	60,80	2,70	1,68	0,02	950	11	2	5	6	5
406	EM	DL	18,80	9,95	14,70	0,42	0,60	0,03	100	5	18	4	3	1
407	EM	DL	20,90	12,30	3,95	0,42	0,68	0,03	250	9	2	5	3	1
408	EM	DL	20,00	11,30	7,13	0,11	0,50	0,02	200	6	2	3	3	1
409	EM	C	1,90	0,40	90,80	0,00	0,45	0,03	1850	14	5	5	6	3
411	EM	CD	17,90	10,20	18,60	0,05	0,31	0,02	250	6	2	3	3	1
412	EM	DL	21,30	12,30	2.80	0,05	0,43	0,02	50	8	2	3	3	1
413	EM	SD	12,80	7,60	40,90	0,50	0,60	0,02	150	12	18	5	4	1
414	EM	DL	19,70	11,40	9,70	0,65	0,55	0,02	100	4	2	4	3	1
415	EM	C	3,45	1,80	84,30	0,06	0,38	0,02	550	7	13	4	6	1
416	EM	SD	16,80	10,10	23,40	0,38	0,50	0,02	50	5	10	4	4	1
417	EM	BD	19,00	10,70	13,60	0,36	0,60	0,02	50	5	23	12	5	3
418	EM	DS	10,20	5,80	51,40	1,35	0,68	0,02	350	7	23	10	6	4
419	EM	SD	11,90	6,70	47,10	0.73	0,40	0,02	400	6	2	4	4	1
421	EM	DL	18,10	10,10	18,10	0,61	0,35	0,02	50	10	2	3	4	1
422	EM	DL	21,70	12,50	0,11	0,00	0,35	0,02	50	9	2	3	3	1
423	EM	C	6,70	4,15	68,60	0,08	0,45	0,02	200	6	2	15	9	1

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NO  FM LI   CA     MG     AI      K      FE   MN      P    ZN     PB   CU  NI  CO
424 EM DL 20,40 11.30   6,00  0.20   0,55 0,02   100    5      2    3   3   1
425 EM DL 20,30 11,80   4,60  0,06   0,28 0,01    50    4      2    4   3   1
426 EM  C  4,30  2.00  78,70  0.00   0,33 0.01   600    5      2    4   9   4
427 EM SD 16,90  8,85  24,20  0.08   0,30 0,02   100   13      2    7   3   1
428 EM DL 19,10 10,70  13,60  0,06   0,28 0,02    50    9      2    3   3   9
429 EM DL 21,10 12,10   4,50  0.00   0,75 0,34   620    5      2    3   3   1
430 EM DL 21,10 12.00   3,80  0.00   0,20 0.02   300    5      2    3   3   1
431 EM DA 21,40 12.20   2,55  0.00   0,25 0,02    50    3      2    8   3   1
432 EM  C  1,90  1.10  90,90  0.00   0,40 0,01   250    4      2    5   8   6
433 EM CD 14,90  8,05  32,20  0.00   0,24 0,03    50    4      2    3   3   1
434 EM DL 20,70 11,30   5,95  0.00   0,24 0,03   350    4      2    3   3   1
435 EM DL 21,30 11,90   0,95  0.00   0,28 0.02    50    5     13    3   3   1
436 EM DL 21,10 12,80   1,75  0.00   0,23 0,02    50    5      8    3   5   1
437 EM  C  0,19  0.13  96,80  0.06   0,75 0,07   400    6      2    3  10   9
438 EM DL 21,10 11,70   1,60  0,00   0,48 0,05    50    4      2    3   3   1
439 EM DL 19,00 10.10   9,70  0.00   0,29 0.03   100    5      2    6   3   1
440 EM DL 21,20 11.90   0,95  0.00   0,18 0,02   250    4      2    3   3   1
441 EY DL 21,60 12.80   2,30  0.00   0,95 0,08   100    3      2    3   3   1
442 EY DL 21,00 12.80   1.40  0.00   0,40 0,02   150    4      2    3   3   1
443 EY DL 21,60 12,00   0,35  0.00   0,27 0,02    50    3      2    3   3   1
444 EY DL 21,50 12,10   0,80  0.00   0,16 0,02    50    4      2    3   3   1
445 EY DL 21,50 12,90   0,80  0,00   0,16 0,02   250    3     10    3   3   1
446 EY DL 20,70 12,80   3,35  0,00   0,25 0,02    50    3      2    3   3   1
301 EM DL 21,20 11,10   2,60  0,00   0,23 0,01    50    9      2    3   3   1
302 EM DL 20,00 11,60   9,10  0.10   0,80 0,00    19   10      2    9   3   1
303 EM DL 21,40 11.10   3,65  0,05   0,25 0,02   350    9      9    3   8   1
304 EY DL 18,60 11,30  14,30  0,00   0,33 0,02    50    6      2    3   5   1
305 EY DL 21,30 12,20   4,15  0,00   0,38 0,03    50    8      2    3   5   1
306 EY CD 16,00  9,65  27,70  0,00   0,31 0,02   200   12      6    3   9   1
307 EY DL 21,50 11,90   2,40  0,00   0,28 0,02    50    7      2    3   9   1
308 TD DL 20,20 13,00   8,40  0,60   0,34 0,03   100    8      3    3   3   1
309 TD DL 20,30 12,30   5,70  0,49   0,29 0,02   200   10     15    3   3   1
310 TD DL 18,70 11,70  14,60  0.60   0,31 0,02   250   14      2    3   5   1
311 TD DL 20,50 12,00   7,50  0,38   0,25 0.02   200    9      4    4   3   1
312 TC DL 20,80 12.70   8,30  0.25   0,40 0.03   500    5      3    7   3   1
314 TC TS  3,50  1,70  84,00  5,75   0,17 0.01   500   12      5    3   8   1
316 TC DL 20,00 11,70   6,85  0.38   0,44 0,03   750   12      6    3   3   1
317 TC  T  0,00  0.05  97,10 12,00   1,13 0,00  1400   21     11   14  20   1
320 TC DL 20,00 11.40  79,00  0.57   0,45 0,03   690    8      8    3   4   1
321 TC DL 20,20 11.50   7,25  0.30   0,44 0,03   300   13      8    3   3   1
322 TC DL 20,20 10,90   7,30  0.44   0,53 0,05   500   10      2    8   5   1
201 TC DL 20,40 12,20   6,40  0.39   0,40 0,02   600   13      3    3   4   1
202 TC DL 20,40 12.30   4,90  0.22   0,38 0,03    50    6      2    3   6   1
203 TC TD 16,60 10,10  28,10  2,05   0,45 0,04   500   11      2   10   3   1
204 BW TD  9,40  5.60  55,90  3,85   0,55 0,01  1790   22      4   19   9   1
205 BW TD 15,60 10,10  23,20  1,45   0,64 0,04    50    8      2    4   5   1
206 BW TD 13,00  7,80  39,40  2,45   2,70 0,08   890   18     19   13  10   4
207 BW DT  6,00  2,80  67,50  6,65   0,95 0,03  1090   26      3    9   9   1
208 BW DT  5,10  2,90  72,00  5.45   1,53 0,03  2000   15     10    8   4   4
209 BW DT  7,50  4,30  59,80  4.15   1,28 0,03  1180   18      2    8   9   1
210 BW DT  4,00  2,10  77,00  5,15   1,90 0.03  2380   17      2   20  10   4
211 BW DT  8,20  4,30  58,40  4,45   1,63 0,05  1580   19      5   19   8   1
213 BW TD 12,00  5,60  43,40  2,55   1,46 0,65   100   18      5   13   8   1
214 BW DT  9,10  5,30  56,40  3,70   1,65 0,45  1590   12      4   13   8   3
215 BW DT  7,80  3,70  62,60  6,15   1,17 0,36   690   11      5    6  10   1
216 BW TD 12,10  7,00  41,50  2,20   1,55 0,60  1500   13      2   10  10   1
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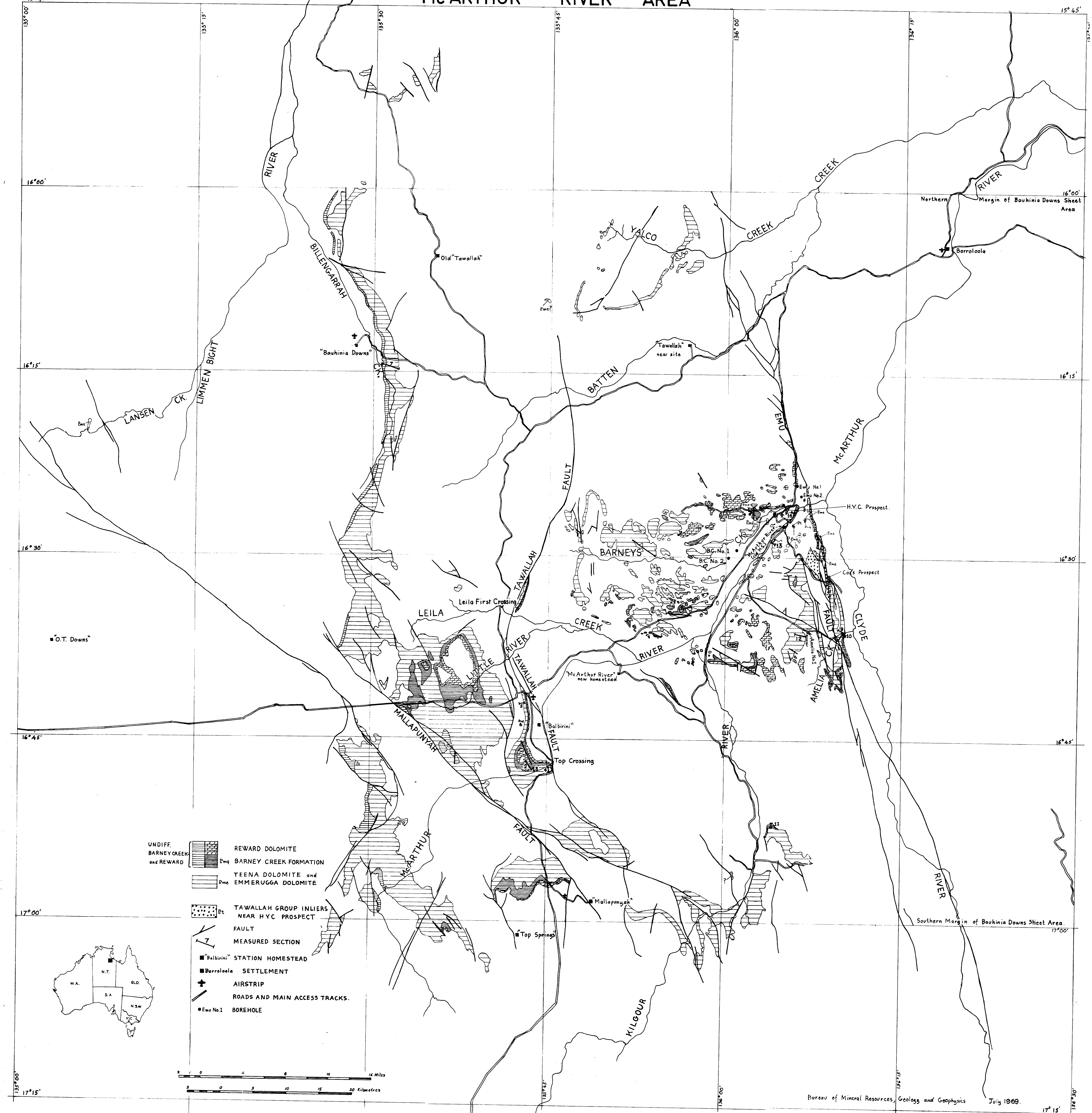
NO	FM	LI	CA	MG	AI	K	FE	MN	P	ZN	PB	CU	NI	CD
217	BW	TD	10,00	6.20	49,80	1.70	1,24	0.31	300	17	11	14	8	1
218	BW	TD	15,20	9.10	26,00	1,20	1,05	0,22	200	14	4	9	4	1
219	BW	DS	11,60	6.90	42,20	1,45	1,23	0.18	500	24	2	10	5	5
220	BW	DS	10,90	6,60	44,80	1,55	0,83	0.08	300	13	5	5	4	1
221	BW	DS	15,10	8,60	27,00	1,15	1,15	0.17	400	15	2	10	4	3
222	BW	DS	12,60	7,80	37,50	1,45	0,93	0.13	450	24	2	6	9	1
223	BW	DS	11,10	6.90	44,50	1,45	0,84	0.11	200	12	3	5	9	1
224	BW	DS	5,70	2,90	72,70	4.85	4,45	0,07	200	10	89	10	10	1
225	BW	DS	5,95	2.40	71,80	7.00	0,80	0,14	300	14	3	30	6	1
226	BW	DS	7,50	3.00	64,50	5,85	0,81	0,16	100	9	2	19	8	1
227	BH	S	0,00	0.00	96,10	4.10	2,72	0.02	550	12	11	10	8	1
228	RD	SD	12,10	5,50	40,50	1,65	1,50	0,10	600	16	5	13	4	1
229	RD	SD	13,70	6,05	36,30	1,15	1,35	0,10	50	9	5	5	3	1
230	RD	SD	13,30	7,40	63,00	2,80	1,28	0,05	150	60	2	6	30	1
231	RD	DS	16,00	3.95	41,00	1,05	1,18	0,08	250	32	2	6	10	4
232	RD	TS	0,00	0,00	99.50	6,00	2,10	0,07	600	47	20	26	20	1
233	RD	DS	14,60	6.20	32,00	1.85	0,70	0,03	200	10	2	6	3	1
234	RD	CD	17,10	7.25	21.50	0.81	0,53	0,04	50	7	5	91	3	1
235	RD	CD	18,40	7,95	14,40	0.51	0,60	0,04	250	8	14	5	6	1
237	RD	DL	20,40	8.70	7,80	0.17	0,30	0.05	400	8	3	5	6	1
238	RD	DL	20,40	11.60	5,00	0.34	0,28	0,03	150	7	2	3	4	1
239	RD	DL	21,00	11.80	5,35	0.17	0,41	0,03	50	9	4	3	6	1
240	RD	DL	21,40	12.20	4,50	0,08	0,44	0,03	50	8	8	4	3	1
241	RD	SD	16,80	10,00	23,00	0,42	0,40	0,03	50	10	4	3	3	1

10 /

PLATE 1

LOCALITY MAP
McARTHUR RIVER AREA

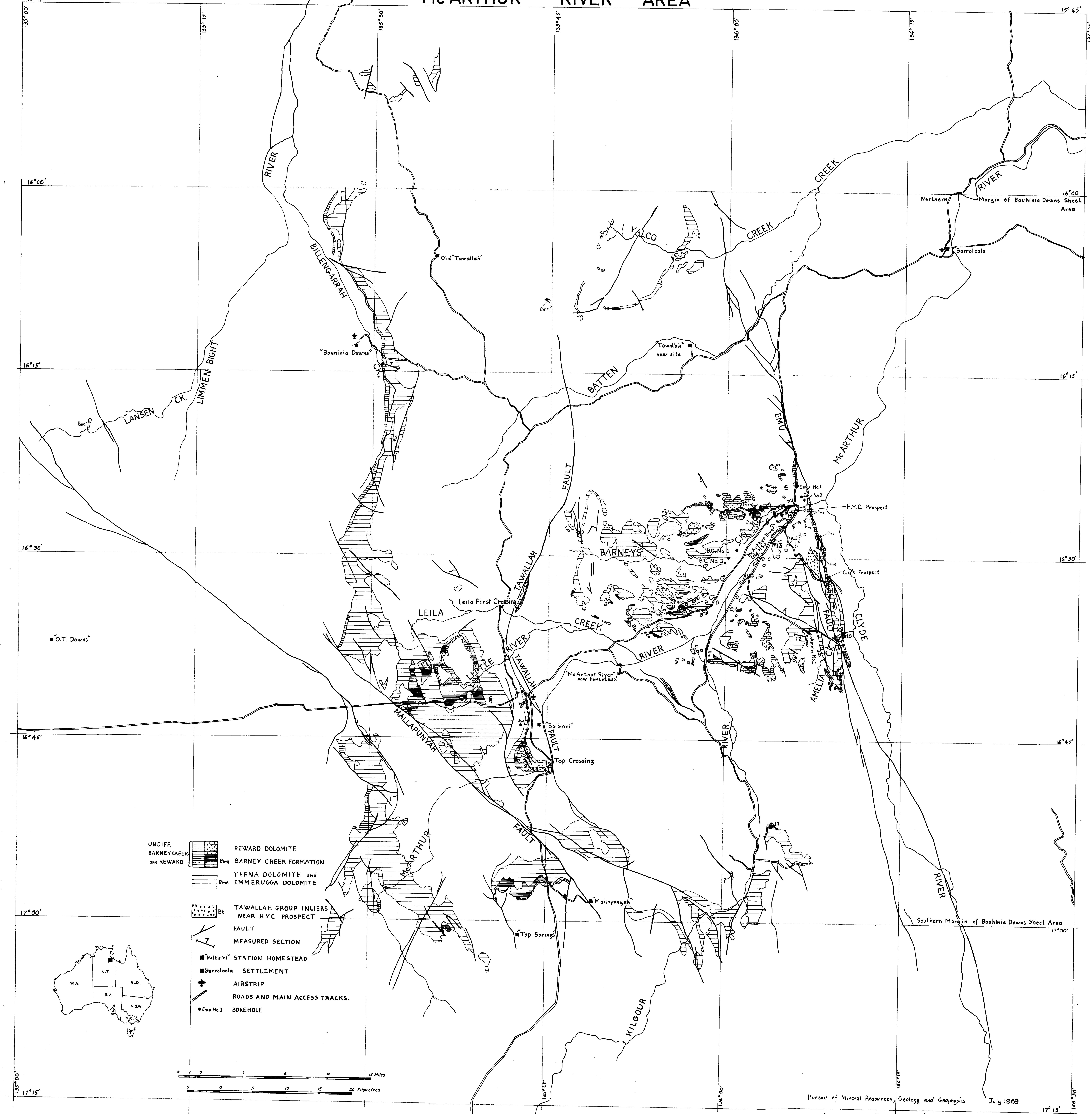


Bureau of Mineral Resources, Geology and Geophysics July 1969.

to accompany Record 1969/145

PLATE 1

LOCALITY MAP
McARTHUR RIVER AREA



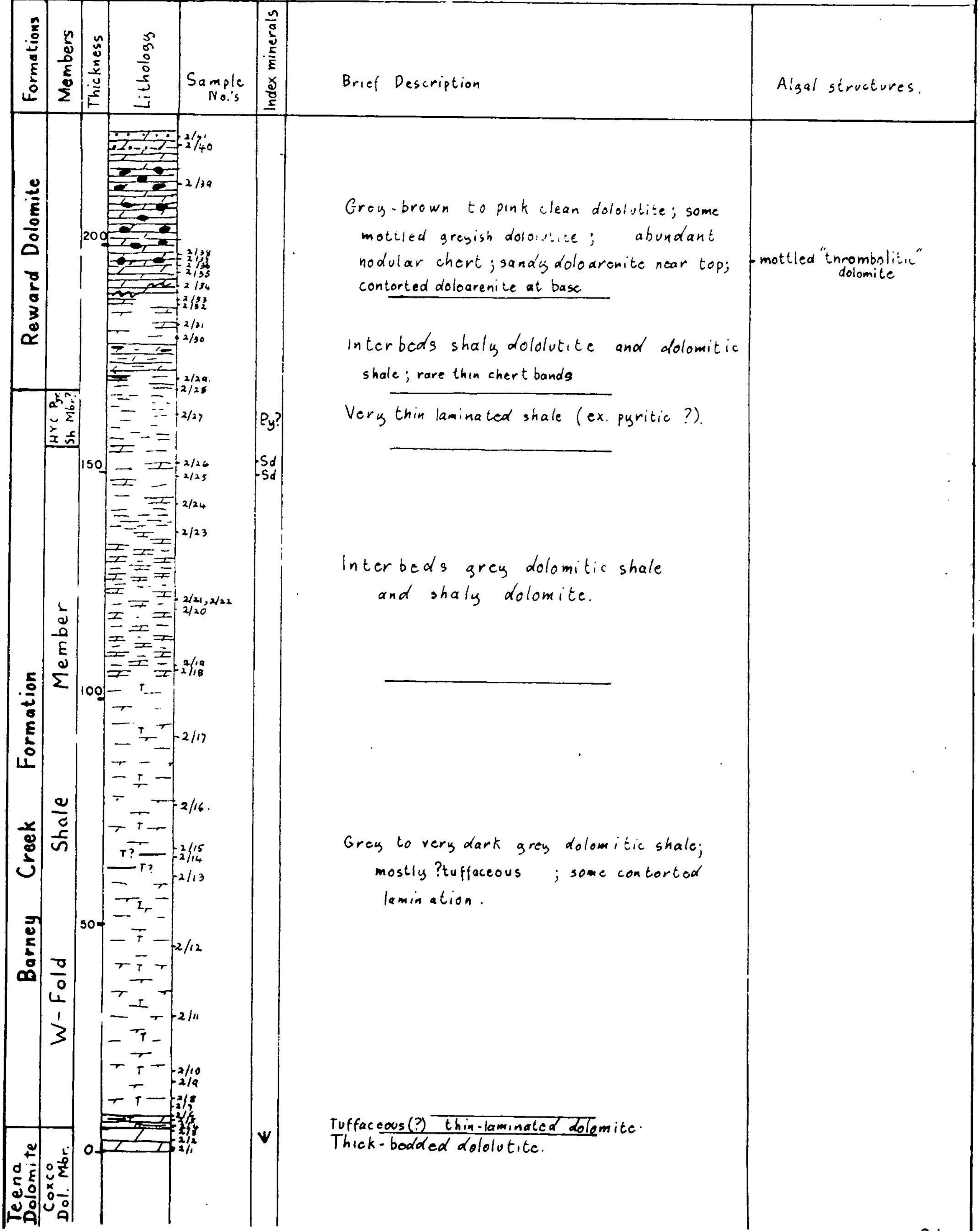
Bureau of Mineral Resources, Geology and Geophysics July 1969.

to accompany Record 1969/145

Plate 2

Measured Section 2, About 40 km West of Top Crossing

Measured with 1·5m staff and Abney Level. Legend as on Plate 12



Grey-brown to pink clean dololutite; some mottled greyish dololutite; abundant nodular chert; sandy doloarenite near top; contorted doloarenite at base

mottled "thrombolitic" dolomite

Interbeds shaly dololutite and dolomitic shale; rare thin chert bands

Very thin laminated shale (ex. pyritic ?).

Interbeds grey dolomitic shale and shaly dolomite.

Grey to very dark grey dolomitic shale; mostly ?tuffaceous ; some contorted lamination.

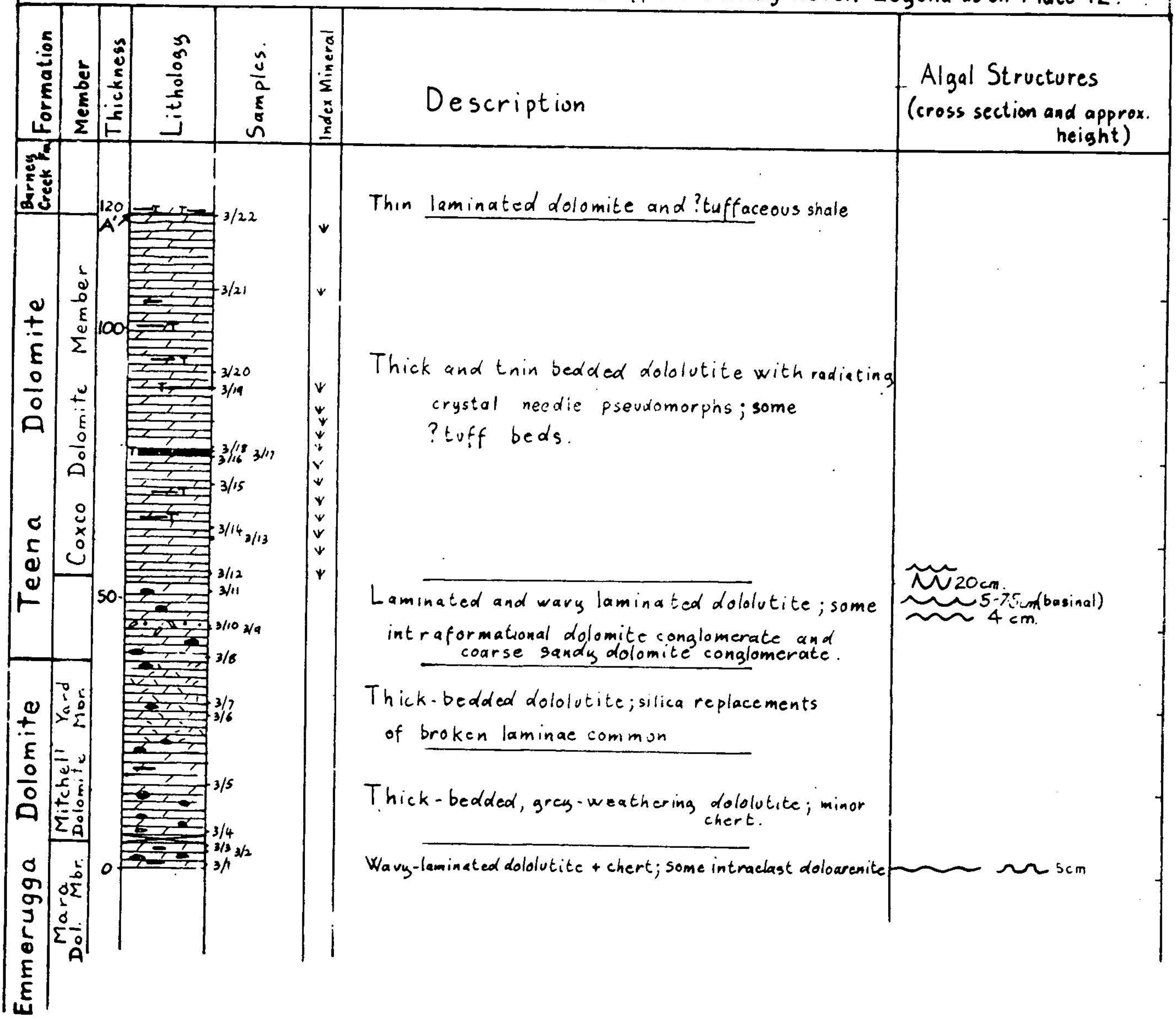
Tuffaceous(?) thin-laminated dolomite.

Thick-bedded dololutite.

Plate 3

Measured Section 3, about 3 km. WSW of Top Crossing

Measured with 1·5m staff and Abney Level. Legend as on Plate 12.



Thin laminated dolomite and ?tuffaceous shale

Thick and thin bedded dololutite with radiating crystal needle pseudomorphs; some ?tuff beds.

Laminated and wavy laminated dololutite; some intraformational dolomite conglomerate and coarse sandy dolomite conglomerate.

Thick-bedded dololutite; silica replacements of broken laminae common

Thick-bedded, grey-weathering dololutite; minor chert.

Wavy-laminated dololutite + chert; some intraclast doloarenite

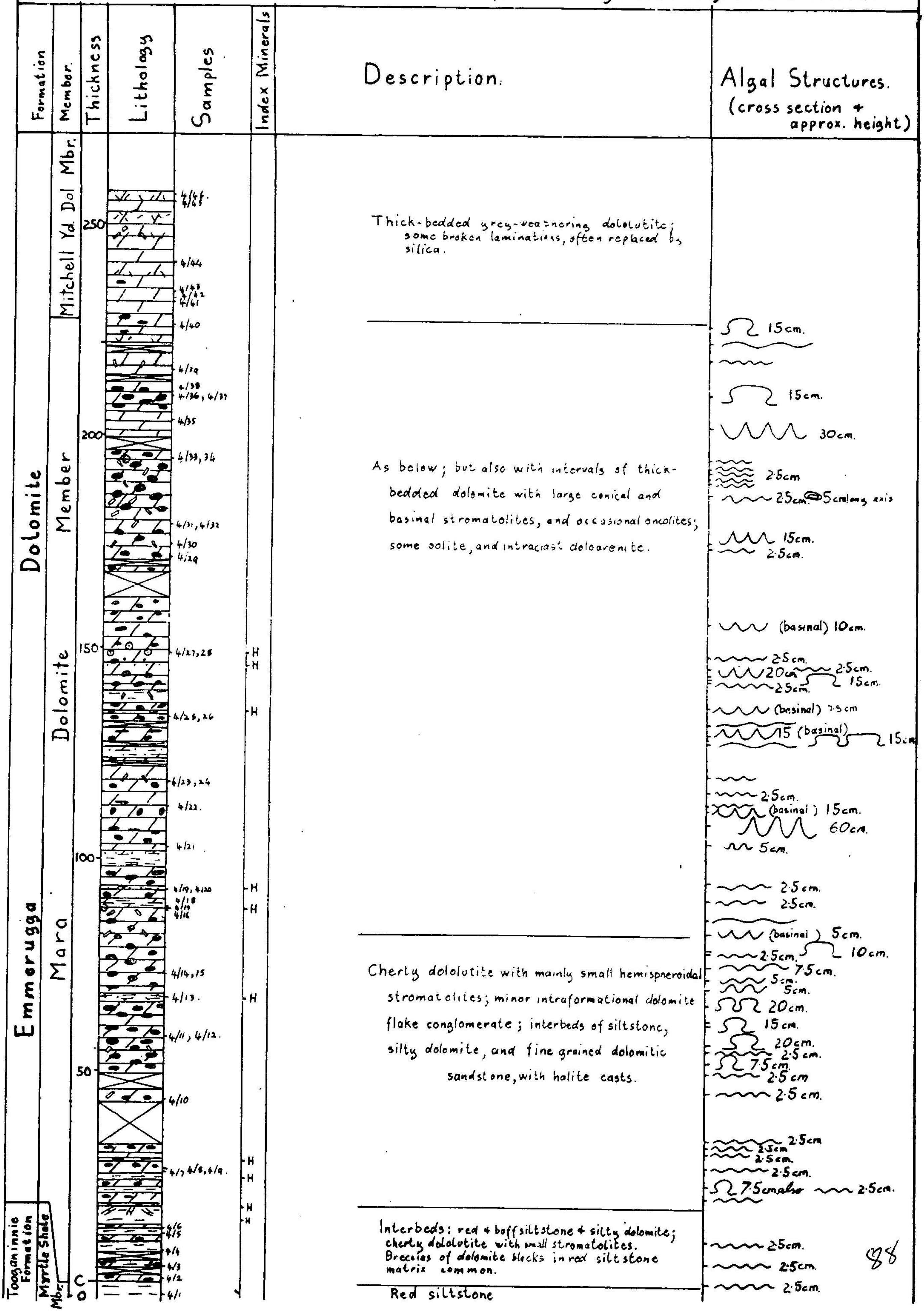
To accompany Record 1969/145

E53/A3/35

Plate 4

Measured Section 4, about 1·5 km. SW of Top Crossing

Measured with 1·5 m staff and Abney Level. Legend as on Plate 12



Thick-bedded grey-weathering dololutite; some broken laminations, often replaced by silica.

As below; but also with intervals of thick-bedded dolomite with large conical and basinal stromatolites, and occasional oncolites; some oolite, and intraclast doloarenite.

Cherty dololutite with mainly small hemispheroidal stromatolites; minor intraformational dolomite flake conglomerate; interbeds of siltstone, silty dolomite, and fine grained dolomitic sandstone, with halite casts.

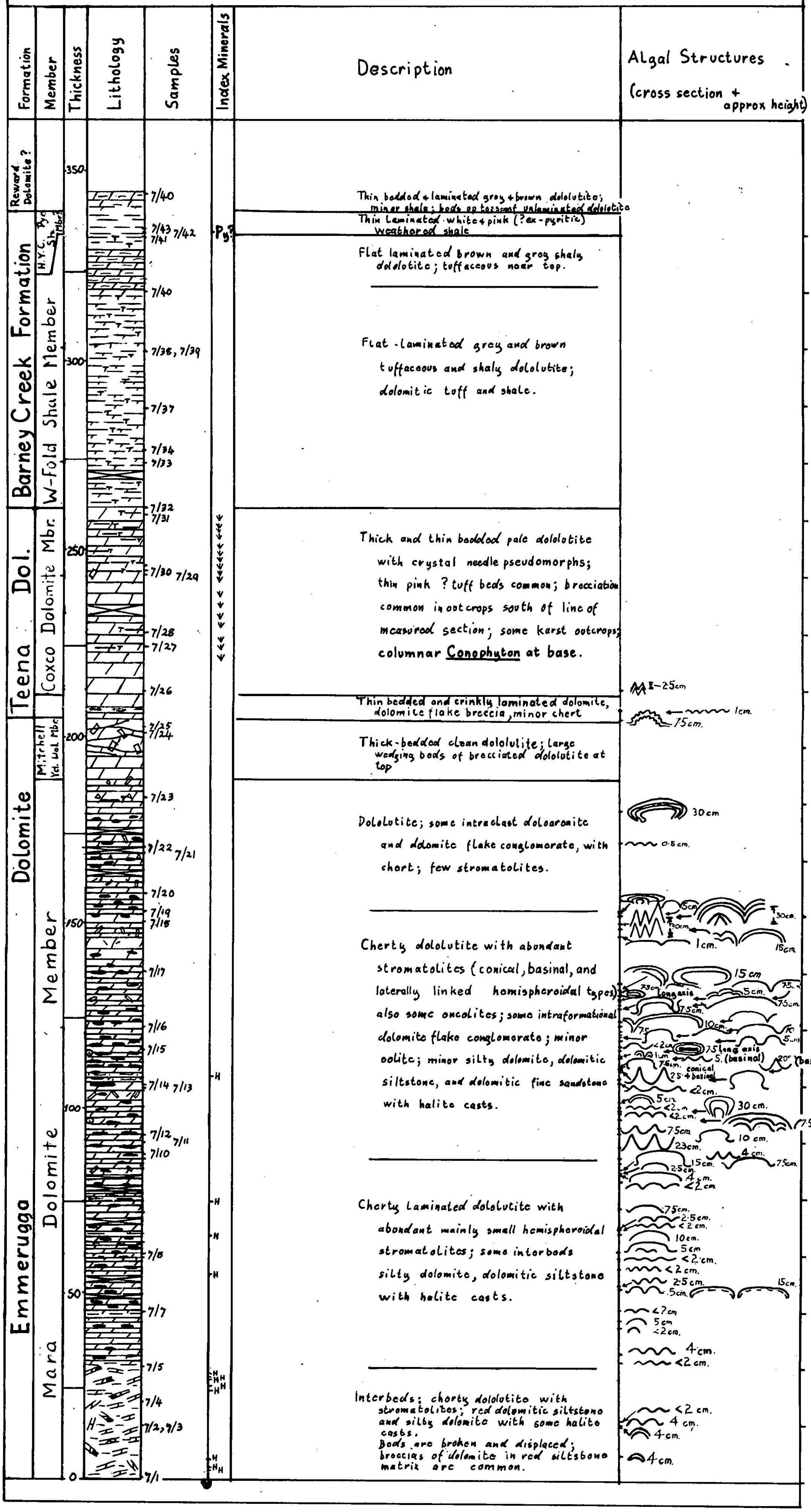
Interbeds: red + buff siltstone + silty dolomite; cherty dololutite with small stromatolites. Breccias of dolomite blocks in red siltstone matrix common.

Red siltstone

Plate 5

Measured Section 7, about 6·5km. ESE of "Bauhinia Downs" homestead

Measured with 1·5m staff and Abney Level. Legend as on Plate 12



Thin bedded + laminated grey + brown dololutite; minor shale; beds on top of unlaminated dololutite

Thin laminated white + pink (?ex-pyritic) weathered shale

Flat laminated brown and grey shaly dololutite; tuffaceous near top.

Flat-laminated grey and brown tuffaceous and shaly dololutite; dolomitic tuff and shale.

Thick and thin bedded pale dololutite with crystal needle pseudomorphs; thin pink ?tuff beds common; brecciation common in outcrops south of line of measured section; some karst outcrops; columnar Conophyton at base.

Thin bedded and crinkly laminated dolomite, dolomite flake breccia, minor chert

Thick-bedded clean dololutite; large wedging beds of brecciated dololutite at top

Dololutite; some intraclast doloarenite and dolomite flake conglomerate, with chert; few stromatolites.

Cherty dololutite with abundant stromatolites (conical, basinal, and laterally linked hemispheroidal types); also some oncolites; some intraformational dolomite flake conglomerate; minor oolite; minor silty dolomite, dolomitic siltstone, and dolomitic fine sandstone with halite casts.

Cherty laminated dololutite with abundant mainly small hemispheroidal stromatolites; some interbeds silty dolomite, dolomitic siltstone with halite casts.

Interbeds: cherty dololutite with stromatolites; red dolomitic siltstone and silty dolomite with some halite casts.
Beds are broken and displaced; breccias of dolomite in red siltstone matrix are common.

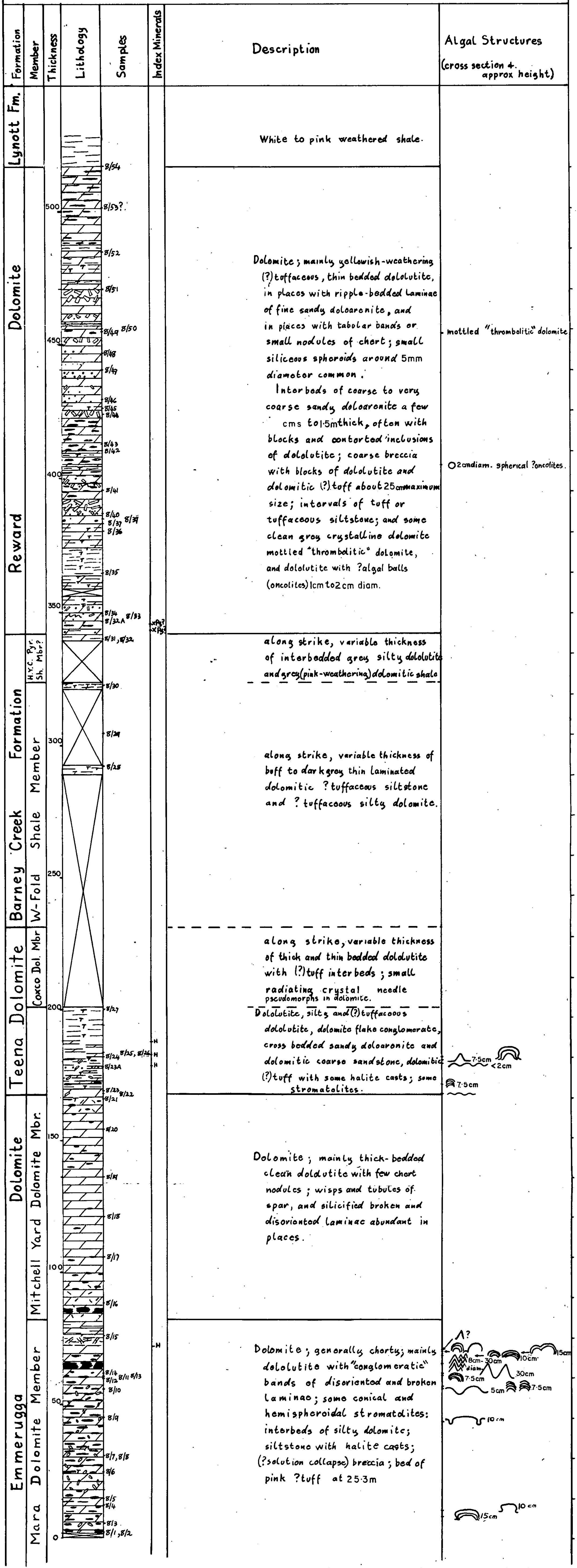
To accompany Record 1969/145

E53/A3/37

Plate 6

Measured Section 8, about 16 km NE of new "Mc.Arthur River" H.S.

Measured with 1.5m staff and Abney Level. Legend as on Plate 12.



White to pink weathered shale.

Dolomite; mainly yellowish-weathering (?)tuffaceous, thin bedded dololutite, in places with ripple-bedded laminae of fine sandy doloarenite, and in places with tabular bands or small nodules of chert; small siliceous spheroids around 5mm diameter common.

Interbeds of coarse to very coarse sandy doloarenite a few cms to 1·5m thick, often with blocks and contorted inclusions of dololutite; coarse breccia with blocks of dololutite and dolomitic (?) tuff about 25cm maximum size; intervals of tuff or tuffaceous siltstone; and some clean grey crystalline dolomite mottled "thrombolitic" dolomite, and dololutite with ?algal balls (oncolites) 1cm to 2cm diam.

along strike, variable thickness of interbedded grey silty dololutite and grey (pink-weathering) dolomitic shale

along strike, variable thickness of buff to dark grey thin laminated dolomitic ?tuffaceous siltstone and ?tuffaceous silty dolomite.

along strike, variable thickness of thick and thin bedded dololutite with (?)tuff interbeds; small radiating crystal needle pseudomorphs in dolomite.

Dololutite, silty and (?)tuffaceous dololutite, dolomite flake conglomerate, cross bedded sandy doloarenite and dolomitic coarse sandstone, dolomitic (?)tuff with some halite casts; some stromatolites.

Dolomite; mainly thick-bedded clean dololutite with few chert nodules; wisps and tubules of spar, and silicified broken and disoriented laminae abundant in places.

Dolomite; generally cherty; mainly dololutite with "conglomeratic" bands of disoriented and broken laminae; some conical and hemispheroidal stromatolites: interbeds of silty dolomite; siltstone with halite casts; (?solution collapse) breccia; bed of pink ?tuff at 25·3m

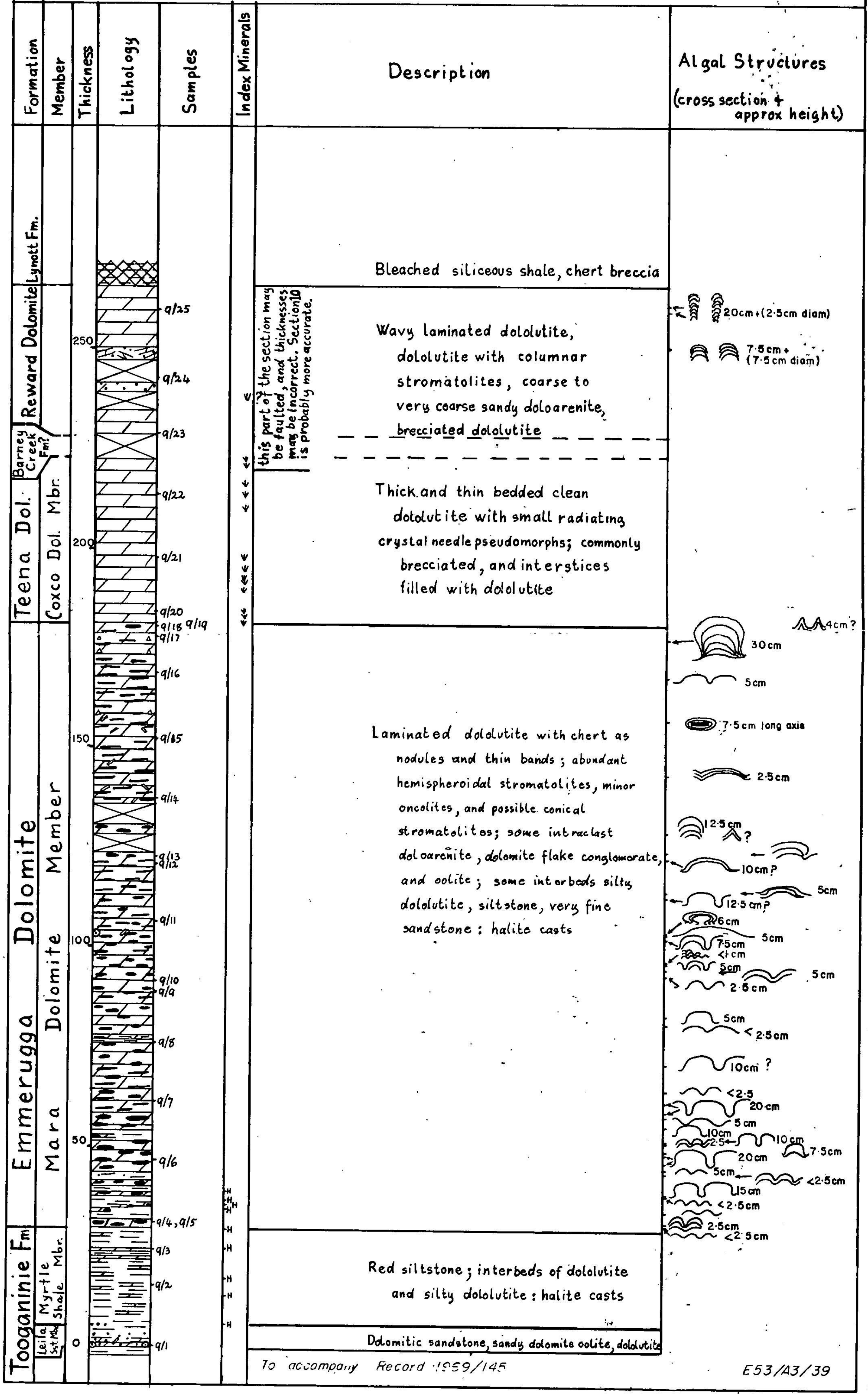
To accompany Record 1969/145

E53/A3/38

Plate 7

Measured Section 9, about 1·5 km W of junction of Amelia Ck. + Clyde R.

Measured with 1·5m staff and Abney Level. Legend as on Plate 12.



Bleached siliceous shale, chert breccia

Wavy laminated dololutite, dololutite with columnar stromatolites, coarse to very coarse sandy doloarenite, brecciated dololutite

Thick and thin bedded clean dololutite with small radiating crystal needle pseudomorphs; commonly brecciated, and interstices filled with dololutite

Laminated dololutite with chert as nodules and thin bands; abundant hemispheroidal stromatolites, minor oncolites, and possible conical stromatolites; some intraclast doloarenite, dolomite flake conglomerate, and oolite; some interbeds silty dololutite, siltstone, very fine sandstone: halite casts

Red siltstone; interbeds of dololutite and silty dololutite: halite casts

Dolomitic sandstone, sandy dolomite oolite, dololutite

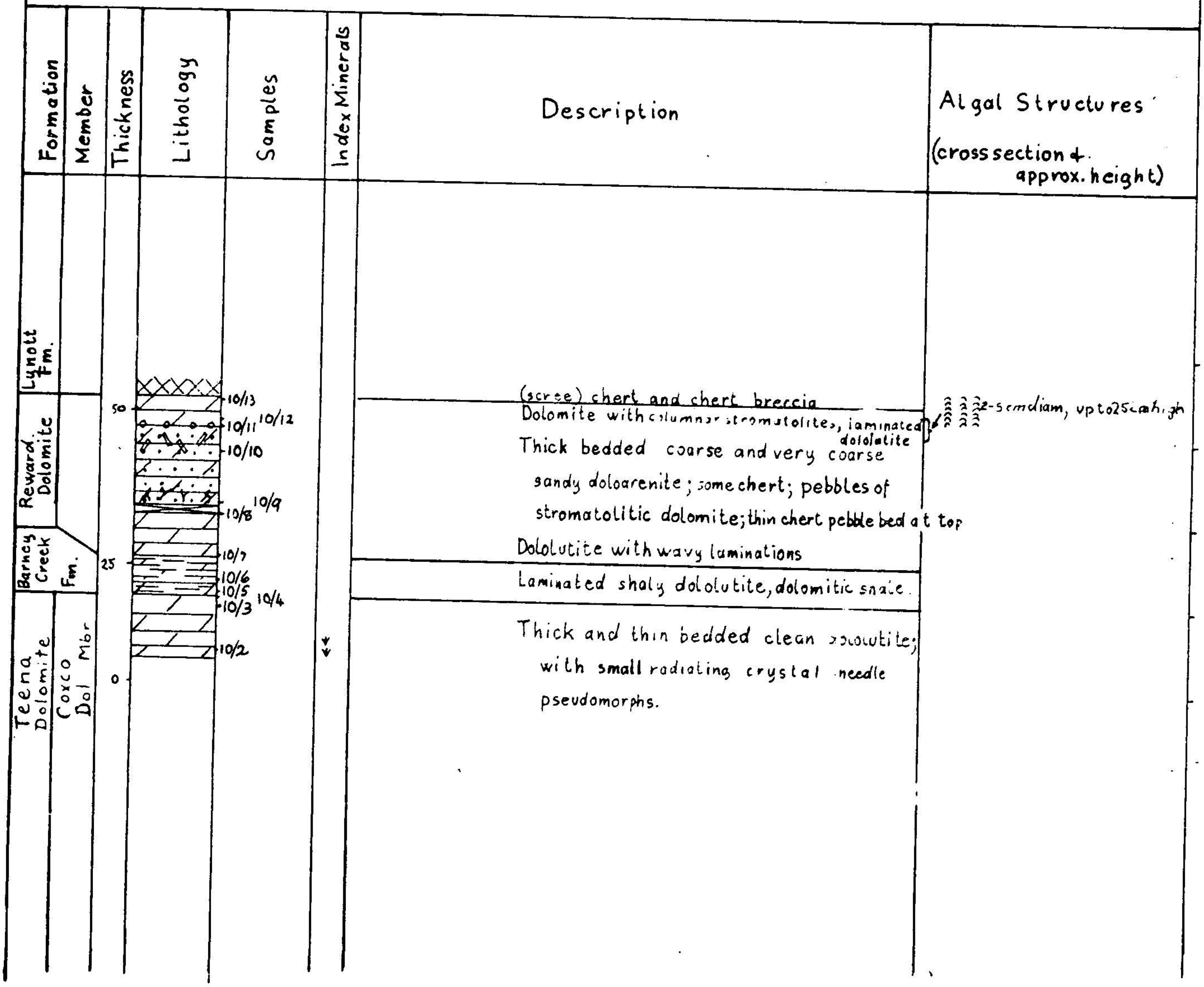
To accompany Record 1959/145

E53/A3/39

Plate 8

Measured Section 10, about 1·5 km west of junction of Amelia Ck and Clyde R

Measured with 15m staff and Abney Level. Legend as on Plate 12.



(scree) chert and chert breccia

Dolomite with columnar stromatolites, laminated dololutite

Thick bedded coarse and very coarse sandy doloarenite; some chert; pebbles of stromatolitic dolomite; thin chert pebble bed at top

Dololutite with wavy laminations

Laminated shaly dololutite, dolomitic shale.

Thick and thin bedded clean dololutite; with small radiating crystal needle pseudomorphs.

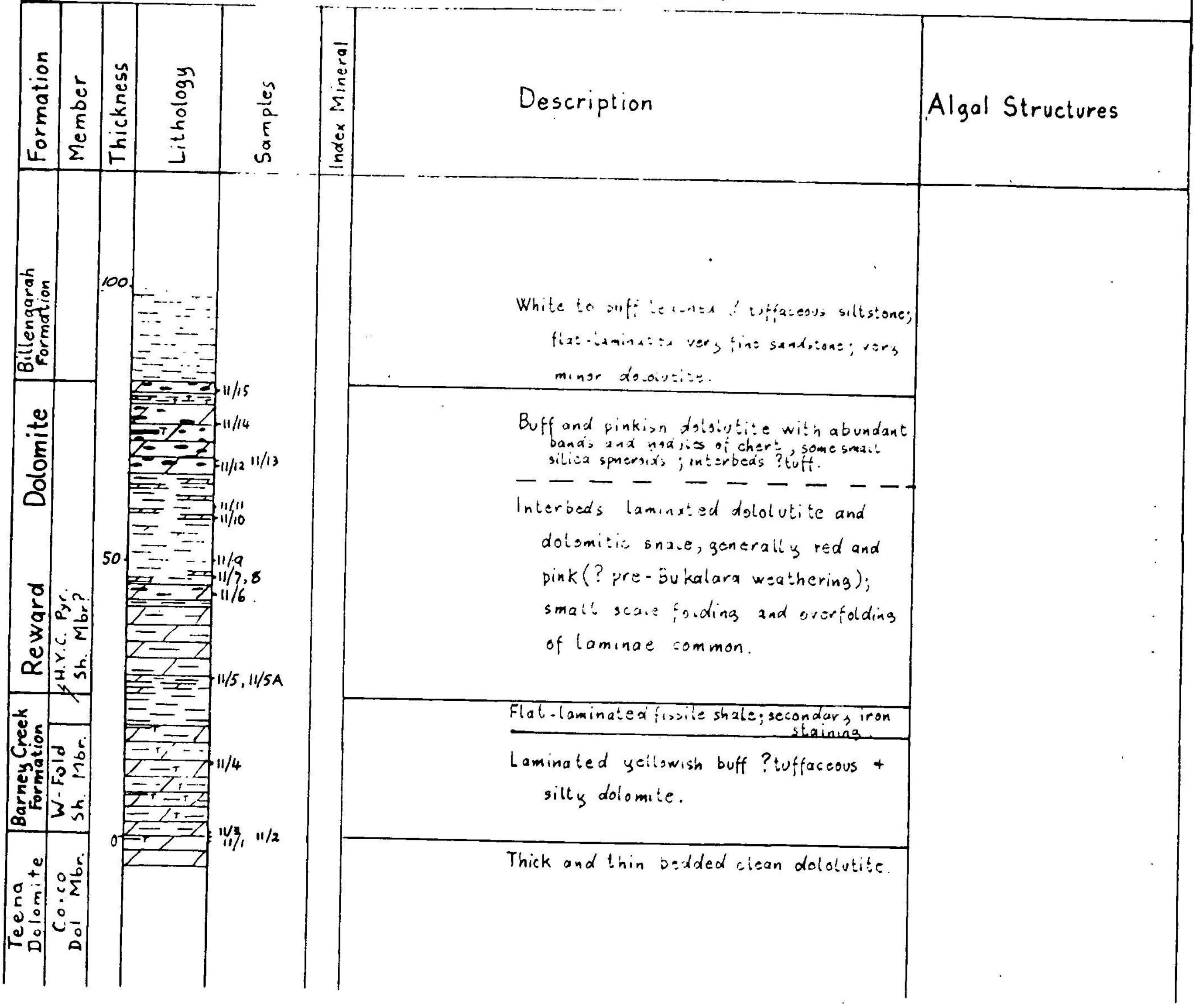
To accompany Record 1969/145

E53/A3/40

Plate 9

Measured Section 11, 1·6 km east of Kilgour River, 25·7 km above its junction with the Mc. Arthur River

Measured with 1·5m staff and Abney Level. Legend as on Plate 12



White to buff laminated ?tuffaceous siltstone; flat-laminated very fine sandstone; very minor dololutite.

Buff and pinkish dololutite with abundant bands and nodules of chert, some small silica spheroids; interbeds ?tuff.

Interbeds laminated dololutite and dolomitic shale, generally red and pink (? pre-Bukalara weathering); small scale folding and overfolding of laminae common.

Flat-laminated fissile shale; secondary iron staining.

Laminated yellowish buff ?tuffaceous + silty dolomite.

Thick and thin bedded clean dololutite.

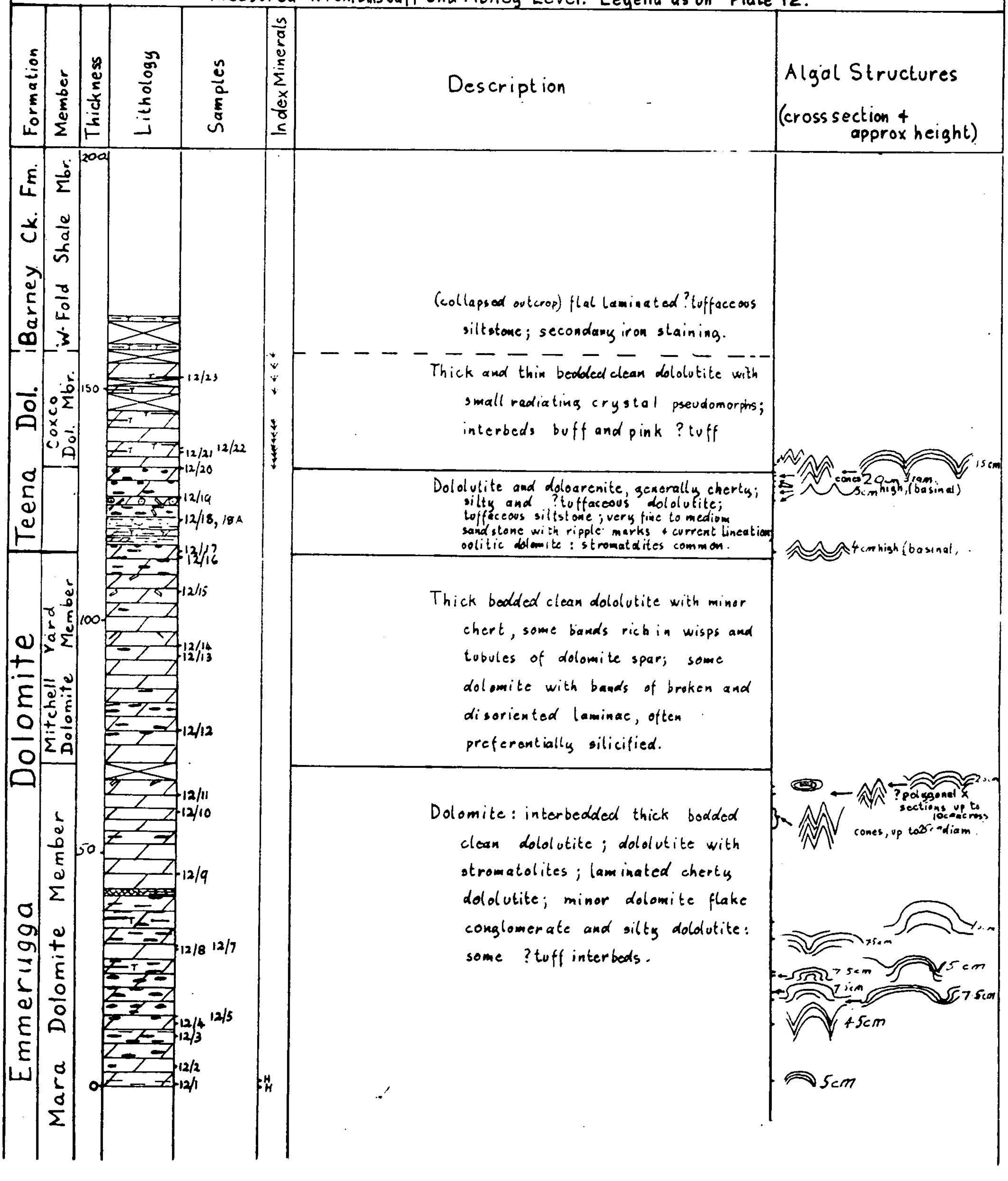
To accompany Record [illegible]

E53/A3/41

Plate 10

Measured Section 12, about 8 km west of junction of Amelia Ck. and the Clyde River

Measured with 1·5m staff and Abney Level. Legend as on Plate 12.



(collapsed outcrop) flat laminated ?tuffaceous siltstone; secondary iron staining.

Thick and thin bedded clean dololutite with small radiating crystal pseudomorphs; interbeds buff and pink ?tuff

Dololutite and doloarenite, generally cherty; silty and ?tuffaceous dololutite; tuffaceous siltstone; very fine to medium sandstone with ripple marks + current lineation; oolitic dolomite: stromatolites common.

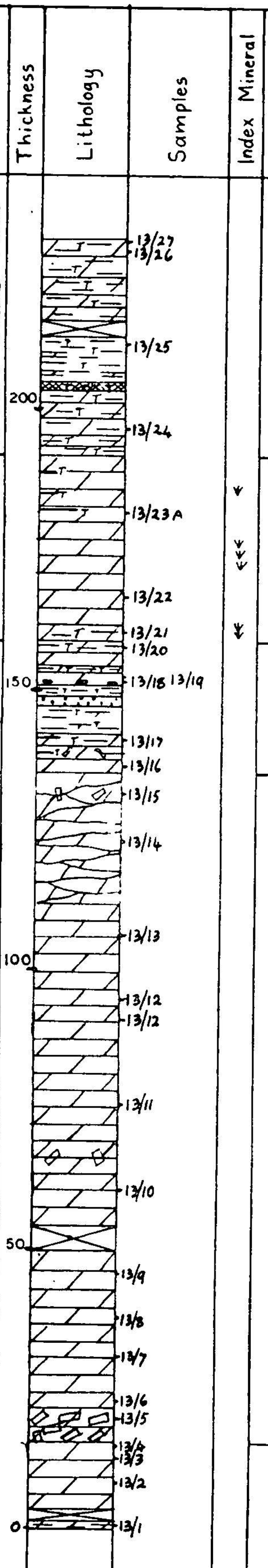
Thick bedded clean dololutite with minor chert, some bands rich in wisps and tubules of dolomite spar; some dolomite with bands of broken and disoriented laminae, often preferentially silicified.

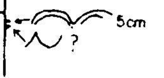
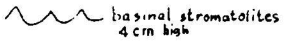
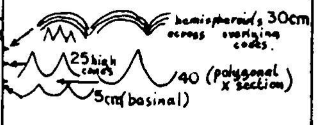
Dolomite: interbedded thick bedded clean dololutite; dololutite with stromatolites; laminated cherty dololutite; minor dolomite flake conglomerate and silty dololutite: some ?tuff interbeds.

Plate 11

Measured Section 13, 3·2 km SW of old Mc. Arthur River homestead.

Measured with 1·5m staff and Abney Level. Legend as on Plate 12.



Formation	Member	Description	Algal Structures (cross section and approx. height)
Barney Creek Formation	W-Fold Shale Mbr.	Laminated ?tuffaceous dololutite and dolomitic ?tuff	
Teena Dolomite	Coxco Dolomite Mbr.	Thick and thin laminated dololutite with thin ?tuffaceous laminae; folded and buckled laminae common; small radiating crystal pseudomorphs present.	
		Dololutite with stromatolites; laminated silty or tuffaceous dolomite and dolomitic ? tuff; leached (ex-dolomitic ?) medium to coarse sandstone; minor dolomite flake conglomerate.	 
Emmerugga Dolomite	Mitchell Yard Dolomite Member	Thick-bedded clean dololutite, in places with wisps and tubules of spar, and in places with brecciated appearance — blocks of thin-bedded dololutite in matrix of dololutite with spar: thick lenticular beds near top of interval.	
	Mara Dol. Mbr.	Thick-bedded dololutite with stromatolite some thin-bedded silty dololutite.	

92

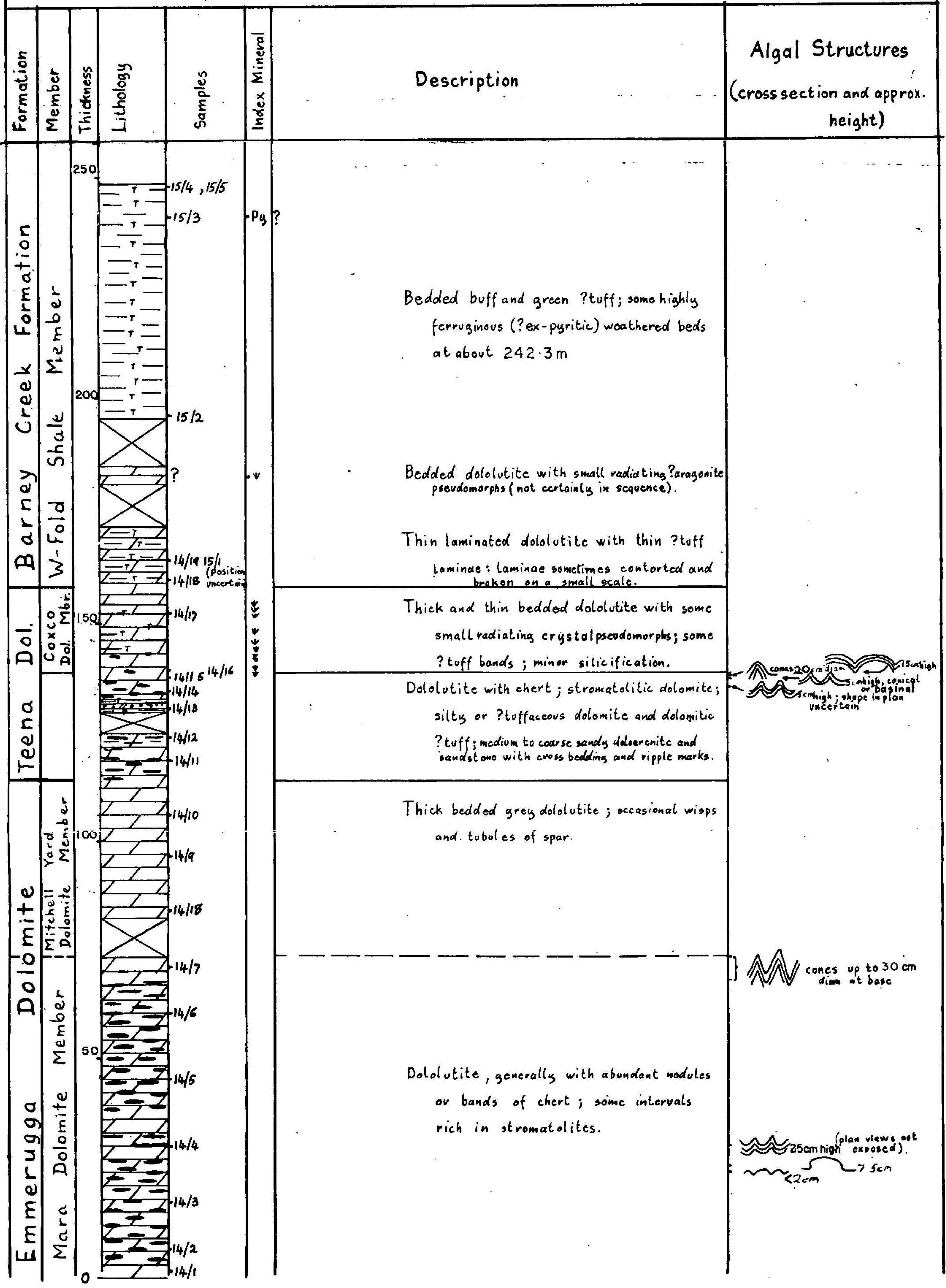
To accompany Record 1969/145

Plate 12

Measured Sections 14, 15, about 490m SSW of HYC V121 prospect shaft

14, Measured with 100'/ 30·48m metallic tape

15, Estimated by pacing



Bedded buff and green ?tuff; some highly ferruginous (?ex-pyritic) weathered beds at about 242·3m

Bedded dololutite with small radiating ?aragonite pseudomorphs (not certainly in sequence).

Thin laminated dololutite with thin ?tuff laminae: Laminae sometimes contorted and broken on a small scale.

Thick and thin bedded dololutite with some small radiating crystal pseudomorphs; some ?tuff bands; minor silicification.

Dololutite with chert; stromatolitic dolomite; silty or ?tuffaceous dolomite and dolomitic ?tuff; medium to coarse sandy doloarenite and sandstone with cross bedding and ripple marks.

Thick bedded grey dololutite; occasional wisps and tubules of spar.

Dololutite, generally with abundant nodules or bands of chert; some intervals rich in stromatolites.

Legend for Plates 2 - 15

▱	dolomite
☰	silt and clay size terrigenous material
⁘	medium to v. coarse grained } terrigenous sand. medium to v. fine grained } terrigenous sand.
☰	dolomitic shale or mudstone with high K content (?tuffaceous)
▱	shaly dolomite
▱	dolomite with large lenticular beds
▨	broken + disoriented beds + blocks of dolomite in mudstone matrix.
〰	contorted bedding
▩	siliceous shale, silicified rocks.
● ▬ ⋌	chert (nodules, bands, irregular veins)
⊙ ⊙	ooliths
/	dolomite flakes + pebbles
/\/	silicified dolomite flakes
▱	blocks
▵	intraclasts
—T	K-rich mudstone (?tuff) bands

Py = pyrite; Gn = galena; Sp = sphalerite

Sd siderite (or ankerite)

H halite casts or moulds

ѱ pseudomorphs of radiating crystal needles, probably after gypsum

Plate 13
Lithologic log, diamond-drill hole, CEC Ie115

Legend as on Plate 12

Soil, alluvium.

Dark grey dolomitic shale with dolomite laminae; disseminated pyrite and thin pyrite-rich laminae.

Thin-bedded and laminated grey and greenish-grey dololutite; fractured and brecciated, with fractures filled in part by crystalline dolomite and in part by brownish dolomite or dolomitic mudstone internal sediment; some intervals contain radiating crystal needle pseudomorphs. Intervals of grey dolomitic mudstone.

Greenish, red, mottled, and grey-green laminated dolomitic mudstone and shaly dolomite.

Laminated and thin-bedded dololutites; with some pseudomorphs of radiating crystal needles.

Laminated pale grey and greenish dololutite, dolomite flake conglomerate, some sandy dolomite; bed of conical stromatolites at top.

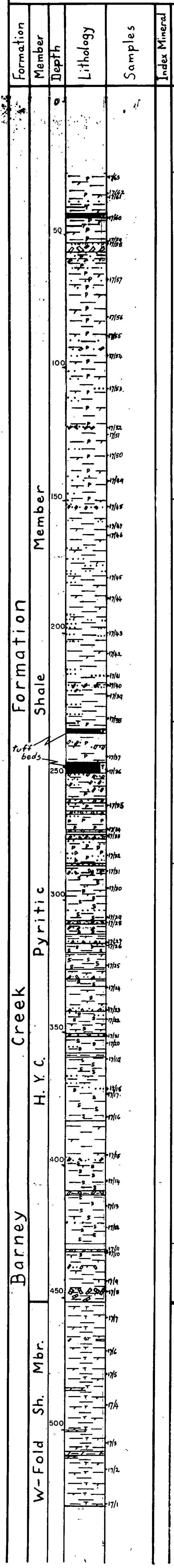
2.5cm diameter stacked forms

To accompany Record 1969/145

E53/A3/49

Plate 14
Lithologic log, diamond-drill hole, CEC Te115

Legend as on Plate 12



Description

Algal Structures (cross section and approx. height)

Soil, alluvium.

Mudstone, bedded pyrite, dolomite arenite and breccia, grey-green tuff.

Carbonaceous shale with disseminated pyrite; dolomite arenite and breccia interbeds.

Mudstone, bedded pyrite, dolomite arenite and breccia, grey-green tuff.

Mineralized zone. Bedded sphalerite, galena, pyrite; with grey-green mudstone, carbonaceous shale, dolomite arenite and breccia interbeds.

(N.B. This interval contains steep-dipping sections, and is probably secondarily thickened by slumping).

"S" in lithological column indicates interlayered sphalerite, galena, and pyrite.

Carbonaceous shale, limestone breccia interbeds.

Red and green dolomitic siltstone

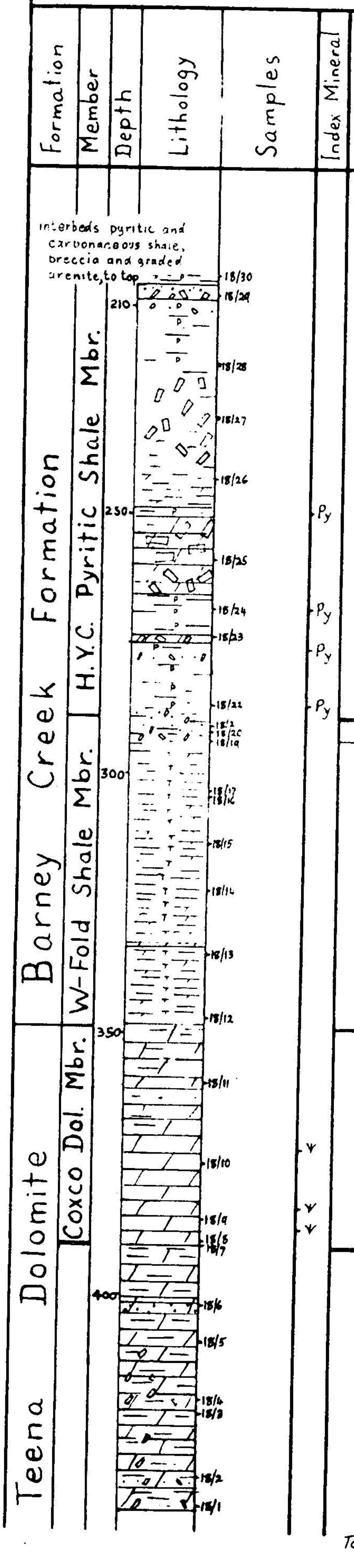
To accompany Record 1969/145

E53/A3/50

Plate 15

Lithologic log, diamond-drill hole, CEC Ue133

Legend as on Plate 12



Description	Algal Structures (cross section and approx. height)
Interbedded and interlaminated pyritic and dark carbonaceous mudstone, with interbeds graded doloarenite and dolomite breccia, and thick intervals of brecciated dolomite. Minor limestone fragments in breccia at 272.8m - 274.3m	
Dark mudstone; thin intervals graded calcarenite and limestone blocks. Green, grey-green, and red laminated dolomitic and (?) tuffaceous mudstone. Laminae frequently crumpled and microfaulted.	
—gradational boundary—	
Pale brown to light grey-green dololutite, becoming more shaly at top. Some radiating crystal needle pseudomorphs.	
Light grey and greenish laminated shaly dololutite. Some intervals of doloarenite and dolomite flake breccia. Coarse sandy doloarenite at about 401.4 m	

93

To accompany Record 1969/145