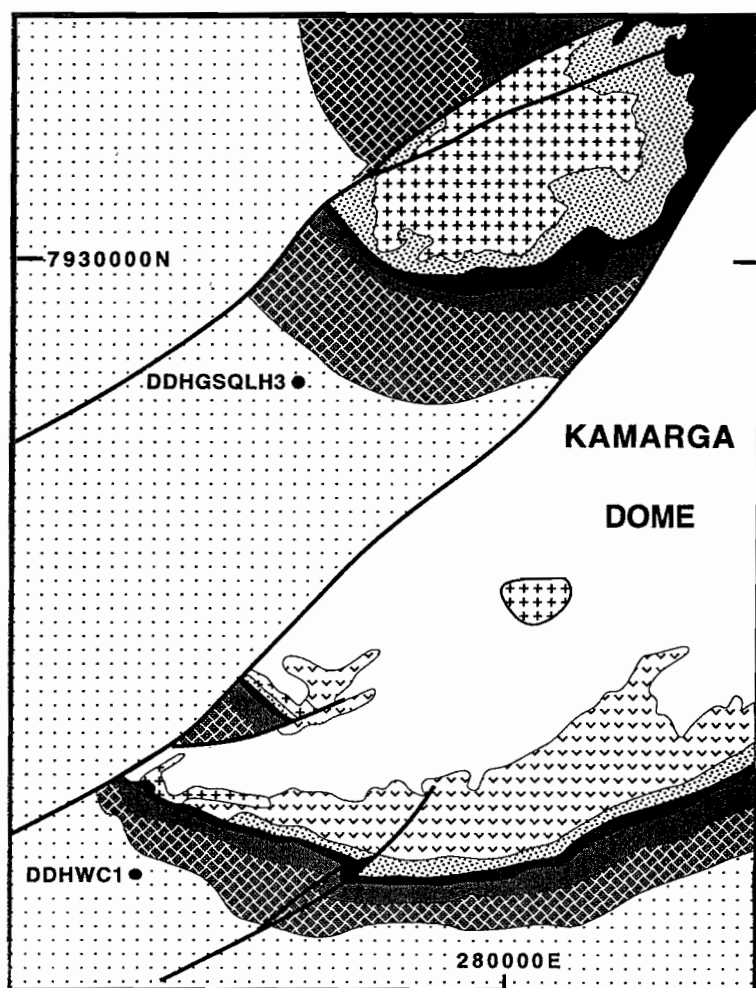


Sediment-hosted base metal deposits



AMIRA/ARC project P384A

Report 1
April 1996



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Introduction

Project Objectives

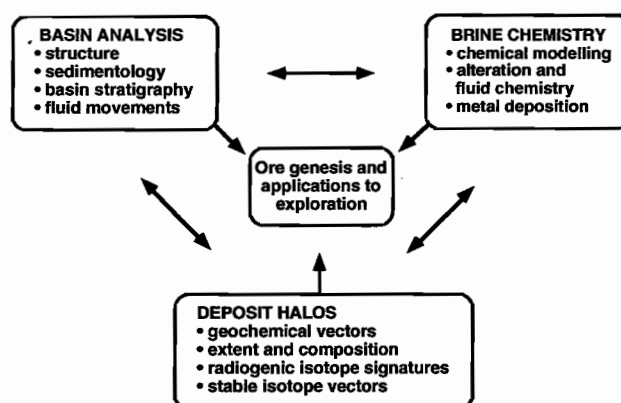
1. To determine the primary geological, geochemical and structural controls on the location and timing of base metal mineral deposits in sedimentary basins.
2. To investigate the physical and hydrological processes involved in the evolution and movement of metalliferous fluids in sedimentary basins.
3. To investigate the chemical processes controlling brine compositions and metal sulphide accumulation during fluid movements in sedimentary basins, including the relationships between copper and lead-zinc deposition.
4. To develop geological and geochemical vectors to a variety of styles of sedimentary base metal mineralisation that may be used in the exploration for large tonnage deposits.

Research Framework

This research project is a three-year extension to project P384. The project involves a multidisciplinary approach using regional geological, geophysical and structural studies, brine

chemical modelling and geochemical and isotopic halo studies to provide a foundation on which to build a network of exploration criteria and ore deposit models for major sediment-hosted base metal deposits.

The project consists of three research modules as outlined below:



This Report

This is the first progress report of the project extension P384A and covers the seven-month period from September 1995 to March 1996. The commencement of the project was delayed for several months in 1995 until the success of the matching ARC Collaborative Grant was confirmed. Good progress has been achieved since the commencement date, although aspects of the research are not fully reported in this progress report.



Emphasis to date has concentrated on sedimentological and diagenetic studies in the Lawn Hill Platform and the McArthur Basin, to support the studies by AGSO on the NABRE project. Stuart Bull, John Dunster and Peter Winefield have been involved with the AGSO team and collaborative arrangements are progressing well. Results from the carbon-oxygen isotope studies (Large, Bull and McGoldrick) in the McArthur Basin and the alteration halo studies at Mt Novit (McGoldrick) will be presented at the April 1996 meeting, and will form the basis of a separate report to be distributed to sponsors within the next two months.

Progress Report: Sedimentology of the lower McNamara Group, Riversleigh Fold Zone, northwestern Queensland

Stuart W Bull

Abstract

In the Kamarga Dome area, two diamond drill cores, DDH GSQ Lawn Hill 3 and DDH WC 1 intersect the same stratigraphic interval at the base of the McNamara Group. They provide comparative sections 6 km apart along depositional strike. All 8 informal members defined in the GCF (Jones, 1986) can be correlated litho-stratigraphically, and thickness changes in the TCQ and the two of the lower members of the GCF suggest a degree of syn-depositional structural control during this period. Roughly uniform thicknesses of intersections of upper GCF members in the two sections suggest that structural activity had waned by this time.

Taken overall, the TCQ and GCF package in the Kamarga Dome area can be considered as two transgressive packages characterised by mudstone-dominated sub-tidal deposits, separated by a regression episode characterised by stromatolitic and sabkha deposits. Although individual facies cannot be correlated, this same broad depositional history is recognisable in the Redie Creek section 120 km to the SSE.

Introduction

This report presents some provisional results from an ongoing study of the sedimentology of the lower McNamara Group (Torpedo Creek

Quartzite [TCQ] and Gunpowder Creek Formation [GCF]) in the Lawn Hill Platform region northwest of Mount Isa (Riversleigh Fold Zone; McConachie et al, 1993; Fig. 1). The main aim is to utilise facies-based sedimentary analysis to describe and interpret palaeoenvironmental variations within the lower McNamara Group package. The resultant facies models will ultimately be used to constrain geochemical studies for the deposit halo module of the project.

The main focus of the study is the southern flank of the Kamarga Dome (Fig. 2), where two diamond drill cores have been used to compare sections through the same stratigraphic interval (TCQ and GCF). To provide some regional control on the Kamarga study, a reconnaissance field section was logged through the same stratigraphic interval in the Redie Creek area, approximately 120 km to the SSE, east of Lady Loretta Mine (Fig. 1).

Stratigraphy of the lower McNamara Group

Kamarga Dome

The Kamarga Dome is an originally sub-circular feature with a diameter in the order of 30 km that is located in the northwestern part of the Lawn Hill Platform (Riversleigh Fold Zone;



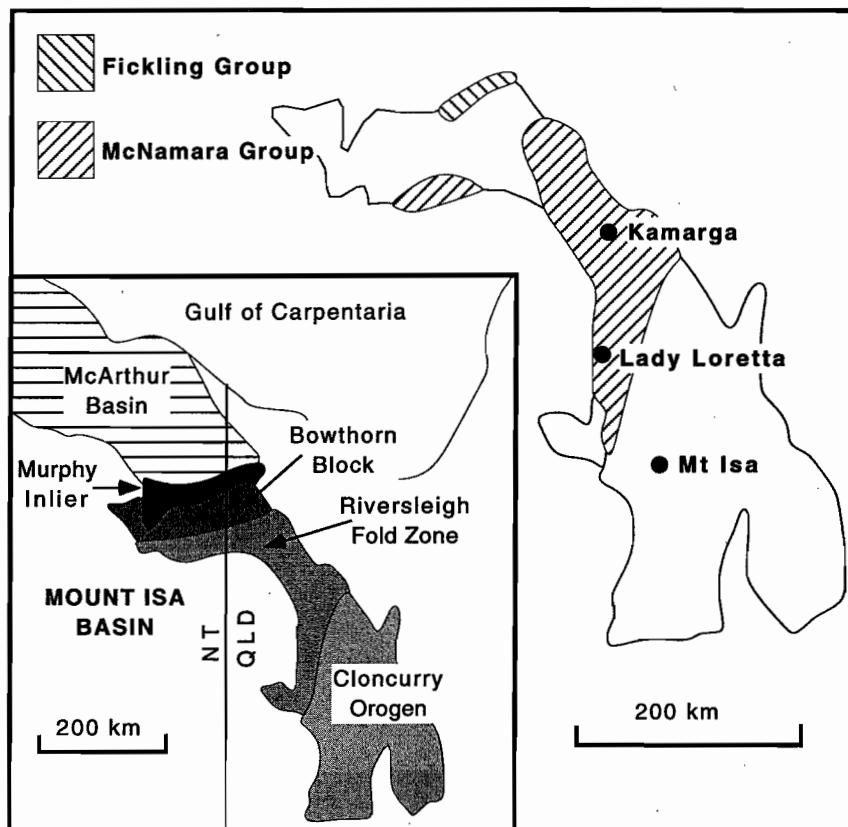


Figure 1 — Regional geology of the Mount Isa Basin (McConachie et al., 1993).

McConachie et al, 1993; Fig. 1). It consists of a core of older units (Kamarga Volcanics [KV] and Yeldham Granite [YG]) flanked/onlapped by McNamara Group sediments (Fig. 2) that dip radially away at shallow angles (i.e. $< 30^\circ$).

The two drill cores examined in this study were taken from lower part of the McNamara Group on the southern flank of the Kamarga Dome (Fig. 2). Diamond drill hole GSQ Lawn Hill 3 was drilled in 1979 by the Queensland Department of mines as a stratigraphic hole (Hutton, 1983). Diamond drill hole WC 1 is one of 18 cores taken between 1973 and 1980 by CRAE and Newmont to evaluate the economic potential of the Kamarga mineralisation, a large low-grade Zn-Pb deposit. Although DDH WC 1 was collared 10.5 km SSW of DDH GSQ Lawn Hill 3, this configuration is due to post-

McNamara Group dextral strike-slip movement on the NE-trending Barramundi Fault (Fig. 2). When this late movement is taken into account, the two drill cores are approximately 6 km apart along depositional strike.

Kamarga Volcanics and Yeldham Granite

In the explanatory notes for the Lawn Hill 1:100,000 Geological Map, Sweet and Hutton (1982) state that "veinlets of granite in the volcanics" indicate that the YG intruded the KV. As a result, Hutton (1983) concluded that the KV are the oldest unit exposed in the Kamarga Dome. In contrast, field work for his PhD on the Kamarga mineralisation led Jones (1986) to conclude that the YG was unconformably overlain by the KV.

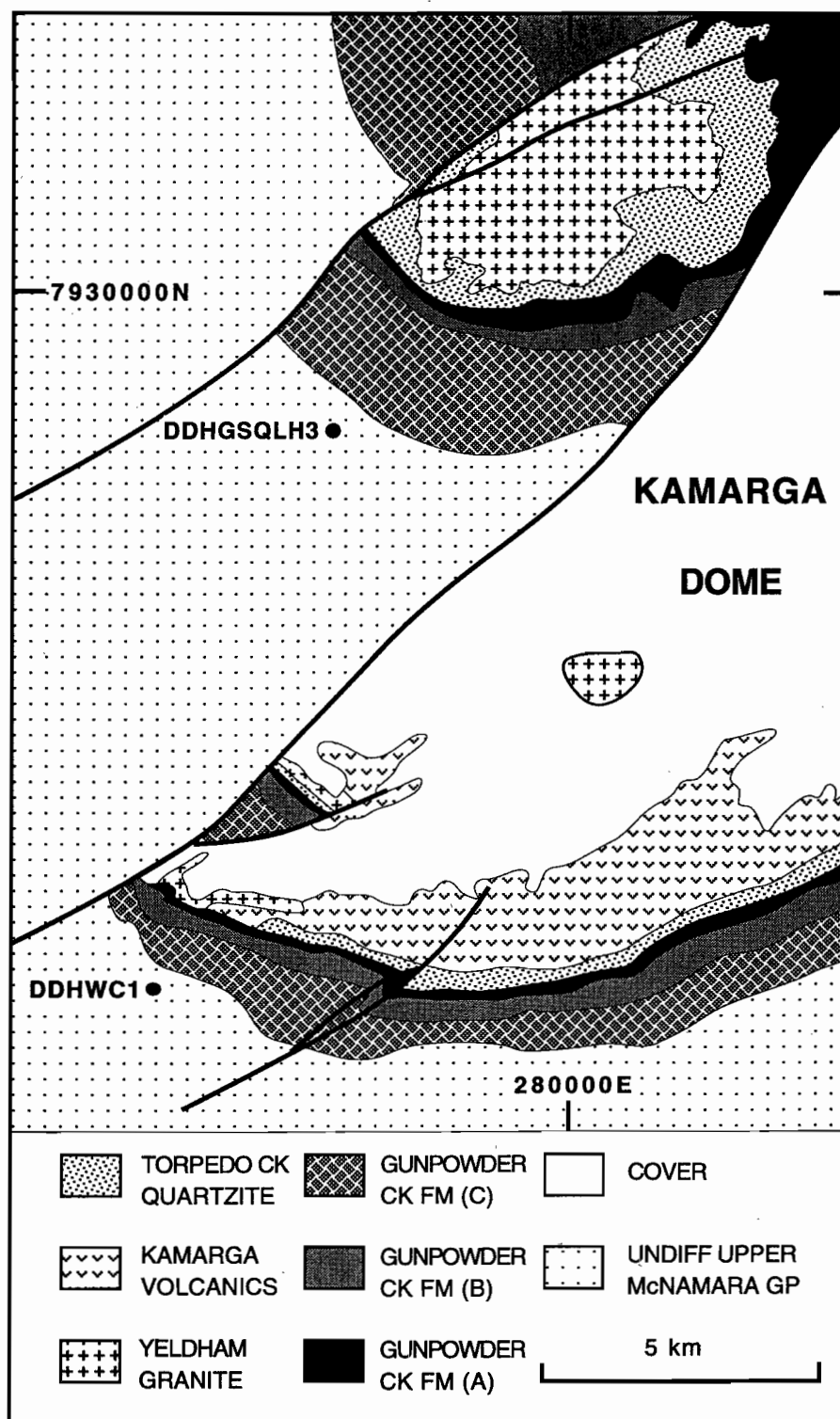


Figure 2 — Geology of Kamarga Dome (modified after the Lawn Hill 1:100,000 geology sheet) showing the collar locations for DDH GSQ Lawn Hill 3 and DDH WC 1.



In the core sections examined in this study, the YG forms the basal 9 m intersection in DDH GSQ Lawn Hill 4 and the KV the basal 67 m intersection in DDH WH1 (Fig. 3). The YG intersection was not studied in any detail by the author, but is reported to comprise fine- to medium-grained, equi-granular, alkali granite and alkali syenite (Hutton, 1983). The KV intersection comprises massive, fine-grained basalt/micro-dolerite with vesicles and amygdaloids increasing in abundance in the uppermost 5 m.

Torpedo Creek Quartzite

In the Kamarga Dome area, the basal unit of the McNamara Group, the TCQ, unconformably overlies the Yeldham Granite and Kamarga Volcanics (Sweet and Hutton, 1982). It comprises interbedded cobble and pebble conglomerate and sandstone at the base (clasts are sourced from both YG and KV), overlain by interbedded medium- to coarse-grained sandstone and minor carbonaceous siltstone intervals. The TCQ has been interpreted to represent the beginning of a transgressive event which continued up into the overlying GCF (Hutton, 1983; Jones, 1986). In this model; the lower part of the unit represents fluvial deposits accumulated over an erosional surface which cut the YG and KV; and the upper part of the unit represents beach deposits transitional to euxinic conditions through the base of the GCF.

The TCQ is well represented in DDH GSQ Lawn Hill 3, where it comprises 17 m of interbedded conglomerate, medium-coarse-grained sandstone and minor siltstone/carbonaceous mudstone (Fig. 3). The interpretation that this interval represents the beginning of a transgressive event is confirmed by the occurrence of at least two upward fining cycles in the cored interval (Fig. 3). The lower cycle, from 446 to

439 m and the upper cycle, from 439 to 432 m, both comprise a transition from pale coloured (essentially grain-supported and matrix-free) sandstone, to grey (matrix-rich) sandstone, to thinly interbedded dolomite and dolomitic siltstone/carbonaceous mudstone. In the case of the upper cycle, the latter facies represents the basal unit of the GCF.

In DDH WC 1, 1.5 m of basalt breccia with sandstone matrix immediately overlying the KV has been interpreted to represent the TCQ (Jones, 1986; Fig. 3). In addition to being much thinner, this unit appears subtly different in character from the conglomerate facies in the TCQ interval in DDH GSQ Lawn Hill 3, in which YG clasts are dispersed in a matrix of stratified sandstone. In the DDH WC interval, basalt clasts are closely packed and in places they clearly have jigsaw-fit relationships. The author concurs that this deposit may be time equivalent to the TCQ in DDH GSQ Lawn Hill 3, in which case it is interpreted to be a residual lag deposit on top of an uplifted block of KV. However, the fact that the volcanic clasts are relatively fresh and unweathered suggests an alternative explanation in which the unit is the same age as the KV. In this case it would represent a remnant of peperite at the eroded upper margin of a high-level intrusive.

Gunpowder Creek Formation

The GCF conformably overlies the TCQ and it has been divided into three informal sub-units for the purposes of 1:100,000 scale mapping (Sweet and Hutton, 1982). In the Kamarga area, the unit has been subdivided into eight members based on diamond drilling (including DDH WC 1), that have been interpreted to represent a range of depositional conditions from ephemeral stream to sub-tidal environments (Jones, 1986). In DDH WC 1 all 8 members can be recognised,

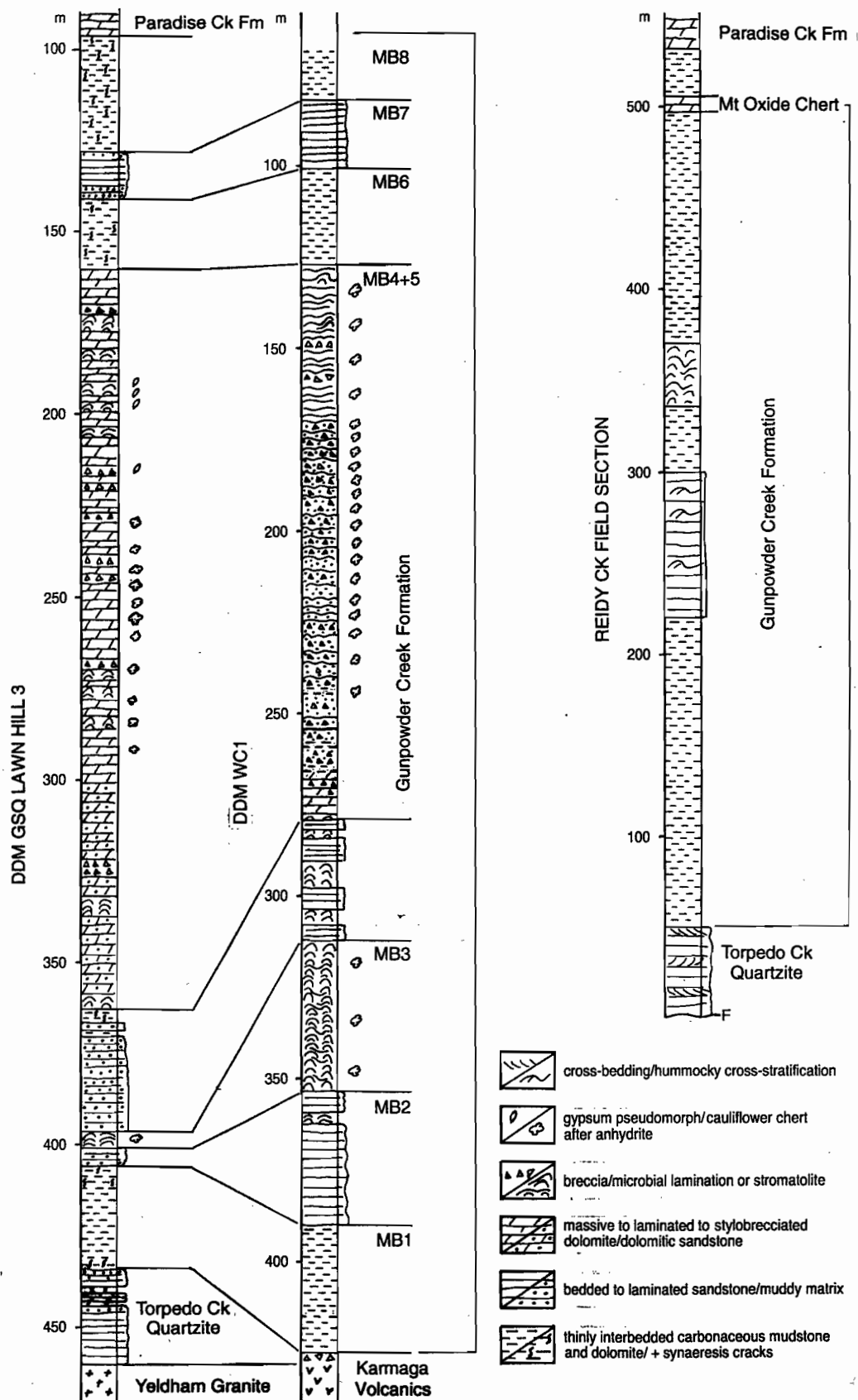


Figure 3 — Facies logs of DDH GSQ Lawn Hill 3, DDH WC 1 and the Redie Creek Field Section.

however, it is difficult to separate members 4 and 5 (Fig. 3).

In terms of sedimentary facies, members 1, 6 and 8 are all represented by thinly interbedded dolomite and carbonaceous mudstone, much of which has scattered to abundant synaeresis cracks. This facies is interpreted to represent sub-tidal deposition in a quiet restricted setting (see discussion section below).

Members 2 and 7 comprise stratified fine- to medium-grained sandstone. This could represent fluvial, beach or shallow subaqueous deposits, however, the precise depositional environment is impossible to determine from the core inter-section due to the inability to recognise definitive sedimentary structures.

Member 3 comprises a 43 m thick sequence of stacked microbial biostromes in the form of domal stromatolites.

Members 4 and 5 comprise a cyclical arrangement of thin (< 1m) intervals of carbonaceous mudstone (microbial mat), microbially laminated dolomite, intraclastic dolomite breccia and dolomitic sandstone. Pseudomorphs after both gypsum and nodular anhydrite are scattered to abundant throughout and enterolithic anhydrite appears to be present locally. This interval has been interpreted as a sabkha sequence (Jones, 1986). In this model the in-situ microbial mat represents sub- to inter-tidal conditions and the breccias and sandstones eroded supratidal material. Particularly convincing is the small-scale cyclicity, which accords well with modern sabkha models based on the coastal deposits in the Abu Dhabi region (Warren, 1989), in which it is generated by repeated desiccation and erosion of the supra-tidal zone.

In DDH GSQ Lawn Hill 3, all 8 GCF members (Jones, 1986) are also recognisable (Fig. 3), however, units 2 and 3 are markedly reduced in thickness (see discussion section below). Members 4 and 5 are also slightly different in

character. Although all of the elements which comprise the sabkha sequence in DDH WC 1 are present (e.g. microbial lamination, intra-formational brecciation and evaporite pseudomorphs), in this case there is no clear cyclicity and the succession is markedly thicker. This is interpreted to indicate that although the setting was clearly similar in character, it was at a slightly lower elevation so that the system remained "wetter" overall. As a result a well-developed supra-tidal zone was not always present, thereby explaining the lack of desiccation and erosion-generated cyclicity and resultant reduction in thickness.

Paradise Creek Formation

In both drill cores studies, member 8 (Jones, 1986) of the GCF is conformably overlain by pale grey dolomites attributed to the PCF, however, this unit was not examined in any detail.

Redie Creek section

The Redie Creek Field section is located approximately 12 km east of Lady Loretta (Fig. 1) on a track to Gunpowder Creek. The base of the section is located on the Mammoth Mines 1:100,000 geology sheet at 7811800N 309400E, and it extends for approximately 1050 m to the ENE incorporating the upper part of the TCQ, the entire GCF and the basal part of the PCF. Dips range between 11° and 19° to the northeast, giving a combined true section thickness of approximately 600 m (Fig. 3). Outcrop consists of a succession of low ridges separated by valleys of subcrop/float.

Torpedo Creek Quartzite

The base of the section comprises approximately 50 m of clean, fine-, medium- and coarse-grained

sandstone overlying a silicified and brecciated fault zone. Sedimentary structures include abundant medium-scale trough cross-bedding and planar and ripple lamination. Mudstone intraclasts are locally abundant. These features are consistent with the general interpretation of the unit in this region as an alluvial/fluvial to marginal marine deposit (e.g. Hutton and Wilson, 1985).

Gunpowder Creek Formation

The GCF interval of the section conformably overlies the TCQ and is approximately 450 m thick. Three general facies are recognisable that divide it into five parts (Fig. 3). The basal 175 m interval comprises purple coloured, thinly-bedded/flaggy micaceous siltstone. Abundant hematite spots (presumed to be after pyrite) are present in the lower and uppermost 50 m of the unit. Scattered thin (< 10 cm), broadly lensoidal, fine-grained sandstone interbeds with wavy and ripple lamination are present throughout.

Above 175 m, fine-grained sandstone beds become thicker (up to 50 cm) and more abundant to comprise approximately half of the section up to around 300 m. Beds often lens out laterally over distances of 5 to 10 m and internal sedimentary structures include ripples, trough cross-beds and apparent incipient hummocky cross-stratification.

From 300 to 340 m there is another interval of flaggy/bedded micaceous siltstone, overlain by 20 m of dolomite that includes a prominent biostrome of domal stromatolites immediately east of the track. The remainder of the GCF section comprises a further 140 m of flaggy/bedded micaceous siltstone. It becomes progressively more dolomitic in the uppermost 50 m and some ripples are also present in this uppermost interval.

Mt Oxide Chert and Paradise Creek Formation

The MOC and PCF were not examined in any detail in this study. In summary, the MOC at this locality consists of approximately 10 m of resistant silicified dolomite. Relict primary features suggest that the unit had similar sedimentary structures (i.e. flaggy and ripple lamination) to the underlying GCF siltstones. The PCF outcrops very poorly, however, the basal 30 m comprises laminated and rippled dolomitic siltstone similar to that of the upper GCF. Scattered float above 30 m suggests that the unit is dominated by massive and microbially laminated dolomite.

Discussion

It is clear from the facies logs of DDH GSQ Lawn Hill 3 and DDH WC 1 (Fig. 3) that the GCF members defined by Jones (1986) are present in both holes. This allows correlation of the GCF for 6 km along strike, however, given the lack of unequivocal time lines and the essential absence of the TCQ in DDH WC 1, two depositional interpretations are possible.

In one scenario, deposition began at both sites simultaneously. In this case, the units which overlie the effective basement of YG and KV, the 17 m thick TCQ intersection in DDH GSQ Lawn Hill 3 and the interbedded mudstone and dolomite of member 1 of the GCF in DDH WC 1, would be at least partial time equivalents.

An alternative model would have involved deposition beginning at the site of DDH GSQ Lawn Hill 3 first, allowing accumulation of the TCQ intersection while the site of DDH WC 1 remained a site of non-deposition (i.e. a topographic high). In this case, the GCF member 1 intersections in each hole are essentially time equivalents. This correlation is preferred (Fig. 3) because:



1. Both interpretations presented above of the 1.5 m volcanic breccia which occurs at the top of the KV in DDH WC 1 (i.e. that it is a lag deposit time equivalent to the TCQ or an eroded remnant of marginal peperite formed during emplacement of the volcanics), are consistent with this area representing a palaeo-high.
2. The GCF member 1 intervals in each hole are similar in thickness suggesting that they are, in fact, time equivalents.
3. The biostrome intervals which comprise member 3 of the GCF in each hole are considered to be the most likely approximate time line in the succession. In this correlation they are time equivalent.

The correlation of the GCF presented in Figure 3 explains the presence of the TCQ in DDH GSQ Lawn Hill 3, in that this site was a depocentre relative to a topographic high which was the site of DDH WC 1 6 km along depositional strike. In this model, by the onset of deposition of member 1 of the GCF, the two areas were apparently similar in setting because the unit is of similar facies character and thickness in each hole (Fig. 3). Immediately above this, however, GCF members 2 and 3 are of greatly reduced thickness in DDH GSQ Lawn Hill 3, indicating that the focus of deposition had shifted to the site of DDH WC 1 by this time. Given that the occurrence of facies such as biostromes and sabkha deposits indicate that the GCF was a relatively low relief depositional system, this suggests a degree of syn-depositional structural control during the accumulation of the lower McNamara Group (i.e. TCQ and lower GCF). The close correlation in facies character and thickness of the upper GCF units (i.e. members 6, 7 and 8; Fig. 3) suggests that any structural activity had waned by this time.

Previous authors have considered the TCQ and GCF in the Kamarga Dome area to represent

a transgressive succession (eg. Hutton, 1983; Jones, 1986). In this model, the TCQ represents fluvial to littoral to sub-littoral sands. The overlying thinly interbedded dolomite and carbonaceous mudstone which comprises member 1 of the GCF must represent quiet-water sub-tidal deposition and given the lack of evidence of subaerial exposure (i.e. abundant evaporites, desiccation cracks etc.), the author concurs with this interpretation.

Considering the GCF intersection in the two drill sections as a whole, the basal transgression is clearly terminated by a regression which led to sub- to supra-tidal sabkha conditions prevailing during accumulation of members 4 and 5. Subsequently, members 6, 7 and 8 record a return to similar conditions which prevailed at the base of the unit (members 1 and 2). This is taken to indicate a second transgressive episode in the upper part of the GCF. With respect to the Redie Creek Section 120 to the SSE, the individual facies which comprise the 8 members defined within the GCF in the Kamarga area (Jones, 1986) cannot be correlated. However, the simplest palaeoenvironmental interpretation that could be applied to the section is that the bedded sandstones and biostrome in the mid-part of the unit represent shallowing conditions, relative to the flaggy bedded, non-evaporitic, pyritic siltstone which comprises the bulk of the section. This interpretation suggests a depositional history at this locality comprising basal and upper transgressions separated by a regressive episode which is broadly similar to that proposed at Kamarga.

Conclusions

The provisional conclusions that can be drawn from this part of the lower McNamara Group study are:

1. In the Kamarga Dome area, all 8 members of the GCF (Jones, 1986) can be correlated 6 km along depositional strike between DDH GSQ Lawn Hill 3 and DDH WC 1.
2. Thickness changes in the TCQ and the two of the lower members of the GCF suggest a degree of syn-depositional structural control during this period, which had waned by the time the upper part of the GCF was deposited.
3. Taken overall, the TCQ and GCF package in the Kamarga Dome area can be considered in terms of two transgressive packages characterised by mudstone-dominated subtidal deposits (GCF members 1, 6 and 8). These are separated by a regressive episode characterised by stromatolitic and evaporitic (sabkha) deposits (GCF members 3, 4 and 5).
4. In the case of the Redie Creek section 120 km to the SSE, individual GCF members cannot be correlated. However, the same broad depositional history of a regressive package separating two transgressive packages can be interpreted.

Appendix 1

Synaeresis Cracks as Palaeo-environmental Indicators

As noted above, intervals of the thinly interbedded dolomite and carbonaceous mudstone which comprises a minor part of the TCQ and members 1, 6 and 8 (Jones, 1986) of the GCF in the DDH GSQ Lawn Hill 3, core have well-developed, scattered to abundant synaeresis cracks. These structures are a type of shrinkage crack and their origin has been the subject of considerable debate in the literature.

The term synaeresis was coined to distinguish subaqueously-generated shrinkage cracks, generally attributed to de-watering due to salinity fluctuations or sediment loading (e.g. Plummer and Gostin, 1981), from subaerial desiccation cracks. The broad environmental interpretation applied to synaeresis structures was that they form in restricted water bodies (e.g. inter-tidal pools, lagoons or shallow lakes).

More recently, the term diastasis crack has been proposed to distinguish an alternative hypothesis as to the origin of similar subaqueous crack structures (Cowan and James, 1992). In this case, their formation is attributed to brittle shear/tensile failure of stiff mud layers induced by current or compaction-induced movement of surrounding sand layers. This process is not limited to particular water depths, implying that shrinkage crack structures have little value as palaeoenvironmental indicators.

The distribution of synaeresis cracks in the thinly interbedded dolomite and carbonaceous mudstone intervals in DDH GSQ Lawn Hill 3, has implications for the debate in their origins and palaeoenvironmental significance. The following observations can be made about the distribution of synaeresis cracks in intervals this facies:

1. They are present to some degree in all intervals of the facies.
2. They are abundant and occur throughout all thin (i.e. <4 m) intervals of the facies.
3. They occur scattered throughout two of the three thicker intervals of the facies (GCF members 6 and 8), however, in the other thick interval (GCF member 1), they occur only in the basal and uppermost few metres (Fig. 3).

If the assumption can be made that thin facies intervals were, in this case, deposited from relatively restricted, small-volume water bodies, then the occurrence of abundant synaeresis cracks in all cases suggests a genetic association.



This association provides circumstantial evidence that salinity changes are a viable mechanism of generating synaeresis crack, because such small-volume water bodies would have been particularly prone to evaporation and re-flooding etc.

The occurrence of cracks at the base and top of member 1 of the GCF, the lowermost of the thicker facies intervals (i.e. at the onset and termination of the water body responsible), is also consistent with this model. It is inconsistent with the model in which the shrinkage (diastasis) cracks are induced by shear associated with movement of surrounding sand layers, as this could only explain the structures developed at the upper margin of the facies, which immediately underlie a sandstone unit (Fig. 3). Two sandstone beds (0.4 and 1.2 m in thickness) which occur within the finer-grained unit do not have associated underlying crack structures.

The thicker facies intervals in which scattered synaeresis cracks occur throughout (i.e. member 6 and 8 of the GCF) can be explained if subsidence kept pace with deposition at this time. In this model, these units would have accumulated by continuous deposition from relatively small-volume water bodies in a gently subsiding system. This is consistent with the model for the upper part of the GCF presented above, in which there is an apparent lack of active structural control on deposition (i.e. generation of accommodation space) at this time.

The depositional model presented previously for the Barney Creek Formation in the central part of the McArthur Basin (Bull, 1995) is also relevant to this discussion. The HYC Pyritic Shale Member and its equivalents are interpreted to represent an aerially extensive, sub-wave base depositional system. Although these deposits have, in part, a similar depositional structure to the facies which hosts the synaeresis structures in DDH GSQ Lawn Hill 3, no shrinkage structures have been recognised. In terms of the

discussion above, this would be consistent with the large volume of the proposed water body. In fact, if synaeresis structures were present in the Barney Creek Formation, the model would suggest that they should occur in the W-Fold Shale Member. This unit is interpreted to represent the transition from deposition in shallow evaporitic brine pools to sub-wave base conditions.

References

- Bull, S. W. 1995. Towards a regional depositional model for the Palaeoproterozoic Barney Creek Formation, southern McArthur Basin, Northern Territory. AMIRA/ARC Project P384, Final Report: 133-158.
- Cowan, C. A. and N. P. James. 1992. Diastasis cracks: mechanically generated synaeresis-like cracks in Upper Cambrian shallow water oolite and ribbon carbonates. *Sedimentology* 39: 1101-1118.
- Hutton, L. 1983. Stratigraphic drilling report — GSQ Lawn Hill 1-4, 84: 228-240.
- Hutton, L. and I. H. Wilson. 1985. Mammoth Mines Region, Queensland — 1:100,000 geological map commentary. Bureau of Mineral Resources, Australia.
- Jones, D. A. 1986. Stratabound zinc-lead mineralisation in the middle Proterozoic McNamara Group, NW Queensland, University of New England, Armidale: 198 pp.
- McConachie, B. A., M. G. Barlow, et al. 1993. The Mount Isa Basin - definition, structure and petroleum geology. *APEA Journal* 33: 237-257.
- Plummer, P. S. and V. A. Gostin. 1981. Shrinkage cracks: desiccation or synaeresis? *Sedimentary Petrology* 51: 1147-1156.
- Sweet, I. P. and L. J. Hutton. 1982. Lawn Hill Region, Queensland — 1:100,000 geological map commentary. Bureau of Mineral Resources, Australia.
- Warren, J. K. 1989. *EVAPORITE SEDIMENTOLOGY*. Prentice-Hall, Inc., New Jersey 07632.

Diagenetic processes in late Palaeoproterozoic McArthur Group carbonates: preliminary studies and further directions

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Abstract

This report documents the application of cathodoluminescence microscopy and cement stratigraphic principles to late Palaeoproterozoic carbonates of the McArthur Group. A number of early carbonate and quartz cements infill fabric selective and fabric non-selective porosity. Bitumen and replacive pyrite are also observed late in the diagenetic sequence. Preliminary studies support a very tentative diagenetic sequence of: (1) early dolomitisation of carbonate sediments; (2) local precipitation of 'dog-tooth' dolomite and/or microcrystalline blocky quartz cement; (3) formation of chalcedony cement; (4) later multiple generations of drusy dolomitic spar in vugs and remaining pore-spaces; (5) accumulation of hydrocarbons with later degradation to bitumen and/or replacement by sulphides. Further work will involve the use of cathodoluminescence microscopy to document cement stratigraphy on a regional basis and utilisation of other techniques (e.g. elemental and isotope geochemistry, SEM, XRD and fluid inclusion studies).

Introduction

The McArthur Group is one of four major sedimentary groups which comprise the

Proterozoic section in the central Batten Fault Zone, southern McArthur Basin. It is unconformably underlain by the Tawallah Group (quartz sandstones with lesser conglomerate, dolostone, and mafic and felsic volcanics) and overlain by the Nathan (dolostone with lesser sandstone) and Roper (quartz sandstones) Groups. The McArthur Group has been further sub-divided into the lower Umbolooga Subgroup and upper Batten Subgroup (Jackson et al. 1987).

Detailed lithofacies analysis of a number of drill cores through the middle McArthur Group was conducted during the 1995 field season (Winefield and Bull, this report). This report documents the preliminary results from the cathodoluminescent study of a number of samples obtained as part of that work. Samples from previous studies on McArthur Group carbonates in the McArthur River area (e.g. AGSO) were also included. This work forms the initial stages of a PhD study into the regional diagenetic and fluid histories of McArthur Group carbonates and their relationship with mineralisation within the central Batten Fault Zone.

Although diagenetic studies of carbonate sediments are common in the literature, there are comparatively very few that have studied Proterozoic carbonates. The McArthur Group is one of the world's best preserved (and unmetamorphosed) late Palaeoproterozoic carbonate sequences and therefore represents a perfect



opportunity to apply commonly used techniques for diagenetic studies of Phanerozoic carbonates to their more ancient counterparts. In addition, although regional diagenetic and related fluid histories have been well studied with regard to Mississippi Valley type (MVT) Pb-Zn mineralisation, no such study has been attempted on the carbonate sequences within the McArthur Group which are host to a number of styles of mineralisation including the large stratiform, sediment-hosted Pb-Zn-Ag HVC deposit and several smaller discordant MVT style deposits including Coxco (Walker et al. 1983), Cooley and Ridge (Williams 1978).

Application of cathodoluminescence to diagenetic studies

Cathodoluminescence microscopy (CL) is routinely used in diagenetic studies of sediments, as evidenced by the large body of literature where CL plays a significant role in the interpretation of the diagenetic history of an area. It involves the bombardment of a sample surface with electrons and observing any resulting luminescence. This shows up many structures and variations that are invisible or very difficult to observe using other petrographic techniques. Variations in luminescence (or zoning) within carbonate cements under CL is due primarily to variations in the absolute and/or relative abundances of Mn^{2+} and Fe^{2+} . Manganese is the most important activator of luminescence in carbonate, whereas iron inhibits (or quenches) luminescence (Frank et al. 1982; Fairchild 1983; Machel 1985; Have and Heijen 1985). Therefore, any process that affects the variation in the amount of Fe and/or Mn incorporated within a growing carbonate crystal will produce CL zoning. Other elements are also involved such as Pb^{2+} and rare earths as activators, and Ni^{2+} and Co^{2+} as quenchers (Machel 1985).

A common application of CL in carbonate sedimentology is the study of successive stages or zones of void-filling cements with far greater precision than that possible with conventional microscopy. Cement stratigraphy involves the application of stratigraphic principles at an intergranular and void level, correlating stages of cementation within a given sedimentary basin (Tucker 1988). Meyers (1974, 1978) pioneered cement stratigraphy, demonstrating that 'zones' of carbonate cement, as revealed by their CL and other petrographic characteristics, could be correlated both vertically and regionally within Mississippian carbonates of the Sacramento Mountains, New Mexico. Detailed cement sequences revealed by CL can be used as a time framework upon which to locate other diagenetic events (e.g. dissolution, compaction, stylitisation, neomorphism and mineralisation), thus providing a more complete diagenetic history.

Previous related work

Although there has been extensive mineral and hydrocarbon exploration in the McArthur Basin, there has only been one significant diagenetic study published on the McArthur Group. Womer (1986) published a study of the hydrocarbon occurrence and diagenetic history of the upper McArthur and Roper Groups from samples collected as part of AMOCO International's hydrocarbon exploration in the McArthur River area during the 1980s. The results from Womer's study documented early chalcedony and microcrystalline quartz infilling vuggy pore-spaces, with later generations of bitumen and sparry dolomite recognised. From petrographic and SEM analysis of samples from the Yalco Formation, Stretton Sandstone and Looking Glass Formation, he suggested the following sequence for the upper McArthur Group:

- (1) early dolomitisation and silicification;
- (2) formation of vuggy (vadose) porosity;
- (3) deposition of chalcedony at shallow burial depth;
- (4) cementation by quartz during deeper burial;
- (5) hydrocarbon migration (contemporaneous with sulphide formation);
- (6) breaching of the reservoir and associated degradation of hydrocarbons;
- (7) deposition of sparry dolomite cement.

There have been a number of studies which have used the presence of regionally and stratigraphically-correlatable CL zoning in carbonate cements associated with MVT Pb-Zn mineralisation (e.g. Ebers and Kopp 1979; Grover and Read 1985; Dorobek 1987) as evidence for hydrologic connectivity during cementation, palaeoflow direction and diagenetic environment. Gregg et al. (1993) documented the effect of basinal fluids and MVT-style mineralisation on porosity in the Bonneterre Dolomite, which is the primary host for mineralisation in the south-eastern Missouri (USA) MVT mineral districts. In the Bonneterre Dolomite, facies related porosity was reduced and fracture and breccia porosity enhanced by basinal brine migration and MVT mineralisation. He therefore concluded that it is important to assess the diagenetic history of a carbonate rock when evaluating its relationship with mineralisation and/or hydrocarbon accumulation.

Methodology

Lithofacies analysis and sampling of selected drill core formed the basis for a reconnaissance cathodoluminescence study of these sediments with the preliminary results detailed below. Polished and unpolished thin-sections were examined under cathodoluminescence using a

Nuclide ELM-2B Luminoscope at the Earth Science Department, University of Melbourne. Operating parameters for cathodoluminescent petrography were 8kV beam energy and approximately 0.6mA beam current.

McArthur Group

Mara Dolomite Member, Emmerugga Dolomite

An early generation of drusy quartz cement (Hesse 1990) is observed infilling fenestral porosity (Choquette and Pray 1970) within the stromatolitic Mara Dolomite Member (Plate 1a). Plate 1b illustrates early finely crystalline quartz cement lining a pore with a later coarsely crystalline dolomitic sparry cement. Quartz and dolomite veinlets are observed cross-cutting early quartz cements.

Barney Creek Formation

Bull (1995) documented an *intraclastic dolomitic sandstone facies* within the Barney Creek Formation intersected by DDH BMR 2. A sample of this facies was examined under plane light and coarsely crystalline cement is evident between the dolomitic intraclasts (Plate 1c). Further work and sampling of this facies throughout the McArthur River area could prove very interesting in regards to mineralisation hosted by the Barney Creek Formation

Reward Dolomite

Multiple generations of both quartz and carbonate cement are recognised in samples from the Reward Dolomite. Plate 1d illustrates an early chalcedonic cement, with a later dolomitic cement infilling a vug in a silicified sample of the Reward Dolomite. Plates 1e, 1f, 1g and 1h illustrate both

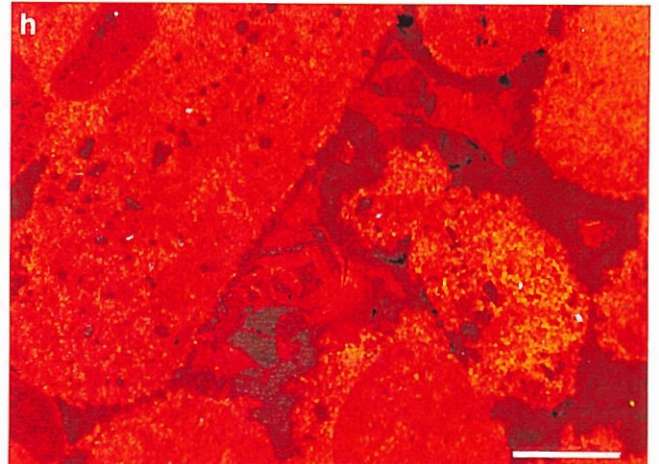
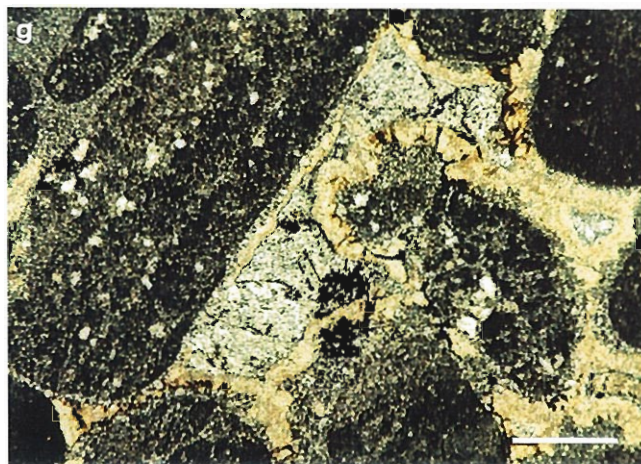
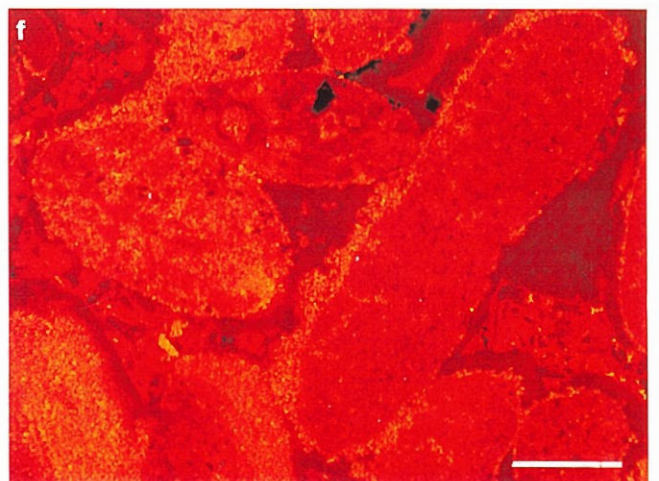
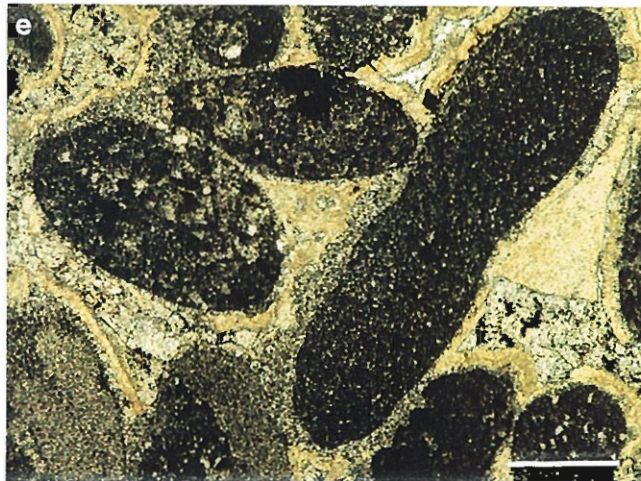
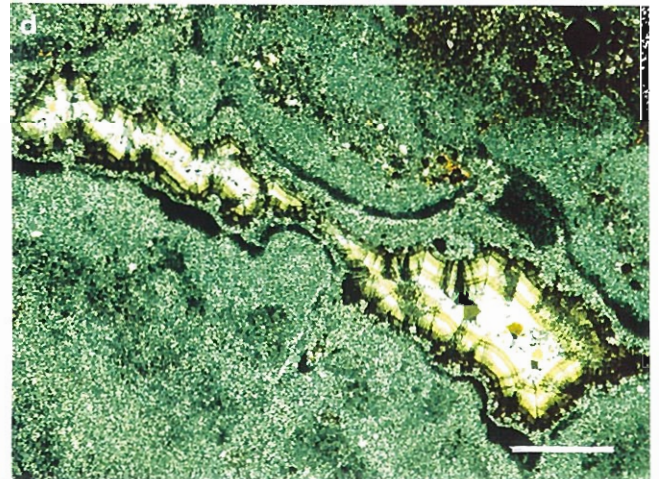
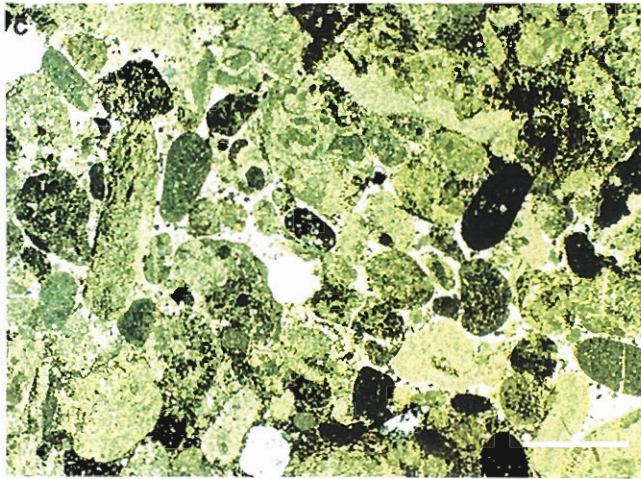
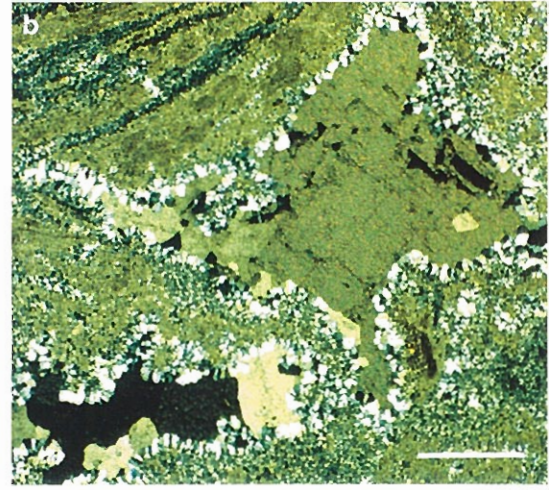
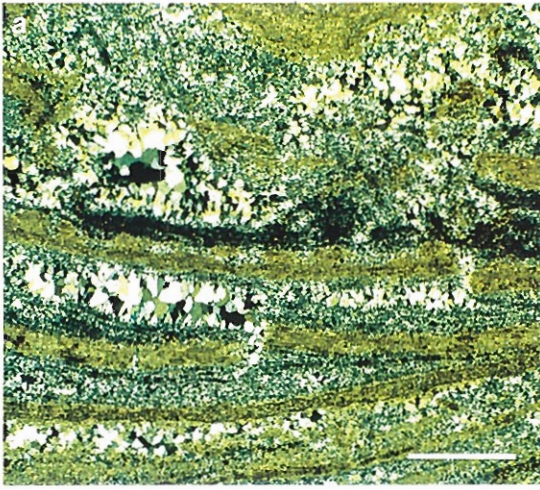


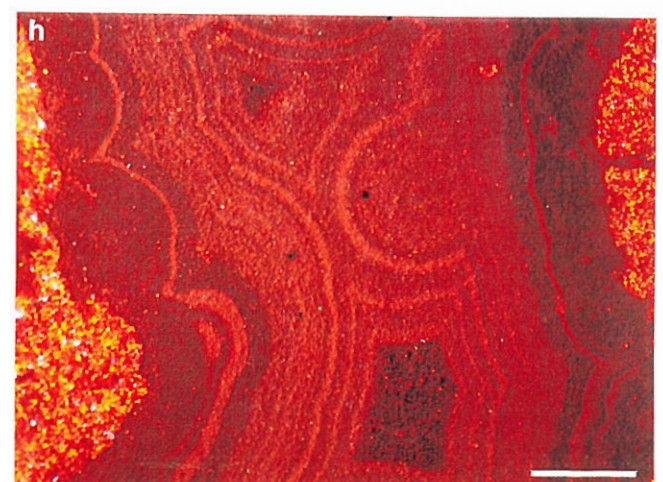
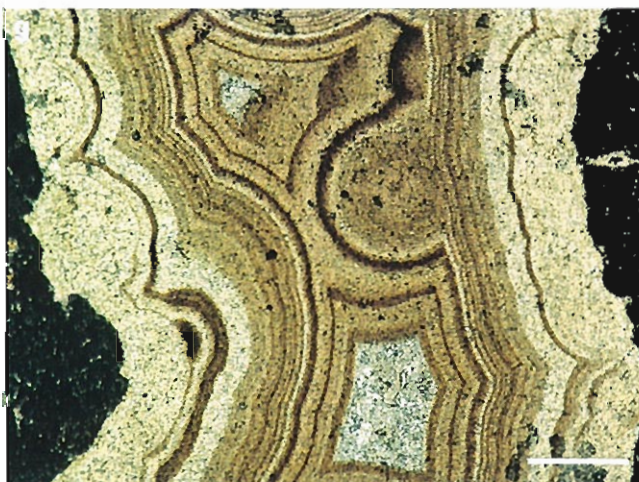
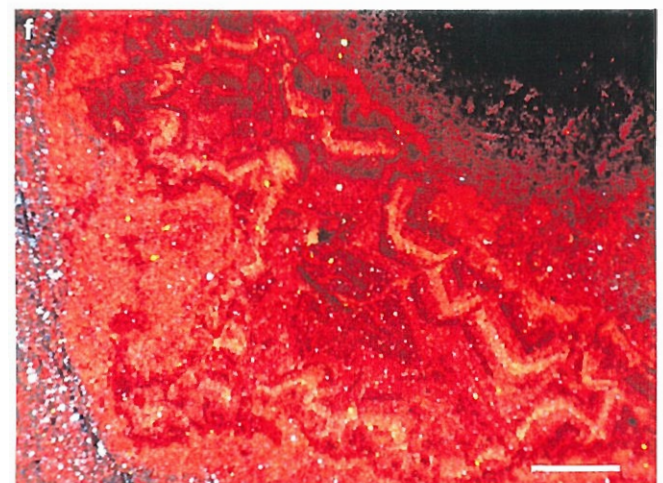
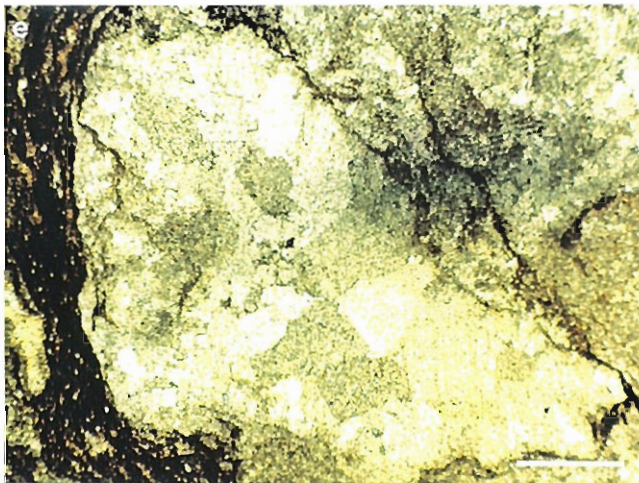
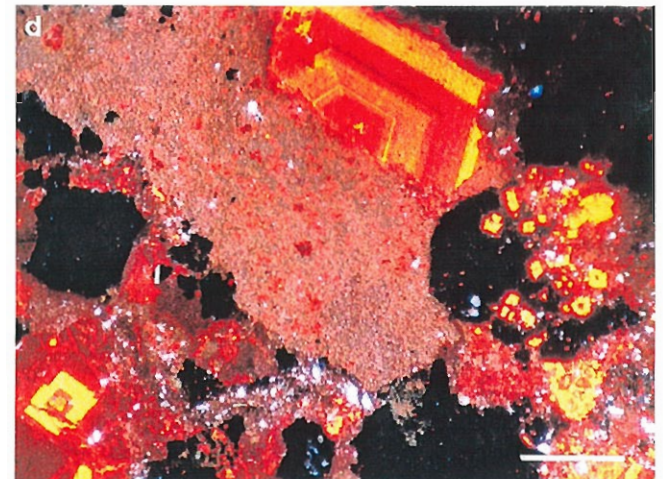
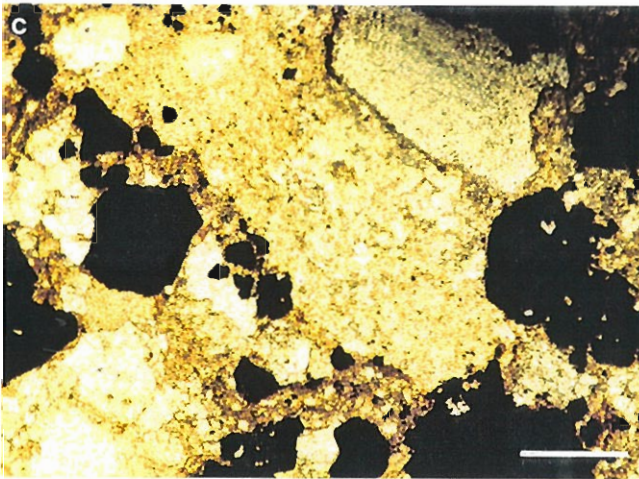
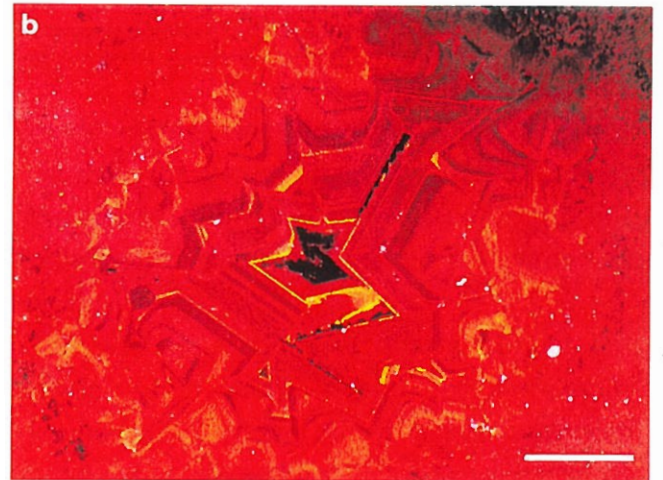
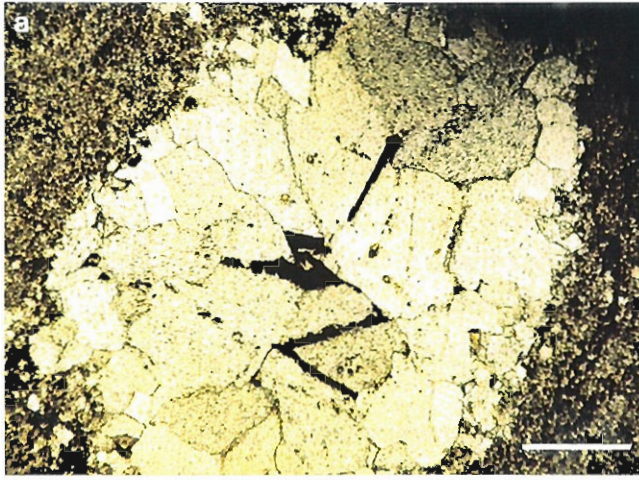
PLATE 1

(a) Drusy quartz cement infilling fenestral porosity in the stromatolitic Mara Dolomite Member of the Emmerugga Dolomite (DDH McA 8 (97.30m)). Scale bar = 1mm. (b) Early quartz cement fringing pore-space with a later coarsely, crystalline dolomitic cement within the Mara Dolomite Member (DDH McA 8 (97.30m)). Scale bar = 1mm. (c) Carbonate cement infilling intraclast pore-spaces within the intraclastic dolomitic sandstone facies of the Barney Creek Formation (DDH BMR2 (160')). Scale bar = 1mm. (d) Chalcedonic cement with a later dolomite cement infilling a vug in a silicified sample of the Reward Dolomite (78481 (Top Crossing)). Scale bar = 0.7mm. (e) Plane light view of a number of carbonate and quartz cements infilling primary porosity in the Reward Dolomite (Pmx Iii (Top Crossing)). Scale bar = 0.5mm. (f) Cathodoluminescent view of (e). Scale bar = 0.5mm. (g) Carbonate and quartz cements infilling primary porosity between dolomitic intraclasts in the Reward Dolomite (Pmx Iii (Top Crossing)). Scale bar = 0.5mm. (h) Cathodoluminescent view of (g). Scale bar = 0.5mm.

PLATE 2

(a) Vug infilled by coarsely crystalline dolomitic cement with late bitumen migration evident in centre of the pore-space (DDH Beryaja 3 (55.90m)). Scale bar = 0.5mm. (b) Cathodoluminescent view of (a). Note the multiple non-bright-dull banding evident in the coarsely crystalline cement and the association of bitumen with the brightly luminescent band in the centre of the pore. Scale bar = 0.5mm. (c) Plane light view of dolomitic intraclastic breccia with carbonate cement and replacive pyrite and other sulphides (DDH Leila Yard 1 (268.60m)). Scale bar = 0.35mm. (d) Cathodoluminescent view of (c) with dolomitic cement exhibiting distinctive zoning. Pyrite appears to be replacing the later generations of dolomitic cement. Scale bar = 0.35mm. (e) Plane light view of a carbonate replacement of an evaporite pseudomorph, presumably anhydrite, in the Hot Spring Member of the Lynott Formation (DDH Leila Yard 1 (265.25m)). Scale bar = 1mm. (f) Cathodoluminescent view of (e). Note the zoning apparent in the coarsely crystalline dolomite cement. Scale bar = 1mm. (g) Plane light view of chalcedonic and later coarsely crystalline quartz cements infilling vuggy porosity within the Donnegan Member of the Lynott Formation (DDH Am 82-6 (279.15m)). Scale bar = 0.5mm. (h) Cathodoluminescent view of (g). Scale bar = 0.5mm.





plane-light and CL views of a sample from the Top Crossing area. An early 'dog tooth' dolomite cement fringes detrital clasts, with a later chalcedony cement. Coarser crystalline dolomite cement with a number of sub-zones appear are being replaced by very coarse, fibrous chalcedony.

Late diagenetic, coarsely crystalline dolomitic cement infills a pore in Plate 2a. The CL image of the same vug demonstrates distinctive zoning in the dolomite cement (Plate 2b). The zoning in the late dolomite follows a common sequence in carbonate cements of non-luminescent, bright and then dull. This sequence represents precipitation in steadily more anoxic environments, associated with increasing burial. Bitumen occurs at the centre of the pore and is interpreted to have been associated with the corresponding thin, brightly luminescent band. It is possible that hydrocarbon accumulation into the Reward Dolomite, as represented by this pore, was related to the migration of a Mn-rich, Fe-poor carbonate saturated fluid.

Lynott Formation

Replacive pyrite and other sulphides are evident in brecciated sample from the Caranbirini Member intersected in DDH Leila Yard 1. Coarsely crystalline dolomitic cement is observed under plane light in Plate 2c. The CL view illustrates a number of dolomite crystals with distinctive luminescent zoning (Plate 2d). Coarsely crystalline, dull luminescent cement appears to be the final pore occluding cement, replaced by pyrite.

The Hot Spring Member has a number of evaporitic pseudomorphs after possibly anhydrite (Winefield and Bull, this report). Evaporite dissolution during burial has created a vug which has been infilled with coarsely crystalline dolomitic cement as seen in Plate 2e.

The view of the same vug under CL demonstrates a number of generations of burial dolomite cement with the characteristic non-bright-dull luminescence sequence related to increasing burial.

Several generations of quartz cement are recognised in samples from the Donnegan Member. Chalcedonic quartz cement nucleates on the pore walls and exhibits distinct banding. Coarsely crystalline quartz occludes porosity in most examples (Plate 2g & 2h) although a later dolomite cement is also present in some examples.

Synthesis

From the results of a preliminary CL and conventional microscopy study of McArthur Group carbonate sediments, the diagenetic history recorded in various cement types and sequences is both interesting and highly complex. There appears to be both early quartz and dolomitic cements, with later chalcedony, megaquartz and coarsely crystalline dolomite cements. Bitumen is observed within late coarse dolomite spar and interpreted to have migrated associated with a Mn-rich, Fe poor fluid. Sulphides were also noted as pyrite replacing late dolomite cement.

A very tentative diagenetic sequence of middle McArthur Group sediments using the above results is:

- (1) early dolomitisation of carbonate sediments at the sediment/water boundary to preserve textures;
- (2) local precipitation of 'dog-tooth' dolomite and/or microcrystalline blocky quartz cement;
- (3) formation of chalcedony cement in pore voids;
- (4) later multiple generations of drusy dolomitic



- spar into vugs and remaining pore spaces;
 (5) hydrocarbon accumulation and/or replacement by sulphides?

Both primary and secondary porosity is observed in samples of the McArthur Group. Womer (1986) suggested that the vuggy porosity, evident in the silicified Yalco Formation, was a direct result of exposure to vadose alteration. The presence of sequence boundaries within the McArthur Group and associated sea-level changes would have had a direct influence on the patterns of carbonate diagenesis and porosity evolution. The relationship between diagenesis of McArthur Group and the regional sequence stratigraphic framework for the McArthur Basin should allow the construction of diagenetic models and allow prediction of diagenetic patterns and porosity to some degree.

Further work and directions

This report has documented the preliminary analysis of carbonate and quartz cements using cathodoluminescent and conventional microscopy. It is apparent, that the application of cement stratigraphic principles in these rocks is possible and will form an important part in overall diagenetic history of these sediments. Other techniques likely to be utilised include elemental and isotopic geochemistry of cements, SEM analysis of inter-cement relationships, XRD and fluid inclusion studies. The use of a CL-capable SEM (located at the University of Tasmania's Launceston campus) will also be attempted.

During the 1996 field season, lithofacies analysis and sampling of open-file DDH's and surface outcrop from throughout the McArthur River area and areas to the north (Mt. Young), west (Top Crossing and Leila 1st Crossing) and

south (Kilgour Gorge). Analysis of samples collected during this field season will hopefully aid in the construction of a regional diagenetic history for the McArthur Group, and allow some constraints on the timing of mineralisation in the basin to be made. Collaboration with NABRE's sequence stratigraphic analysis of the McArthur Basin should allow the identification of sequence boundaries within the McArthur Group and therefore allow patterns in porosity evolution and diagenetic processes to be better assessed.

Acknowledgments

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References

- Choquette, P.W., and Pray, L.C., 1970. Geologic nomenclature and classification of porosity in sedimentary carbonates. *AAPG Bulletin*, v54: 207-250
- Dorobek, S.L., 1987. Petrography, geochemistry, and origin of burial diagenetic facies, Siluro-Devonian Helderberg Group (carbonate rocks), central Appalachians. *AAPG Bulletin*, v71:492-514
- Ebers, M.L., and Kopps, O.C., 1979. Cathodoluminescent microstratigraphy in gangue dolomite, the Mascot-Jefferson City district, Tennessee. *Economic Geology*, v74:904-918
- Fairchild, I.J., 1983. Chemical controls of cathodoluminescence of natural dolomites and calcites: new data and review. *Sedimentology*, v30:579-583
- Frank, J.R., Carpenter, A.B., and Oglesby, T.W., 1982. Cathodoluminescence and composition of calcite cement in the Taum Sauk Limestone (Upper Cambrian), southeast Missouri. *Journal of Sedimentary Petrology*, v52:631-638
- Gregg, J.M., Laudon, P.R., Woody, R.E., and Shelton, K.L., 1993. Porosity evolution of the Cambrian Bonnetterre Dolomite, south-eastern Missouri, USA. *Sedimentology*, v40:1153-1169

- Grover, G., and Read, J.F., 1985. Palaeoaquifer and deep burial related cements defined by regional cathodoluminescent patterns, Middle Ordovician carbonates, Virginia. AAPG Bulletin, v67:1275-1303
- Have, T., and Heijnen, W., 1985. Cathodoluminescence activation and zonation in carbonate rocks: an experimental approach. *Geologie en Mijnbouw*, v64:287-310
- Hesse, R., 1989. Silica diagenesis: origin of inorganic and replacement cherts. *Earth-Science Reviews*, v26:253-284
- Jackson, M.J., Muir, M.D., and Plumb, K.A., 1987. Geology of the southern McArthur Basin. Bureau of Mineral Resources Bulletin, v220: 173pp
- Machel, H.G., 1985. Cathodoluminescence in calcite and dolomite and its chemical interpretation. *Geoscience Canada*, v12:139-147
- Meyers, W.J., 1974. Carbonate cement stratigraphy of the Lake Valley Formation (Mississippian), Sacramento Mountains, New Mexico. *Journal of Sedimentary Petrology*, v44:837-861
- Meyers, W.J., 1978. Carbonate cements: their regional distribution and interpretation in Mississippian limestones of southwestern New Mexico. *Sedimentology*, v25:371-400
- Tucker, M.J. (ed), 1988. *Techniques in Sedimentology*. Blackwells, Oxford. 394pp
- Walker, R.N., Gulson, B., and Smith, J., 1983. The Coxco deposit - a Proterozoic Mississippi deposit in the McArthur River district, Northern Australia. *Economic Geology*, v78:214-249
- Williams, N., 1978. Studies of base metal sulfide deposits at McArthur River, Northern Territory, Australia: I. The Cooley and Ridge deposits. *Economic Geology*, v73:1005-1035
- Winefield, P.R., and Bull, S.W., this report. Carbonate-evaporite sediments in the McArthur River area: revision of middle McArthur Group lithofacies and recognition of key surfaces. AMIRA/ARC Project 384A.
- Womer, M.B., 1986. Hydrocarbon occurrence and diagenetic history with Proterozoic sediments, McArthur River area, Northern Territory, Australia. *APEA Journal*: 363-374



Carbonate-evaporite sediments in the McArthur River area: revision of middle McArthur Group lithofacies and recognition of key surfaces

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Abstract

Lithofacies analysis of selected drill core (DDH McA 7, 8, 9, 10, Leila Yard 1 and Am 82-6) in the McArthur River area and a review of earlier sedimentological studies of the McArthur Group are used to: compile a composite section for the middle Umbolooga Sub-group (Emmerugga Dolomite) to the upper Batten Sub-group (Yalco Formation); form a baseline for later diagenetic studies on McArthur Group sediments; and identify possible key surfaces or sequence boundaries which would affect porosity evolution and therefore the diagenetic history of these sediments.

Preliminary interpretation of characteristic lithofacies of middle McArthur Group sediments suggests an overall shallowing sequence through the Emmerugga Dolomite culminating with the emergent, evaporitic Coxco Dolomite Member of the Teena Dolomite. The deposition of the Barney Creek Formation in a quiet, sub-wave base environment supports a transitional event punctuated by a slight shallowing marked by the Reward Dolomite. The Caranbirini Member of the Lynott Formation is interpreted to have been laid down in a similar setting to the Barney Creek Formation, with the Hot Spring and Donnegan Members displaying characteristics consistent with a progradational sabkha sequence. The extensively silified Yalco Formation has been previously interpreted as an

ephemeral lake deposit. This is consistent with observations from this study and it is thought the Yalco Formation, with the underlying Lynott Formation, forms part of an overall regressive sequence.

The Coxco Dolomite Member of the Teena Dolomite, the Reward Dolomite and the Yalco Formation are identified as units likely to contain key surfaces or sequence boundaries. Collaboration with AGSO and NABRE in the correlation and recognition of key surfaces throughout the McArthur Group will play an important part in understanding the diagenetic history of these sediments.

Introduction

In the McArthur River area, the McArthur Group forms a thick succession of late Palaeoproterozoic carbonate and evaporitic sedimentary rocks (Jackson et al. 1987). It includes the economically important Barney Creek Formation, host to the HYC Pb–Zn–Ag deposit. Two regional sedimentological studies by Brown et al. (1969) and Jackson et al. (1987) have reported detailed sections through the McArthur Group, while others have focused on the Barney Creek Formation in the vicinity of HYC (e.g. Williams and Logan, 1981; Muir, 1983; Logan and Williams, 1984). Two distinct depositional models for these sediments resulted from these



studies. Brown et al. (1969) invokes the accumulation of deeper shaly carbonates, while Muir (1983) proposed lacustrine/sabkha deposition. In addition, a combination of these two depositional models has also been put forward by others (Williams and Logan, 1981; Logan and Williams, 1984). Bull (1995) documented a regional framework of Barney Creek Formation sections throughout the central Batten Fault Zone which suggested: a quiet, reduced, sub-wave base depositional setting for the Barney Creek Formation, with the possible exception of the area immediately adjacent to HYC mineralisation; a gradational deepening through the Barney Creek Formation with two maximum flooding surfaces recognised at the base and top of the HYC Pyritic Shale Member; and a shallowing recorded by deposition of the Reward Dolomite.

The aims of this report are to document the sedimentology of middle McArthur Group sediments in selected drill core (DDHs McA 7, 8, 9, 10, Leila Yard 1 and Am 82-6) in order to:

- establish a composite section through the upper Umbolooga Subgroup (Emmerugga Dolomite) to the middle Batten Subgroup (Yalco Formation) in the McArthur River area;
- form a baseline for later diagenetic studies;
- identify possible key surfaces which are likely to have played an important role in the diagenetic history of these sediments.

Regional Geology

The McArthur Basin is an extensive Proterozoic sedimentary system located along the southern and western margins of the Gulf of Carpentaria in northern Australia (Fig. 1). The Walker and Batten Fault Zones comprise the central tectonic elements of the northern and southern parts of the basin respectively. Each fault zone is bounded

by regional north-south trending structures and are separated by the east-west trending Urapunga Fault Zone. McArthur Group sediments are exposed in the central Batten Fault Zone, as two north-south trending extended bands. Both bands are separated by the north-south trending Tawallah Fault, with the western band bounded by Roper Group cover in the west and the other band by the Emu Fault in the east (Fig. 2).

Stratigraphy

Southern McArthur Basin stratigraphy has been defined by geological mapping of the Bauhinia Downs (Pietsch et al., 1991a), the Abner Range (Jackson et al., 1987) and McArthur River (Pietsch et al., 1991b) regions. Four major groups are recognised which are, from oldest to youngest: the Tawallah Group (dominated by quartz sandstone with lesser conglomerate, dolostone, and mafic and felsic volcanics); the McArthur and Nathan Groups (both dominated by dolostone with lesser sandstone); and the Roper Group (dominated by quartz sandstone).

The McArthur Group has been further subdivided into the lower Umbolooga Sub-group and the upper Batten Sub-group (Jackson et al., 1987; Pietsch et al., 1991a,b; Fig. 3). The contact between the two sub-groups has been defined on the basis of local unconformities adjacent to the major fault zones (Pietsch et al., 1991a) and the presence of local karstic surfaces and palaeo-regolith (Jackson et al., 1987).

Sedimentology of DDH McA 7, 8, 9, 10, Leila Yard 1 and Am 82-6

Lithofacies analysis of the selected drill core from the McArthur River area (Fig.2) gives a relatively

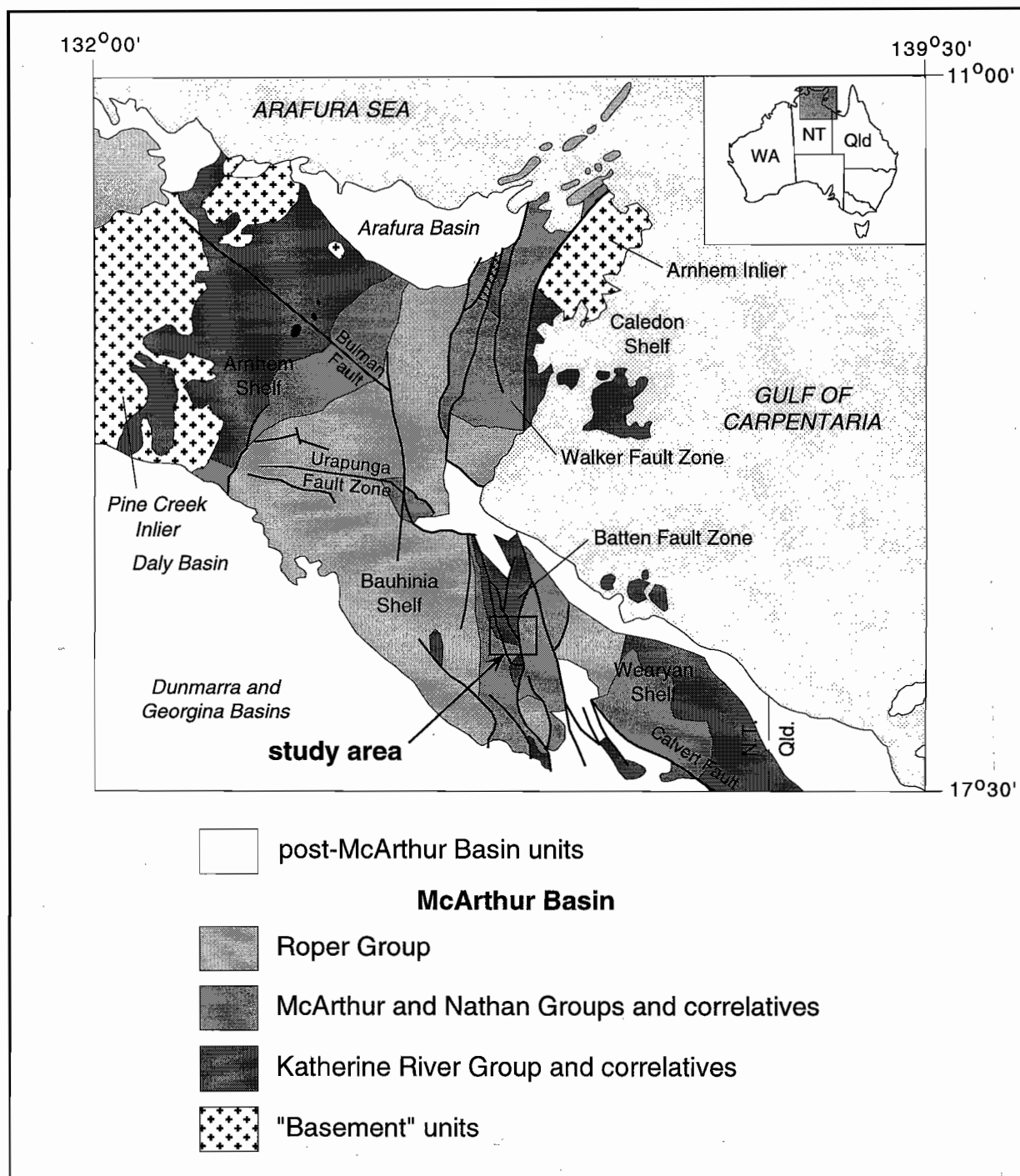


Figure 1 — Major tectonic elements of the McArthur Basin (adapted after Pietsch et al. 1991a).



McARTHUR GROUP STRATIGRAPHY

CENTRAL BATTEN FAULT ZONE (McArthur River Area)

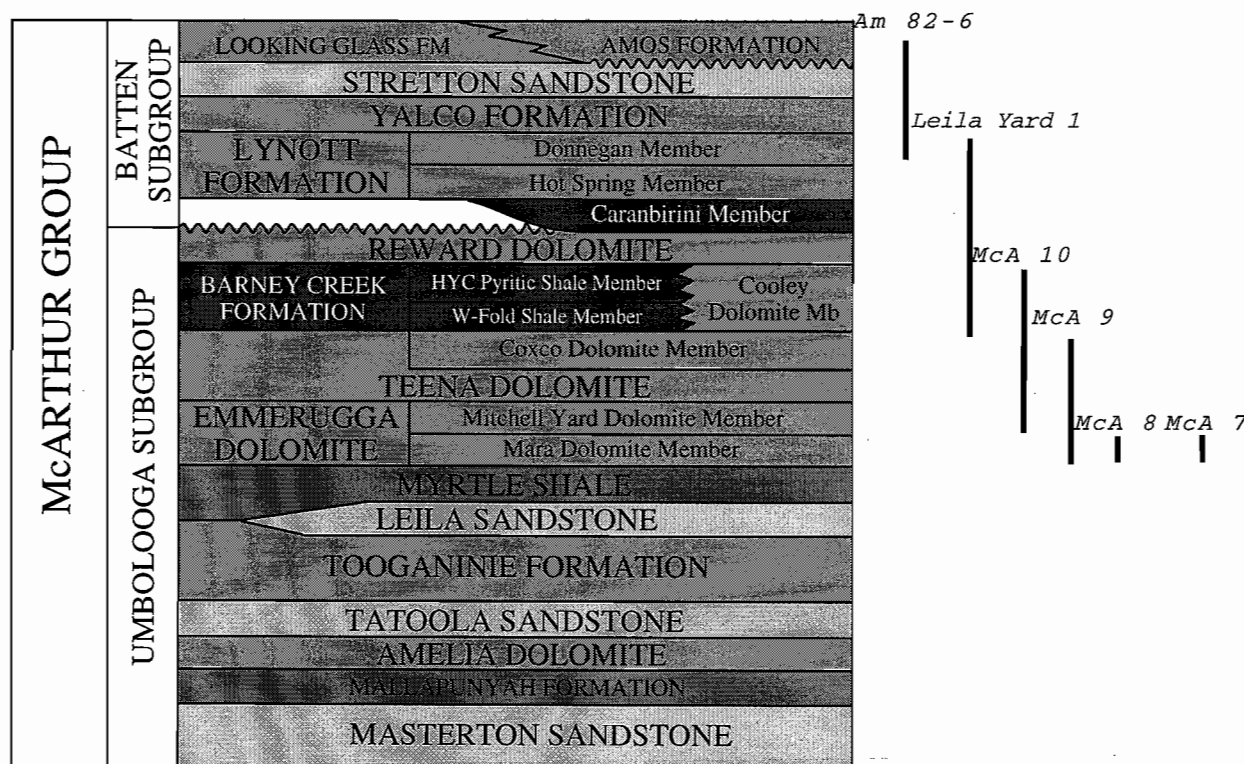


Figure 2 — McArthur Group stratigraphy with examined drill core intersections (adapted from Pietsch et al 1991a).

continuous sequence of carbonate and evaporite dominated sediments through the Emmerugga Dolomite to the Yalco Formation (Fig. 3). The characteristic lithofacies of the composite section are summarised below and in Figure 4A.

Emmerugga Dolomite

The contact between the Myrtle Shale and Mara Dolomite Member of the Emmerugga Dolomite is represented by red-green intraclastic solution-collapse breccias (DDH McA 7 (130–154 m);

Plate 1a) within the lower Mara Dolomite Member. These intraclastic breccias are associated with evaporitic dissolution of the underlying Myrtle Shale and are consistent with similar features noted by Jackson et al. (1987) in sections at the southeast end of the Abner Range. The upper Mara Dolomite Member is characterised by cyclic microbial (Plate 1b, c) and planar laminated light grey dolomite with a number of white crystalline evaporite pseudomorph bands, possibly after gypsum (Pietsch et al., 1991a).

Surface exposures of the Mitchell Yard

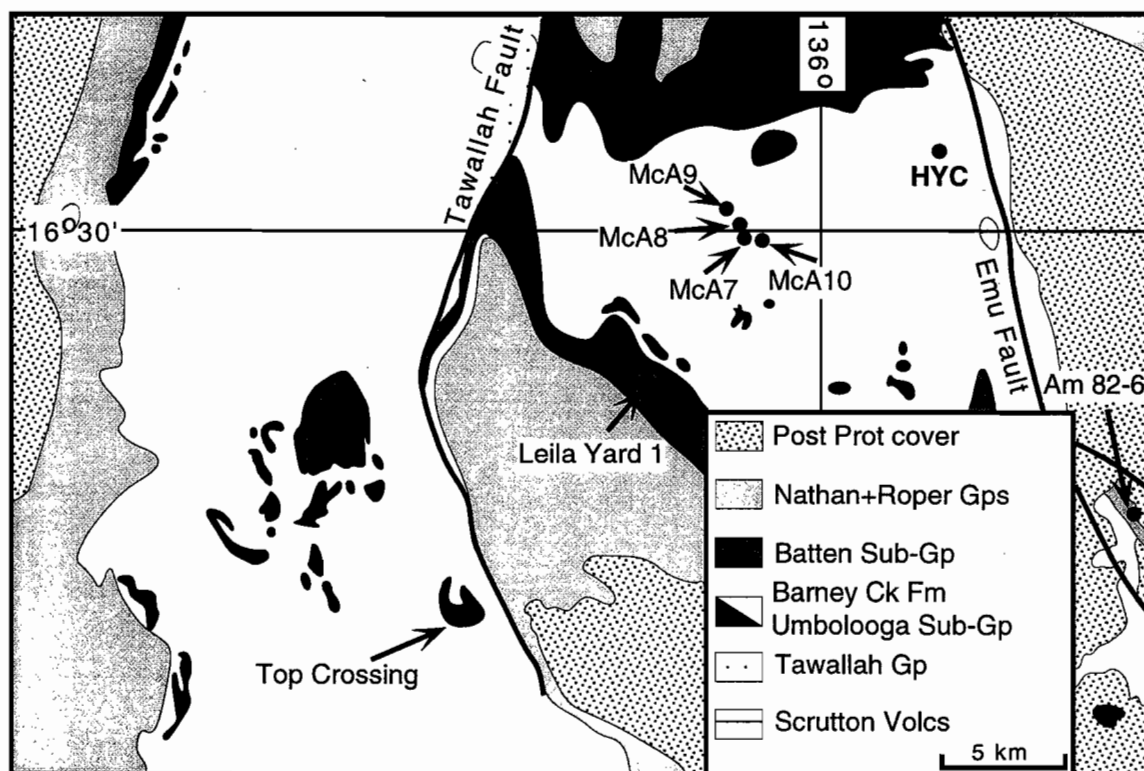


Figure 3 — Geology of the central Batten Fault Zone showing location of examined drill-core (after Pietsch et al. 1991b).

Dolomite Member are characterised by massive, featureless and karstic dolostone (Pietsch et al., 1991b). However, in drill core it comprises dolostone exhibiting unusual chaotic, 'wormy' textures (DDH McA 9 & 10; Plate 1d) and dolomitic, crystalline infills. It is thought that these textures were formed by differential compaction of alternating semi-coherent dark and light grey dololutite laminations.

Teena Dolomite

The lower Teena Dolomite contains well-sorted, coarse grained dolarenite and dolorudite [DDH McA 9 (55 m) & 10 (146–148 m); Plate 1e] interbedded with fine-grained, planar and microbial laminated dololutite. Occasional imbricated plate breccias were also noted. The Coxco Dolomite Member is generally buff coloured, thinly bedded to finely laminated with local disruption caused by partially displacive growth (perpendicular to

bedding) of acicular radiating pseudomorphs after gypsum (DDH McA 9 (11–45 m) & 10 (98–134 m) and Leila Yard (520 m); Plate 1f).

These six-sided acicular zoned crystals ('Coxco' needles) were originally interpreted as pseudomorphs after aragonite (Brown and others, 1969), but Walker et al. (1977) demonstrated the crystal angles were more characteristic of gypsum. Similar crystal casts have also been reported in marginal-marine brine pools in Holocene deposits at Marion Lake, South Australia (von der Borch et al., 1977) and in the Arabian Gulf.

Barney Creek Formation

In drill core, the W-Fold Shale Member (DDH McA 10 (40–97 m) & Leila Yard 1 (517–520 m); Plate 1g) is characterised by lenticular, wavy and flaser laminated green-grey dololutite and dolarenite. There is no evidence of evaporites.

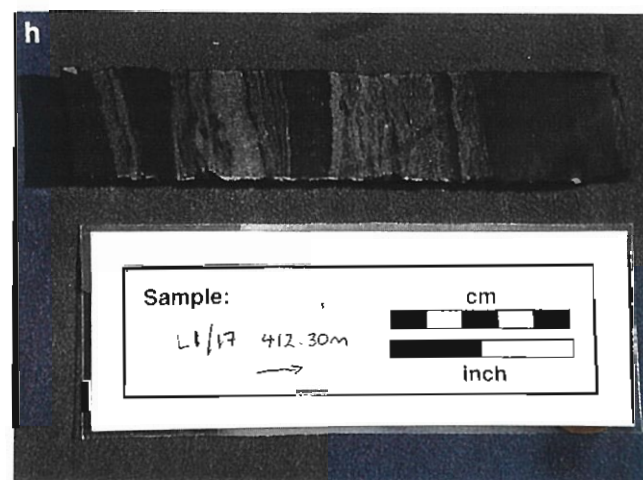
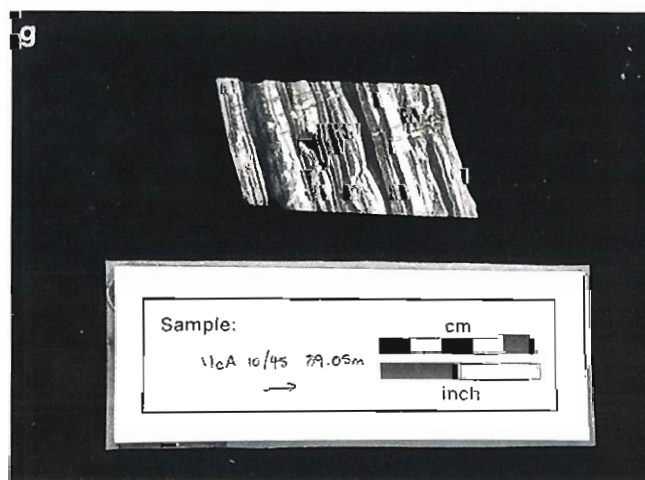
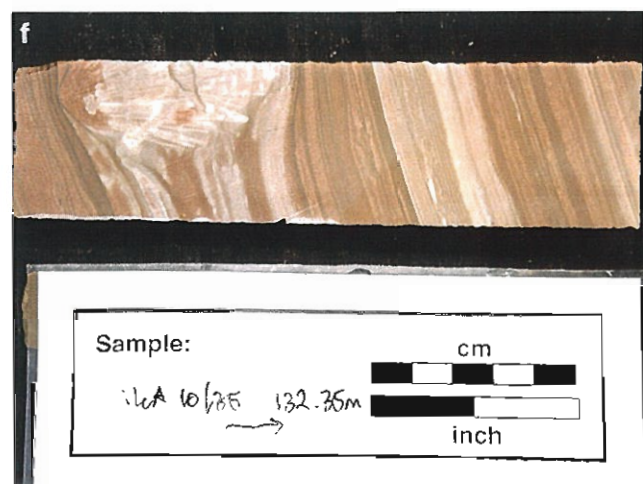
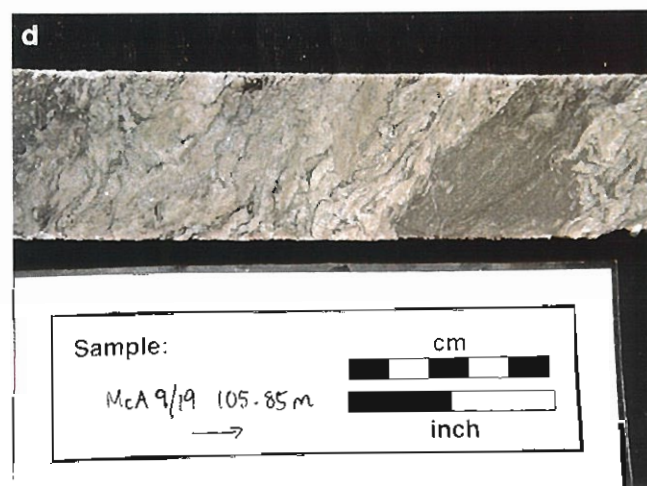
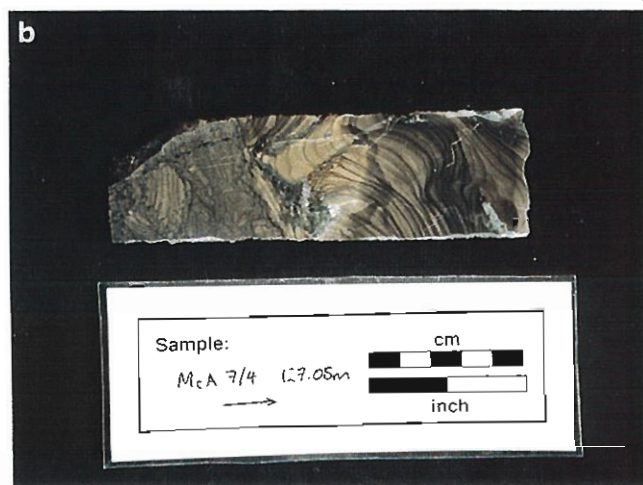


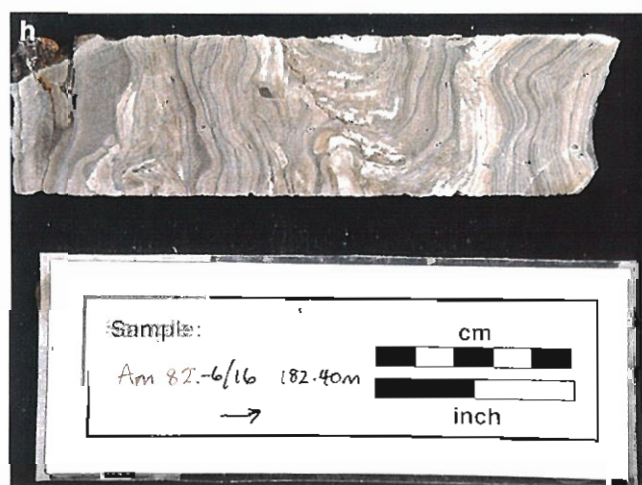
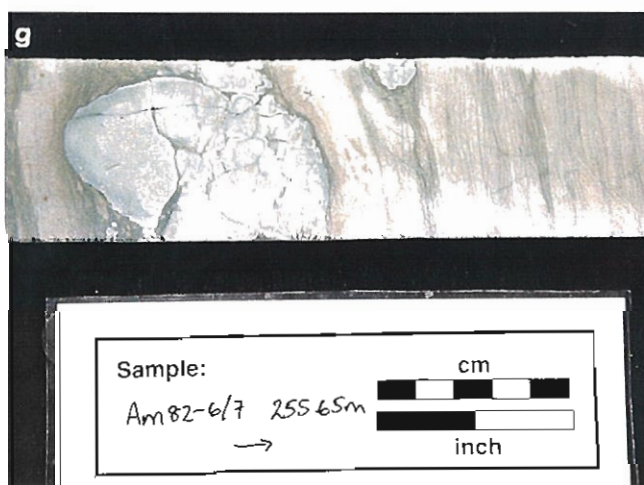
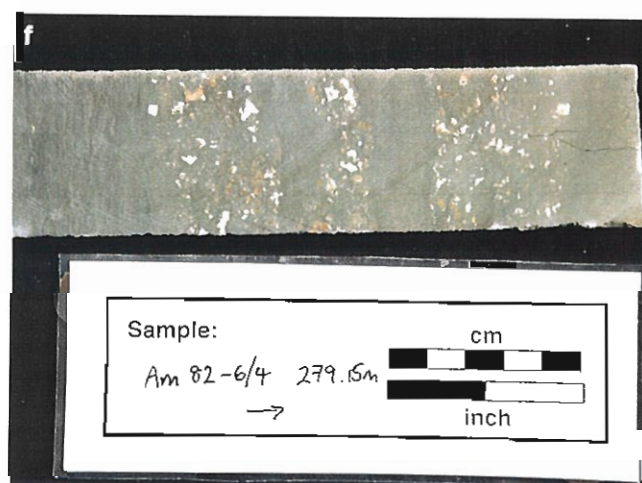
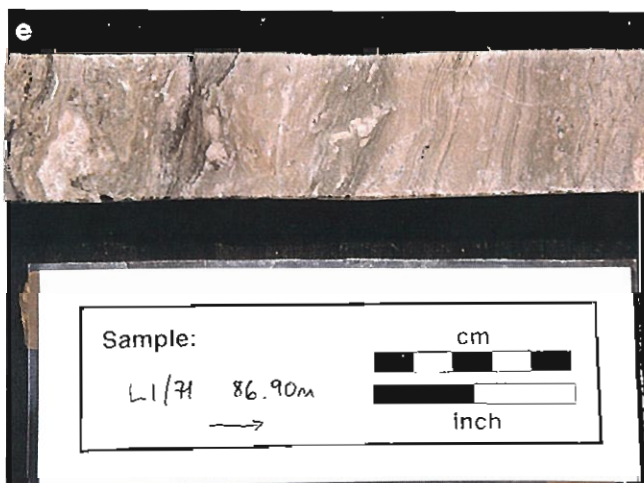
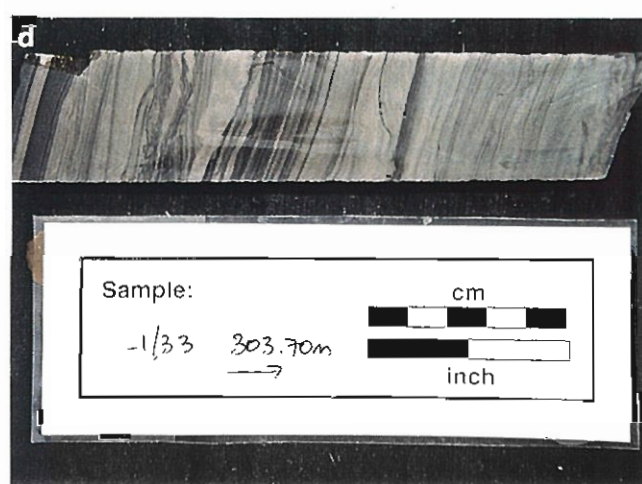
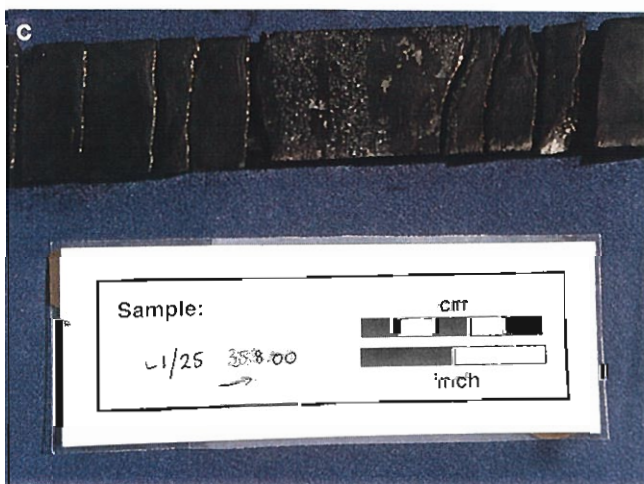
PLATE 1

(a) Red-green breccias (Mara Dolomite Member) associated with evaporite dissolution of the underlying Myrtle Shale (McA 7 (141.50m)). (b) Domal stromatolite, Mara Dolomite Member (McA 7 (127.05m)). (c) Microbial lamination occurring at high angle to the core (McA 9 (147.70m)). (d) Chaotic, 'wormy' textures characteristic of the interval interpreted as the Mitchell Yard Dolomite Member (McA 9 (105.85m)). (e) Coarse-grained quartz and dolarenite, lower Teena Dolomite (McA 9 (54.85m)). (f) Distinctive 'Coxco' needles within planar laminated and disrupted dololomite, Coxco Dolomite Member (McA 10 (132.35m)). (g) Planar, flaser and wavy lamination within the W-Fold Shale Member (McA 10 (89.05m)). (h) Fine- and coarse-grained dolarenite interbedded within carbonaceous shale, upper HYC Pyritic Shale Member (Leila Yard 1 (412.30m)).

PLATE 2

(a) Wavy laminated dololomite interlaminated with massive carbonaceous shale, Reward Dolomite (Leila Yard 1 (372.05m)). (b) Wavy and planar laminated dololomite with isolated pod of pyrite (Leila Yard 1 (369.40m)). (c) Possible early diagenetic deposition of silica forming distinctive bands within carbonaceous shale of the Caranbirini Member (Leila Yard 1, 358m). (d) Disrupted lamination and possible cross-bedding within the lower Hot Spring Member (Leila Yard 1 (303.70m)). (e) Syneresis cracks and crystal-line (probably silica) infills characteristic of upper Hot Spring Member (Leila Yard 1 (86.90m)). (f) Banded silica infilled vugs within the Donnegan Member (Am 82-6 (279.15m)). (g) Large cauliflower chert diagnostic of the Donnegan Member (Am 82-6 (255.65m)). (h) Domal stromatolite from the lower Yalco Formation (Am 82-6 (182.40m)).





This consistent with studies of surface exposure (e.g. Jackson et al., 1987) which identified graded beds, scour, and flame structures as indicative of subaqueous deposition.

The HYC Pyritic Shale Member intersected in DDH's McA 10 (25–40m) and Leila Yard 1 (377–517m) comprise lithofacies which are consistent with those facies defined by Bull (1995) for the Barney Creek Formation.

Reward Dolomite

The Reward Dolomite was intersected in DDH Leila Yard 1 (364–377 m) and is characterised by massive or finely laminated, carbonaceous, slightly dolomitic mudstone and dolarenite (Plate 2a, b). The boundary with the underlying Barney Creek Formation is defined by an increase in carbonate content into the Reward Dolomite. There is considerable variation in the lithologies which comprise the Reward Dolomite (Jackson et al., 1987; Pietsch et al., 1991b; Bull, 1995) and an enigmatic relationship exists between it and the underlying Barney Creek Formation. Thicker siltstone and shale-dominated intervals (up to 350m) reportedly coincide with thicker Barney Creek Formation sections (Jackson et al. 1987; Pietsch et al. 1991a).

Lynott Formation

The Caranbirini Member of the Lynott Formation, intersected in DDH Leila Yard 1 (340–364m), consists of a number of carbonaceous, pyritic and slightly dolomitic shale intervals interfingering with layers of clean, fine-grained dololite and dolarenite (Plate 2c). The sand-sized grains evident in Plate 2c display features consistent with early diagenetic silica deposition within algal cysts and spores in black shales described by Schieber (1996). The boundary between the Caranbirini and overlying Hot

Spring Members is gradational and characterised by increase in carbonate content and grain size.

The lower Hot Spring Member (DDH Leila Yard 1 (~130–340m) is characterised by coarse-grained dolarenite interbedded with planar, flaser and wavy laminated dololite (Plate 2d) with occasional microbial lamination. The upper Hot Spring Member (64 m–~130m) displays imbricated plate breccias with tepee structures, evaporite pseudomorphs, syneresis and desiccation cracks (Plate 2e). A distinctive feature of the Hot Spring Member is the presence of abundant chert 'blebs' or pods.

The Donnegan Member is defined by the occurrence of cauliflower chert, after anhydrite, within fine-grained dololite and coarse-grained dolarenite. Cross-bedding and ripples are common (Plate 2f, g). The uppermost DDH Leila Yard 1 (9–64 m) intersected the Donnegan Member which displayed a gradational contact with the underlying Hot Spring Member. A gradational contact was also observed between the Donnegan Member and the overlying Yalco Formation in DDH Am 82-6 (~200 m).

Yalco Formation

The Yalco Formation, as observed in DDH Am 82-6, consists of thinly bedded dololite and dolarenite with abundant chert nodules and laminae, consistent with intensive silicification. Small domal stromatolites (Plate 2h) and desiccation cracks are ubiquitous. Jackson et al. (1987) interpreted this overprinting as a product of weathering that followed a period of erosion. Muir et al. (1980) described the Yalco Formation as an ancient analogue of the Coorong Lagoon of South Australia, where the sediments are the product of deposition in an ephemeral dolomitic lake environment. Thin dolarenite and sandstone beds, which have no equivalent in the Coorong lakes are likely to have been deposited by



intermittent flooding of these lakes (Jackson et al. 1987).

Interpretation

Lithofacies analysis of selected drill core and review of earlier studies (e.g. Muir et al. 1980; Jackson et al. 1987; Pietsch et al. 1991a&b; Bull 1995) on McArthur Group sediments supports the deposition of the Emmerugga Dolomite in a shallow lagoonal environment, with possible differential compaction responsible for the textures evident in the Mitchell Yard Member. The deposition of the Teena Dolomite is interpreted to have occurred in locally evaporitic, shallow to emergent conditions, and the subsequent deposition of the Barney Creek Formation in a relatively quiet, sub-wave base setting (Bull 1995). The overlying Caranbirini Member contains similar lithofacies to that of the HYC Pyritic Shale Member and is interpreted to have been deposited in a similar environment. These quiet water facies are separated by the more dolomitic Reward Dolomite. The Hot Spring Member represents intertidal to supratidal conditions, while the Donnegan Member probably represents a supratidal to sabkha environment, and the Yalco Formation an ephemeral lake setting.

In terms of palaeoenvironmental interpretation, features of the interval preceding the deposition of Coxco Dolomite Member are consistent with a period of shallowing to emergent conditions represented by the distinctive 'Coxco' needles (Fig. 4B). This shallowing, recorded in the Emmerugga and Teena Dolomites, is followed by a transitional period marked by deposition of the W-Fold Member and then the quiet water, sub-wave base HYC Pyritic Shale Member of the Barney Creek Formation (Bull 1995). This event is consistent

with the transition originally proposed by Brown et al. (1969). The Reward Dolomite is here interpreted as a slight shallowing sequence after deposition of the Barney Creek Formation, followed by a deepening event represented by the overlying and conformable Caranbirini Member of the Lynott Formation. The deposition of the Hot-Spring Member (intertidal) and Donnegan Member (supratidal) of the Lynott Formation is characteristic of a progradational or shallowing upward sabkha sequence (Warren 1989). The deposition of the Yalco Formation in an ephemeral lake setting, as proposed in earlier studies (e.g. Muir 1980; Jackson et al. 1987), is consistent with the features observed in this work. Therefore Yalco Formation thought to represent a further part of the overall regressive sequence which began during deposition of the Lynott Formation.

Exposure of carbonate sediments to subaerial or vadose conditions and the presence of relatively dilute waters with a range of saturation states is likely to cause the generation of secondary porosity (e.g. vugs) as well as possible porosity destruction via passive cementation (Moore 1989). It is therefore very important to identify surfaces which represent these conditions and gain an understanding of the porosity evolution that has occurred and its relationship with the diagenetic history of these sediments (Tucker 1993).

Middle McArthur Group sediments likely to contain possible key surfaces or sequence boundaries include: the Coxco Dolomite Member of the Teena Dolomite because of its emergent and evaporitic nature; the Reward Dolomite due to the identification of karstic weathering features and local unconformities between it and the overlying Batten Sub-group; and the Yalco Formation as it is extensively silicified and together with the Lynott Formation forms part of a broad regressive, progradational sequence

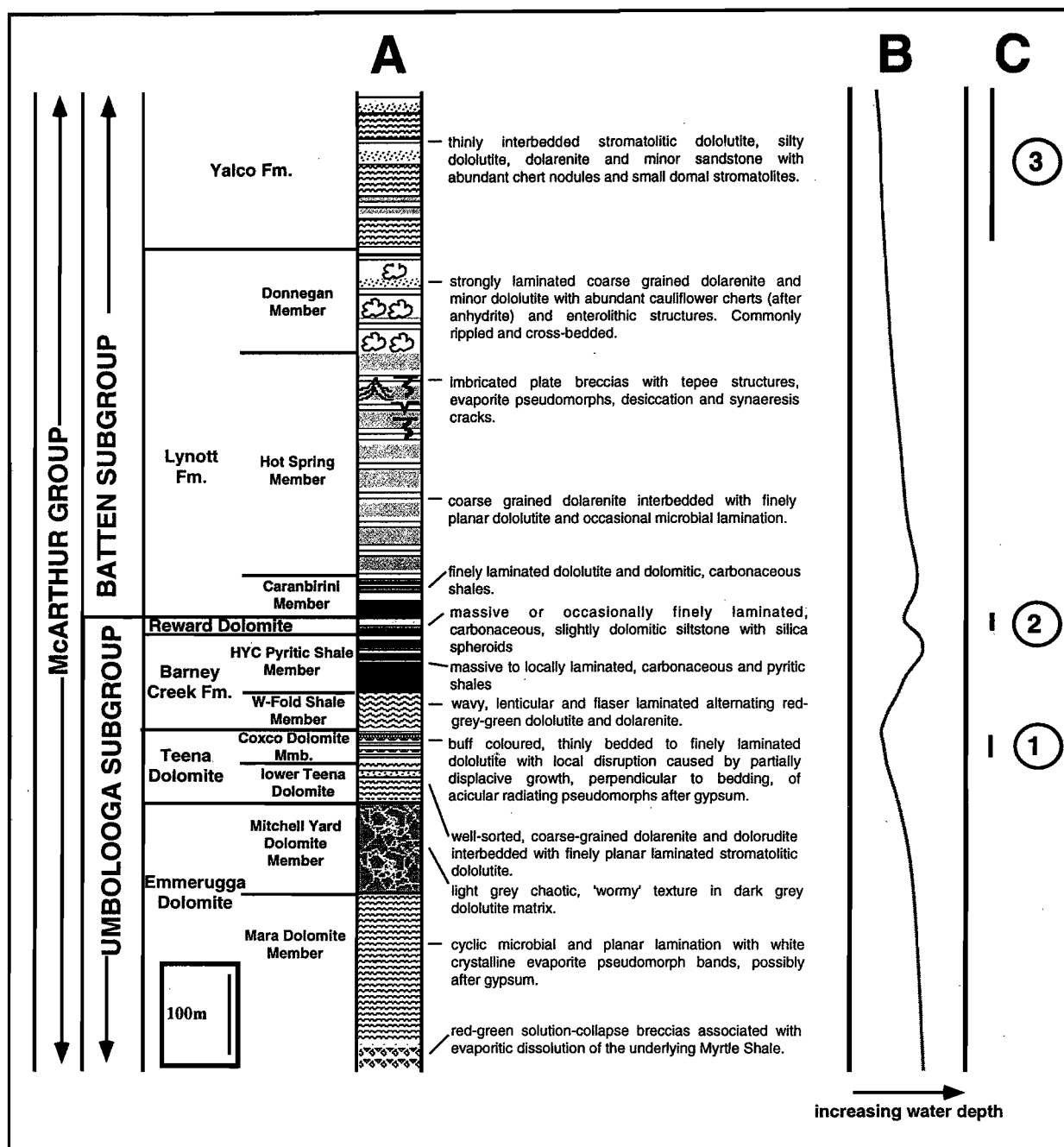


Figure 4 — (A) Schematic composite log through middle McArthur Group sediments. (B) Interpretative, relative water depth curve. (C) Units identified as containing possible key surfaces or sequence boundaries.



(Fig 4C). Sequence stratigraphic analysis of the McArthur Basin by AGSO as part of the NABRE study should allow correlation and identification of significant regional sequence boundaries throughout the McArthur Group, especially within the interval targeted by this study. This is an area where interaction with AGSO/NABRE is likely to be very useful in regards to diagenetic studies of the McArthur Group and as such is seen as being mutually beneficial.

Conclusions

Analysis of selected drill core through the middle McArthur Group has enabled identification of characteristic lithofacies represented in this sequence which will form a baseline for later diagenetic studies (Winefield, this report). Interpretation of these lithofacies and review of previous sedimentological studies on McArthur Group sediments supports a period of shallowing preceding the deposition of the Coxco Dolomite Member, followed by a deepening event recorded by the deposition of the Barney Creek Formation in a relatively quiet, sub-wave base setting. The Caranbirini Member displays similar lithofacies characteristics to the Barney Creek Formation, and as such is presently interpreted to have been deposited in a similar setting. The intervening Reward Dolomite, as observed in this study, represents a relative shallowing event. Deposition of the Hot-Spring Member, Donnegan Member and Yalco Formation is believed to be part of an overall regressive, progradational sequence.

The identification of key surfaces (Jackson et al. 1996) or sequence boundaries will aid in evaluation of the diagenetic history of these sediments. For example the exposure of carbonate sediments to subaerial or shallow subsurface diagenetic environments and dilute

porewaters can cause secondary porosity as well as cementation. This study has identified units likely to contain possible key surfaces. These include:

- the evaporitic and emergent Coxco Dolomite Member;
- the locally karstically weathered Reward Dolomite;
- the silificied Yalco Formation.

These surfaces need to be recognised and correlated regionally, and it is here that collaboration with AGSO/NABRE will prove invaluable in elucidating the diagenetic history of these sediments.

Future work

1. Extension of lithofacies analysis regionally on DDH and surface outcrop sections throughout the McArthur River area and areas to the north (Mt. Young), west (Top Crossing and Leila 1st Crossing) and south (Kilgour Gorge).
2. Collaboration with AGSO/NABRE to apply sequence stratigraphic principles to the above to allow correlation of key surfaces in a regional section framework. This would allow regional patterns in the porosity evolution and diagenetic processes to be better assessed.

Acknowledgments

The work which comprises this report was conducted during the 1995 field season. The authors would like to thank and acknowledge the AMIRA P384A - Sediment-hosted base metal deposits research project and the Northern Territory Geological Survey for logistical support

while in the field. Comments and discussion from Jim Jackson (AGSO) David Rawlings, John Dunster, Steve Hunns and Peter McGoldrick was also much appreciated.

References

- Brown, M.C., Claxton, C.W., and Plumb, K.A., 1969. The Proterozoic Barney Creek Formation and some associated units of the McArthur Group, Northern Territory, Australia. Bureau of Mineral Resources Record 1969/145.
- Bull, S.W., 1995. Towards a regional depositional model for the Paleoproterozoic Barney Creek Formation. AMIRA/ARC Project P384A Report 7: 133–157.
- Jackson, M.J., Muir, M.D., and Plumb, K.A., 1987. Geology of the southern McArthur Basin. *Bureau of Mineral Resources Bulletin* 220: 173pp.
- Jackson, M.J., Southgate, P.N., Krassay, A.A., McConachie, B.A., Wells, A.T. and Scott, D.L., 1996. New techniques/concepts for choosing the right ground for sediment-hosted mineralisation, lower McNamara Group, Lawn Hill Platform. *Geological Society of Australia Abstract* 41: 216.
- Logan, R.G. and Williams, N., 1984. Sedimentary controls on the hydrothermal system that formed the H.Y.C deposit at McArthur River, Northern Territory. Geosciences and the development of natural resources. *Geological Society of Australia Abstract* 12: 339.
- Muir, M.D., 1983. Depositional environments of host rock to northern Australian lead–zinc deposits, with special reference to McArthur River. Geological Assoc. Can. Min. Assoc. Can. Annual Meeting, Victoria, May 1983, short course contribution: 141–174.
- Muir, M.D., Lock, D. and von der Borch, C.C., 1980. The Coorong-model for penecontemporaneous dolomite formation in the Middle Proterozoic McArthur Group, Northern Territory, Australia. *Society of Economic Palaeontologists and Mineralogists Special Publication* 28: 51–67.
- Pietsch, B.A., Rawlings, D.J., Creaser, P.M., Kruse, P.D., Ahmad, P., Ferenczi, P.A. and Findhammer, T.L.R., 1991a. Bauhinia Downs 1:250000 Geological Map Series. Northern Territory Geological Survey Explanatory Notes SE53-3.
- Pietsch, B.A., Wyche, S., Rawlings, D.J., Creaser, P.M., and Findhammer, T.L.R., 1991b. McArthur River Region 1:100000 Geological Map Series. Northern Territory Geological Survey Explanatory Notes SE53-3 (6065–6165).
- Schieber, J., 1996. Early diagenetic silica deposition in algal cysts and spores. *Journal of Sedimentary Research* 66: 175–183.
- Tucker, M., 1993. Carbonate diagenesis and sequence stratigraphy. In Wright, V. P. (editor). *SEDIMENTOLOGY REVIEW* 1. Blackwell Scientific Publications.
- von der Borch, C.C., Bolton, B., and Warren, J.K., 1977. Environmental setting and microstructure of subfossil lithified stromatolites associated with evaporites, Marion Lake, South Australia. *Sedimentology* 24: 693–708.
- Walker, R.N., Muir, M.D., Diver, W.L., Williams, N. and Wilkins, N., 1977. Evidence of major sulphate evaporite deposits in the Proterozoic McArthur Group, Northern Territory, Australia. *Nature* 265: 526–529.
- Williams, N. and Logan, R.G., 1981. Depositional environments of the sediments hosting the McArthur River stratiform Pb–Zn deposits. In Groves, D.I., McNamara, K., Brown, R.G., and Johnstone, M.H., (Editors). *Sediments through the ages. Fifth Australian Geological Convention, Perth. Geological Society of Australia Abstracts* 3: 8.



Primary dispersion halos associated with the Mount Novit Zn-Pb-Ag mineralisation

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Summary

Gossanous ridges between 15 and 20 km south of Mt Isa are the surface expression of a pyritic interval up to 25 m thick containing sporadic Zn-Pb-Ag mineralisation. The mineralised sequence dips steeply west and is structurally complex, reflecting proximity to the Mount Isa Fault Zone.

The host sediments are interpreted as an overturned sequence of lower Mount Isa Group rocks (Moondarra Siltstone) lying to the west of the Mount Isa Fault.

Metamorphism has reached greenschist to lower amphibolite grade and a variety of unusual rock textures are thought to reflect deformation at or near, the brittle-ductile transition.

Mineralisation is stratiform (or stratabound) disseminated to massive granular (?recrystallised) pyrite with variable amounts of sphalerite, galena, pyrrhotite and magnetite. More than 15 diamond drill holes have been drilled to test the mineralisation, but only a handful of intersections exceed 10% Pb+Zn over thicknesses of more than a metre.

Three drill holes through the mineralisation at about 2 km spacing were systematically sampled to encompass the mineralised interval.

The ore position in the northernmost hole (G880) is represented by 5-10% disseminated pyrite. Thick massive pyrite intervals are present in the other sampled holes (4 m in D496 and about 25 m in F681).

Sixty-one samples were analysed for major and trace elements by XRF at the University of Tasmania and the standard set of geochemical vector parameters have been calculated.

Although texturally diverse, most sample samples had suitable bulk composition for the Alteration Index ('SedexAI' and 'AI3') and MnOd to be meaningful.

The southernmost hole (D496) yields inconclusive results, by contrast, in drill hole F681, AI3 and TI are anomalous for a few tens of metres above and below the ore position, and in drill hole G880 for the 50 m that includes the (barren) disseminated pyrite zone. Both G880 and F681 have encouraging MnOd values in samples from near the mineralisation.

The implications for the origin of the Mount Novit mineralisation, and the preservation of primary dispersion halos at elevated metamorphic grades will be discussed.

A comprehensive report will be presented at a later date.



Velkerri Formation geochemistry: previous work and new data

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Summary

The Velkerri Formation is an areally extensive organic carbon-rich, but generally low carbonate-carbon, mudstone unit in the early Mesoproterozoic Roper Group. The Roper Group comprises several cycles of coarse clastic sandstones to fine carbonaceous mudstones or shales, and the bulk of the finer units are interpreted to have been deposited in an open marine shelf setting below storm wave base (Jackson and Raiswell, 1991). Although no base metal mineralisation is known from the Velkerri Formation, live oil has been reported (Jackson et al., 1986).

In the mid 1980s the BMR drilled several stratigraphic holes through parts of the Roper Group (Sweet and Jackson, 1986). Two of these (DDH BMR Urapunga 3 & 4), about 60 km apart in the Roper River area, intersected Velkerri Formation. Material from these holes has been investigated by several groups of researchers, who largely concentrated on the sedimentary facies and the C/S and S isotope systematics. No published whole rock geochemistry is available, however, Mark Norman (Macquarie University) provided a set of 37 major and trace element

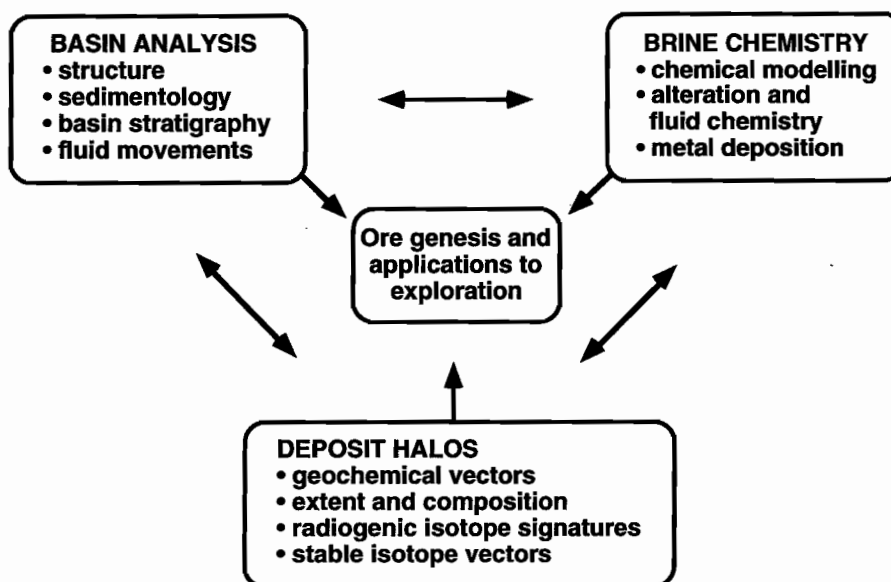
analyses from a 590 m intersection of U4. A further 18 samples from a 200 m intersection of U3 have recently been analysed for major elements and selected trace elements by XRF at the University of Tasmania.

Preliminary examination of these data sets confirms the low carbonate carbon content of the Velkerri Formation, with all samples containing less than 10% normative dolomite, and about half of these having less than a percent dolomite. Furthermore, the more carbonate-rich samples are generally from the upper (more silt, and less Corg-rich) part of the Formation. The AI and MnOd values for samples with more than a percent dolomite are generally not anomalous. The 'shale effect' is very apparent in the SedexAI data from both holes, but the SedexAI trends closely mimic the AI3 patterns. Anomalous AI and MnOd values are present in a few places in U4, and there is a distinct AI and TI 'spike' at about 45 m in U3. It is not possible to correlate anomalies between the two holes.

Further work will include measuring TI in the U4 samples and a more detailed investigation of trace elements in the low-carbonate samples. If access can be obtained to other drill core closer to U3 or 4, these will be sampled and analysed.



ARC/AMIRA Project P384A 1996 Program



Major objectives of P384A

The objectives for P384A as stated in the original proposal are as follows:

First Priority Objectives

- Continue research on the geological environment of stratiform Zn–Pb deposits, and further develop new applications to exploration.
- Continue collaboration with AGSO and NTGS on the McArthur Basin research — structural/sedimentological/geochemical/fluid migration.
- Conduct broad scale sedimentology, diagenesis, alteration, fluid flow studies in the McArthur Basin and Lawn Hill Platform and tie into proposed AGSO/NTGS sequence stratigraphic approach.
- Study secular variations in S, C, O isotopes through the stratigraphy in McArthur Basin

and Lawn Hill platform and relate these to the geochemical signatures of mineralised horizons.

- Extend brine chemistry modelling research to better understand processes of Zn, Pb and Cu sulfide deposition and the formation of alteration halos and index vectors.
- Distinguish exploration criteria for stratiform Zn–Pb deposits that are basin/time specific from those common to all major deposits.

Second Priority Objectives

- Expand the project to include a study of Cu mineralisation (characteristics and deposit models) within the McArthur Basin and Lawn Hill Platform.
- Expand halo studies to include other deposit types (e.g. Irish style, Mississippi Valley type, stratiform-Cu, Broken Hill type, Pb–Zn skarn) — pilot studies only.



[NB After discussion with sponsors it was decided that expanding the halo studies to other deposit types was not appropriate to the project extension.]

- Pilot study and review of mineralisation and source rock lead isotopes in McArthur Basin to assist in fluid migration studies and genetic modelling of halos and mineralisation (this work will be in collaboration with Dr Graham Carr, CSIRO).

1996 Program

Basin Analysis (BA) Module

Lawn Hill Platform region

BA1. Carbonaceous and pyritic facies in the McNamara Group — Stuart Bull (SB), Peter McGoldrick (PMcG)

- aims to examine selected core from recent Aberfoyle drilling to better understand the relationship of pyritic and carbonaceous mudstone packages to the platform carbonates
- methods will be core logging and, possibly, measuring outcrop sections
- outcome will be detailed sedimentary sections; link to DH4

BA2. Regional geophysical modelling — David Leaman

- aims to extend the potential field geophysical modelling further south to cover remaining Lawn Hill Platform
- methods used will match modelled gravity and magnetic profiles using existing AGSO small scale gravity and magnetics data sets
- outcomes will be reports, cross-sections and subsurface architecture models

Lady Loretta area

BA3. Surprise Creek Fm/Torpedo Creek Quartzite transition — Richard Keele (RK), SB

- aims to determine what pre-existing architecture controlled early McNamara Group sedimentation, and its subsequent influence on regional fluid flow directions (the "Lady Annie Culmination" — Keele, 1995)
- methods to be used include traverse mapping of structures and sedimentary facies in key areas
- outcomes will include maps and measured sections

BA4. Structure and mineralisation in the Lady Annie area — RK, PMcG, David Cooke (DC)

- aims to document textures, mineralogy and paragenesis of the Lady Annie/Flying Pig mineralisation and decipher how structures control higher grade areas of mineralisation
- methods include surface mapping and examination of old workings and core
- outcome will be a map and report; link to BA3

Kamarga Dome area

BA5. Kamarga Volcanics/Torpedo Creek Quartzite/Gunpowder Creek Formation transition — SB, PMcG, Honours student (Ben Jones)

- aims to determine the relationship between KV and TCQ on the southern flank of the Kamarga Dome, and to investigate cause of abrupt lateral thickness changes in the overlying GCF
- methods used will be air photo interpretation, traverse and boundary mapping, and where appropriate, volcanic facies analysis
- outcomes will be a geological map and Honours thesis

BA6. Gunpowder Creek Formation/Paradise Creek Formation sedimentology — SB, Honours student (Suzanne Cooper)

- aims to document lateral and vertical facies variations in GCF and PCF to the south and east of the Kamarga prospect
- methods used will be air photo interpretation, traverse mapping, measured surface sections, and core logging
- outcome will be detailed sedimentary sections, Honours report; link to DH2&4

Southern McArthur Basin

BA7. Diagenesis of the McArthur Group — Peter Winefield, SB, PMcG, Malcolm Wallace

- aims to document the detailed diagenetic history of the middle McArthur Group sediments and determine the nature of the fluids present at different times during basin evolution
- methods include sedimentary facies analysis, petrography (including cathode luminescence), isotopic and geochemical studies; 1996 field work in the Top Crossing and 'Gorge Prospect' areas, core logging in Darwin
- outcomes will be a PhD thesis and progress reports; links to DH2 and BC1

BA8. The interplay of sedimentology and structure during deposition of the Barney Creek Formation — Structural geologist, SB

- aims to determine how thickness changes in the Barney Creek Formation relate to syn-depositional faulting
- methods include field mapping of key areas (e.g. Top Crossing and 'Gorge Prospect')
- outcomes will be a report, maps and sections; links to BA7

Deposit Halos (DH) Module

Mineralisation Case Studies

DH1. Mt Novit Zn-Pb-Ag mineralisation — PMcG

- aims are to document vector parameters for stratiform sediment-hosted base metal deposits in the host rocks to the Mt Novit mineralisation; and to determine the effect of amphibolite grade metamorphism on these parameters
- methods include whole rock geochemistry, petrography, and electron probe microanalysis of carbonates
- outcomes will be a report; links to DH6

DH2. Carbonate geochemistry and isotope signatures in stratabound and stratiform sediment-hosted base metal mineralisation — PMcG, Ross Large (RRL)

- aims are to compile analytical data for carbonate minerals from Australian late Palaeoproterozoic Zn-Pb deposits and their environs and to measure the C and O isotopic signatures of representative carbonates and S isotopes in sulfides
- methods used will be conventional electron probe analysis for major and minor elements and state of the art laser probe microanalytical techniques for trace elements and isotopic measurements
- outcome will be a report; links to BA7

Regional Studies

DH3. Velkerri Formation geochemistry — PMcG, SB

- aims to document the geochemistry of a low carbonate, carbonaceous siltstone package
- methods will be whole rock major and trace element analyses
- outcome will be a report; links to DH6



DH4. Geochemical and isotopic chemostratigraphy of the McNamara and Fickling Groups — PMcG, SB, RRL

- aims to focus on pyritic and carbonaceous facies in the lower McNamara Group and Fickling Group and compare their chemistry to known mineralised packages and carbonate dominant packages
- methods include whole rock major and trace element analyses, laserprobe isotope measurements and using gamma logs and lithostratigraphy to correlate regionally between drill-holes; links to DH6
- outcome will be a report; links to DH6

DH6. A geochemical atlas of northern Australian Palaeoproterozoic sedimentary rocks — PMcG, RRL

- aims to produce pictorial summaries of case studies and regional geochemical data sets
- methods will be data massaging and graphic presentation using commercial computer programs
- outcome will be a series of standardised A3 sized pages

DH7. Fluid flow pathways and base metal source rock studies in the southern McArthur Basin — DL, DC, PMcG, RRL

- aims to determine (i) which rock(s) were the source for the base metals in the HYC deposit, and (ii) fluid flow pathways in the Tawallah and McArthur group related to HYC genesis and later tectonic events
- methods will include a pilot study using conventional and ICP-MS lead isotope measurements on a variety of rocks and ores
- outcome will be a report; links to BC2

Brine Chemistry (BC) module

BC1. Sandstone diagenesis — DC, SB

- aims to determine the character of transient fluids in major basal sandstone units in the northern Australian late Palaeoproterozoic (e.g. Torpedo Creek Quartzite, Masterton Sandstone)
- methods used will be a pilot study of fluid inclusions in authigenic cements and veins the Torpedo Creek Quartzite, and O isotope measurements of quartz
- outcome will be a report; links to DH6, BA7

BC2. Chemical modelling — DC

- aims to continue modelling mineralising fluid and mineral precipitation scenarios
- methods will be computer modelling using CHILLER and SOLVEQ
- outcomes will be metal solubility data relevant to constraints derived from BC1&3, DH7, and BA7.

BC3. Fluid inclusions in the Lady Loretta mineralisation — PMcG et al.

- aims to investigate fluid inclusions in a variety of mineralisation styles from the Lady Loretta Zn-Pb-Ag deposit to better constrain temperatures of mineralising fluids
- methods will be conventional heating and freezing stage measurements
- outcome will be data to constrain Lady Loretta genetic models