THE GEOLOGY AND ORIGIN OF MANGANESE DEPOSITS AT PERNATTY LAGOON, SOUTH AUSTRALIA.

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November, 1987

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Thesis submitted as partial fulfilment of the Honours Degree of Bachelor of Science.

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National Grid Reference: TORRENS Sheet SH 53-16. (1:250,000)

LIFE UNTESTED, IS MERELY LIVING!

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ABSTRACT

The origin of small manganese deposits along the margins of Pernatty Lagoon, a dry salt lake 425 km NNW of Adelaide in South Australia's Mid-north, has not previously been adequately explained. This region comprises part of the Stuart Shelf, where a condensed sequence of sediments was deposited between the stable Gawler Craton and the subsiding Adelaide Geosyncline, during late Proterozoic times.

After the formation of the Gawler Range Volcanics (and its equivalents) the clastic Pandurra Formation was deposited in a fluvial environment. Horst movements formed elevated structural highs, with the most prominent being the Pernatty Culmination. A further period of volcanism saw the Gairdner Dyke Swarm acting as feeder conduits to the basaltic subaerial Beda Volcanics. All the Stuart Shelf volcanic units are noted for their high concentration of manganese.

An extended period of exposure ensued, during which the sediments of the Stuart Shelf were open to weathering and erosion, with clastic sediments accumulating in the Adelaide Geosyncline. Manganese leached from the volcanics was transported in the aqueous system and precipitated in favourable non-marine environments upon the Stuart Shelf, hence further concentrating manganese. Some of the available manganese may have been disseminated within the clastic sediments of the Adelaide Geosyncline.

During Sturtian times the anoxic nature of the Tapley Hill Formation Sea resulted in the retention of introduced ionic manganese in the Adelaide Geosyncline, where there was the geochemical removal of iron by pyrite formation. Remobilization of manganese from both the Adelaide Geosyncline and accumulations on the Stuart Shelf was achieved by the transgression of the Tapley Hill Formation Sea upon the Stuart Shelf. Transported by estuarine currents, the manganese-rich waters were eventually forced to upwell against the Pernatty Culmination. Precipitation of manganese-oxides in shallow, tidal-lagoonal environments against the Pandurra Formation basement high, is associated with the stromatolitic Woocalla Dolomite, which was forming in the same environment. Manganese-rich waters influenced the carbonate sediments, resulting in the high manganese content of the Woocalla Dolomite. Particulate manganese-oxides are deposited within protected areas and on regression of the Tapley Hill Formation Sea, with later burial by regressive sands and further clastic units.

During the Tertiary, the removal of overburden opened the Woocalla Dolomite to further degradation and perhaps the formation of supergene manganese deposits. However there has been destruction and contamination of existing ore and the formation of secondary iron-rich units, due to the remobilization of iron.

Palaeogeographic analysis reveals further areas of possible manganese deposition at the maximum extent of the Tapley Hill Formation Sea. A large intracratonic basin formed on the Stuart Shelf, which could contain further manganese accumulations associated with the Tapley Hill Formation transgression.

1. INTRODUCTION

1.1 Aims and Objectives

The formation of sedimentary manganese deposits in shallow-marine environments can be applied to a number of manganese deposits including the giant Groote Eylandt,(Australia) and Chiatura and Nikopol,(USSR) deposits. The manganese is generally derived through the weathering of rocks with the retention of manganese in aqueous environments. Concentration can occur with later remobilization resulting in the formation of deposits in zones around intracratonic basin margins.

Apart from the giant Groote Eylandt deposit, Australia is not blessed with substantial deposits of manganese. Minor accumulations can be found in New South Wales and Queensland (Segnit,1984), with slightly larger deposits in Western Australia (De La Hunty,1970). In South Australia, only small manganese deposits are found, including the deposits in the Pernatty Lagoon region, which will form the basis for this present study.

It is the main aim of this thesis to interpret the significance of these minor accumulations of manganese with respect to the Woocalla Dolomite Member of the Tapley Hill Formation to which the manganese is related. This involves several specific objectives, including extensive study and mapping of the Woocalla Dolomite and the other units around Pernatty Lagoon and at Woocalla, with the detailed physical, petrographic, mineralogical and geochemical analysis of the manganese deposits.

Discussion regarding the origin of the deposits can then be attempted with a model for manganese accumulation proposed. The

model can then be applied using palaeogeographic interpretations to suggest regions where future economically viable manganese deposits may be located.

1.2 Geographical Location and Setting

Pernatty Lagoon is a dry saline lake in South Australia's Mid-north, 425 km NNW of Adelaide and 50 km W of Lake Torrens, with co-ordinates of Latitude 31° 30' South and Longitude 137° 15' East. The area contains flat-lying Late-Proterozoic sediments which are partly covered by sand dunes, and, in the lagoon, by a veneer of mud. The areas under consideration are dominated by a pebble-strewn surface with only sparse vegetation and are revealed in the geological field maps, which form Appendix A.

1.3 Previous Geological Investigations

The manganese deposits have previously been studied by a number of investigators. Dickinson (1953), during a review of the deposits, noted how common manganese is in the Woocalla Dolomite. The report concludes by suggesting that due to the occurrence of manganese in broken zones within the Woocalla Dolomite, the origin for the deposits is due to manganese-rich hydrothermal solutions replacing the limestone.

Johns (1968), details much of the physiography, geology and occurrences of mineralization in the Pernatty Lagoon area, and concludes that the origin of the manganese deposits is due to decomposition of dolomite. A further review by Johns (1974) indicates that the initial concentration of the manganese was in restricted lagoonal environments associated with the Woocalla Dolomite upon basement highs.

Knutson et al (1983) studied the copper occurrences in the region but continue by indicating that the manganese, copper and barite deposits in the area form due to the concentration of metallic ionic species in a reducing aquatic environment.

A number of workers have made contributions on the various aspects of the geology and mineral occurrences on a regional scale, including the major summaries by Dickinson (1953) and Johns (1968). References to these are acknowledged in the following chapters.

2. GEOLOGICAL SETTING

2.1 Regional Geological History

The Adelaide Supergroup has been subdivided into four major lithostratigraphic units representing four cycles of shallow water sedimentation: the Callanna, Burra, Umberatana and Wilpena Groups (Forbes et al,1981). These Adelaidean sediments overlie Mid-Proterozoic crystalline basement which provided the foundation for the sedimentary sequence. The general tectonic framework is revealed in Figure 1 with the Gawler Craton, which became stabilized as part of the Australian Precambrian Shield in late Carpentarian times (Thomson, 1975), being downwarped and block faulted along its eastern margin.

To the east of the Torrens Hinge Zone, lies the great geosynclinal trough known as the Adelaide Geosyncline. It is within this basin that numerous transgressions and regressions produced the thick sedimentary Adelaidean succession. However on the adjacent downwarped basement, deposition occurred only during times of maximum transgression, resulting in a condensed sequence frequently punctuated by disconformities (Plummer, 1983). These are the sediments which form the Stuart Shelf. Periods of exposure would result in the weathering and erosion of established sediments with the deposition of clastics within the Adelaide Geosyncline. Therefore sediment cover gradually thickens across the Gawler Craton to form the Stuart Shelf, then rapidly thickens east of the Torrens Hinge Zone after passing into the Adelaide Geosyncline.

Figure 2 gives the stratigraphic relationships between the Adelaide Geosyncline and the Stuart Shelf with comprehensive summaries of Adelaidean sedimentation given by Parkin (1969); Preiss and Forbes (1981); Rutland et al (1981).

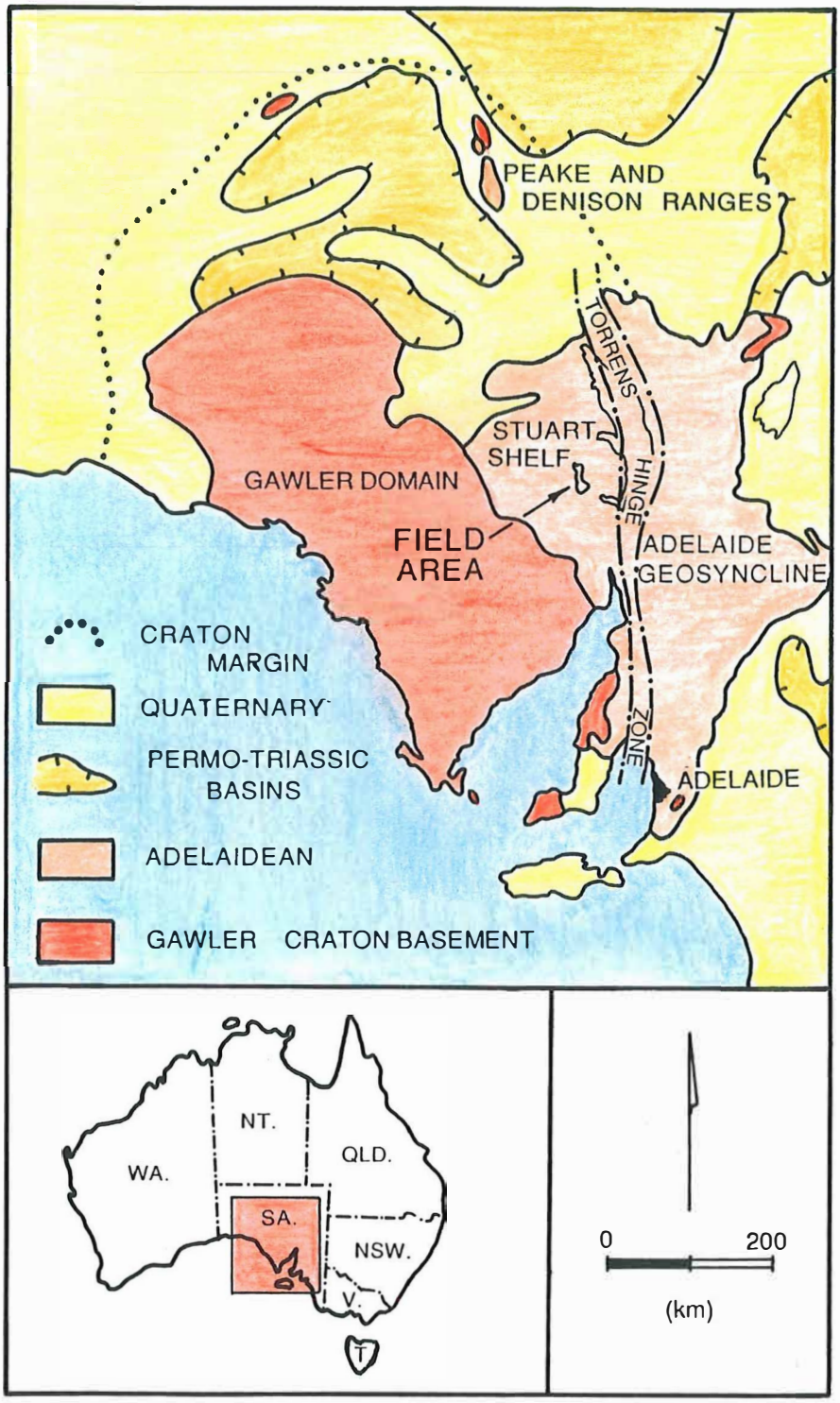


FIGURE 1: Locality Map

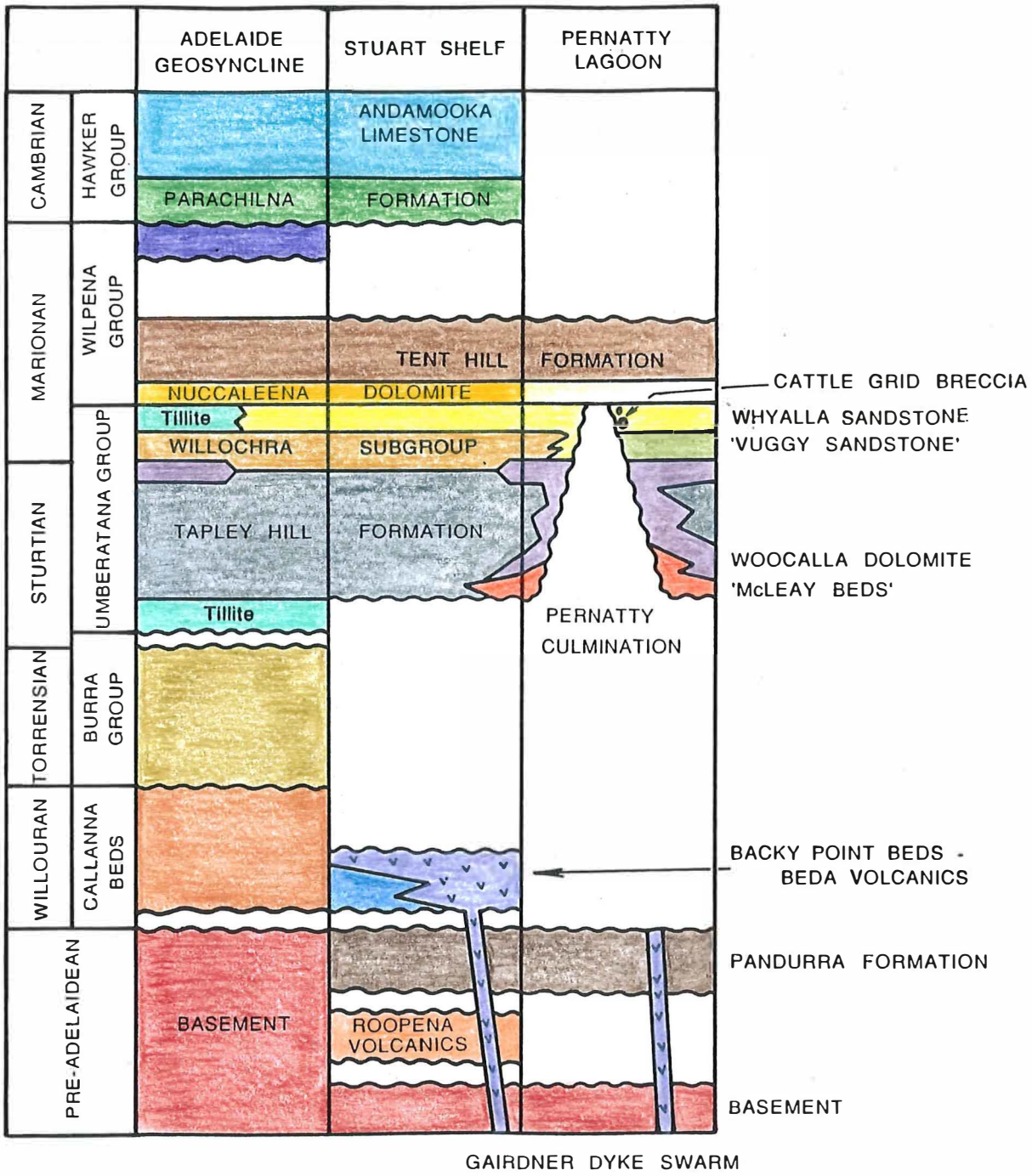


FIGURE 2: Stratigraphic Tables of the Adelaide Geosyncline Stuart Shelf and the Pernatty Lagoon Region. (Adapted from Knutson et al,(1983)).

Stuart Shelf history began in pre-Adelaidean times with the oldest cover rocks being extensive subaerial, andesitic flood basalts known as the Roopena Volcanics. Compston et al (1966) give the age of formation as 1320±25 Ma, with this unit related to other volcanics on the Gawler Craton, including the Gawler Range Volcanics. These volcanics are related to a period of mantle diapirism and crustal melting (Giles and Teale, 1979).

The oldest clastic unit found on the Stuart Shelf is the widespread red, cross-bedded sandstones of the Pandurra Formation. This unit rests unconformably on the Roopena Volcanics (Rutland et al,1981) and often contains pebbles of Roopena Volcanics at its base (Parkin, 1969). Isotopic work gives a well-fitting Rb-Sr age of 1425±51 Ma, which brings into question the validity of the 1320±25 Ma age for the Roopena Volcanics (Webb et al,1983).

Initial Adelaidean sedimentation is represented on the Stuart Shelf by a sandstone and conglomeratic unit known as the Backy Point Beds. This unit forms wedges against downfaulted basement blocks and often contains Pandurra Formation pebbles, suggesting that some reworking has occurred (Mason et al,1978). The Backy Point Beds intertongue with altered subaerial basalts known as the Beda Volcanics.

The Gairdner Dyke Swarm is a NW-SE trending group of basaltic dykes which cut the Gawler Craton and Stuart Shelf area (Figure 3) and extends for approximately 1000 kilometres from the southern Gawler Craton to the Musgrave Block (Parker et al, in press). These dykes are petrographically and chemically similar to the Beda Volcanics (Knutson et al,1983) and have been radiometrically dated at 1050 Ma (Blisset,1985), which correlates well with the radiometrically dated age of 1075 Ma (Webb and

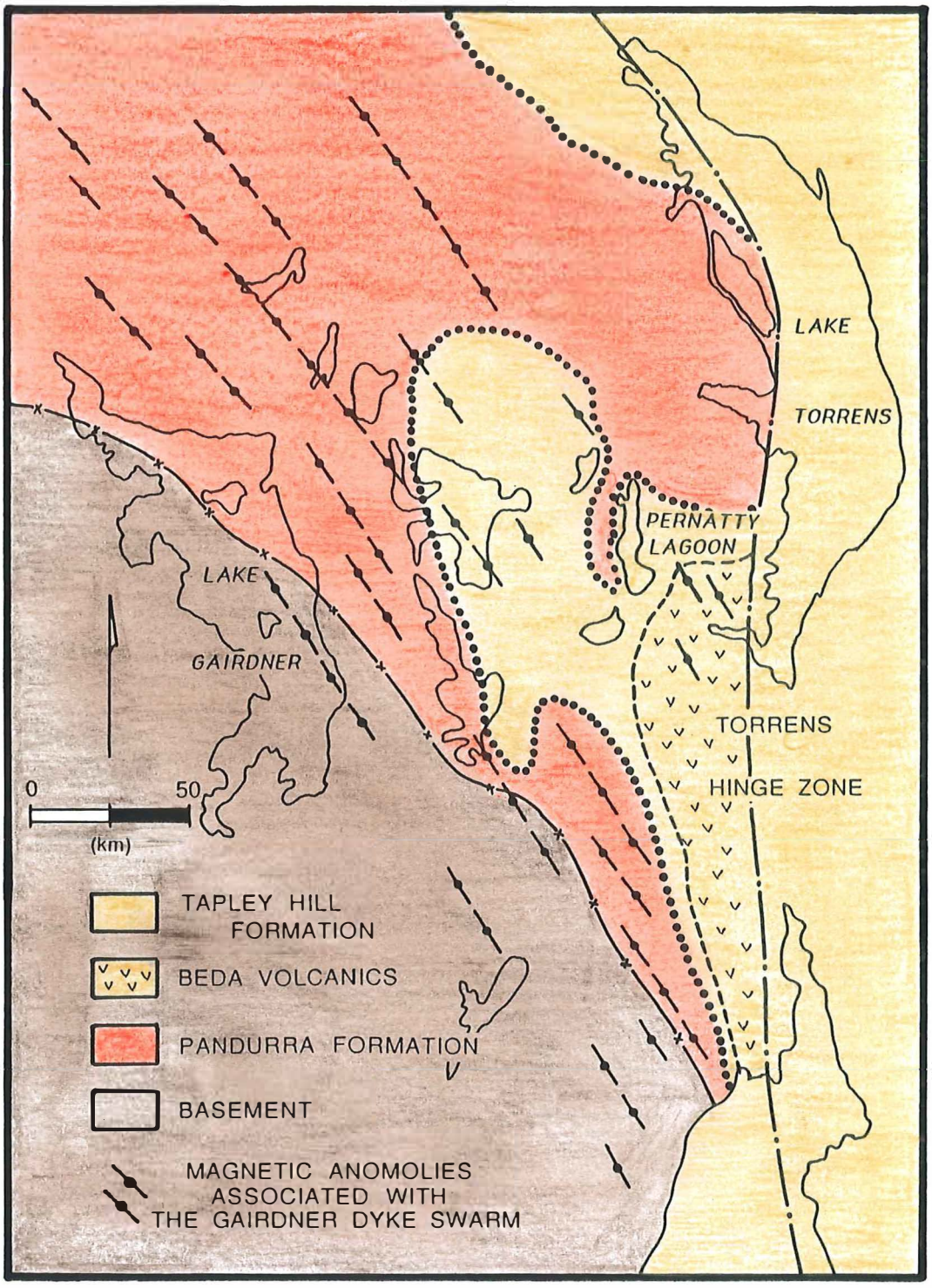


FIGURE 3: Extent of Tapley Hill Formation Sea and other Stuart Shelf Units. (Adapted from Preiss,W.,(1983)).

Coats,1980) for the Beda Volcanic basalt flows. Hence the Gairdner Dyke Swarm most likely represents plugs or feeder dykes from which the basalts of the Beda Volcanics were erupted over established sediments (Mason et al,1978). The extensive nature of the Gairdner Dyke Swarm throughout the area suggests that the Beda Volcanics were also quite extensive when initially formed.

The Stuart Shelf then underwent an extended period of exposure and erosion, implied from the small present-day extent of the Beda Volcanics in the SE of the Stuart Shelf (Figure 3) and the absence of Burra and Early Umberatana Group sediments which were forming in the Adelaide Geosyncline. This hiatus represents 300 Ma.

Sedimentation finally recommenced on the Stuart Shelf, with the finely laminated black and grey shales and buff, thinly laminated dolomites (Johns, 1968) of the Tapley Hill Formation unconformably overlying the Beda Volcanics and the Pandurra Formation. These sediments were deposited on the Stuart Shelf as a widespread marine transgression invaded the area. This unit is indicative of a time of submergence, with shallow lagoonal environments forming adjacent to ancient shorelines, while in other areas representing deep basinal environments. The extent of the Tapley Hill transgression is revealed in Figure 3.

The Tapley Hill Formation sediments are studied due to mineral concentrations (particularly manganese), associated with shallow marine dolomites forming around black shale basins. The Woocalla Dolomite which formed in a shallow marine environment in the Pernatty Lagoon region and its related manganese deposits, form the basis for the present study.

Overlying the Tapley Hill Formation, are the clastic sediments of the Willochra Subgroup, which is represented on the

Stuart Shelf by the Yudnapinna Beds and the Whyalla Sandstone. These units are found to drape over older rocks, filling in irregularities and forming above an extensive disconformity (Thomson and Johnson, 1968).

The Yudnapinna Beds consist of red and green dolomitic siltstones found in the SW of the Stuart Shelf (Gersteling and Heape, 1975), and undergo a gradual transition towards the north into a white, well rounded, coarse-grained sandstone known as the Whyalla Sandstone. This sandstone displays very large scale cross-bedding (Tonkin and Williams,1983) and is characterized by its markedly spherical quartz grains (Johns,1974). Gersteling and Heape (1975), suggest these factors indicate an aeolian origin. The recognition of fossil periglacial forms within the Whyalla Sandstone, (Tonkin and Williams,1983; Williams and Tonkin,1985) was critical to the interpretation of a palaeopermafrost environment and the correlation to Marinoan glacial sequences.

The following Marinoan, Tent Hill Formation records at least two postglacial transgressive and regressive cycles (Rutland et al,1981), with an extensive blanket of shallow water and continental sediment extended from the Adelaide Geosyncline, over the Stuart Shelf and onto the Gawler Craton.

The Tregolana Shale Member represents the earliest expression of this transgression (Plummer, 1983) and is characterized by laminated purple and green shales, interbedded with thin red siltstones and sandstones (Thomson, 1966). The Corraberra Sandstone Member is a red-brown sandstone grading downwards into red shales and siltstones (Johns, 1968). This fact indicates that the lower boundary is transitional with the underlying Tregolana Shale (Thomson, 1966). The Simmons Quartzite

Member consists of a massive white quartzite cap representing a further transgression from an intertidal to a shallow submerged environment (Plummer, 1983).

Final Adelaidean sedimentation on the Stuart Shelf is represented by the red and purple shales of the Yarloo Shale. Any further sediments are unknown on the Stuart Shelf, due to an extensive regression of the sea from the Stuart Shelf and substantial erosion of existing sediments. A marine transgression during the early Cambrian finally reinitiated sedimentation in both the Adelaide Geosyncline and the Stuart Shelf.

The Cambrian sea transgressed across the Stuart Shelf, while the floor of the Adelaide Geosyncline gradually, but persistently subsided (Parkin, 1969). Sediments deposited during this transgressive phase are collectively known as the Hawker Group.

Hawker Group sediments are represented on the Stuart Shelf by the shallow-water, cross-bedded Parachilna Formation sandstones. The overlying Andamooka Limestone includes reef type limestones containing abundant Archaeocyatha and phosphatic brachiopods (Parkin, 1969). These were the last Cambrian sediments laid down on the Stuart Shelf.

The Cambrian-Ordovician Delamerian Orogeny effected profound structural changes in the sediments of the Adelaide Geosyncline, while to the west, the Stuart Shelf sediments have only been gently folded. These orogenic movements effectively stopped major sedimentation on the Stuart Shelf.

2.2 Geology of the Pernatty Lagoon Region

2.2.1 Introduction

The local geology, was studied as part of an extensive field mapping exercise in which a number of Proterozoic units were delineated. Recent sediments form unconsolidated deposits on alluvial plains, in low saline lakes and in extensive sub-parallel, longitudinal sand dunes. All rock types which crop out are represented on the accompanying maps (Appendix A), and their lithology is described in detailed rock and thin section descriptions (Appendix B).

2.2.2 Pandurra Formation

The Pandurra Formation is the oldest rock unit exposed in the field area, and is a moderately well-sorted, clastic sequence consisting mainly of red sandstones with minor white, micaceous siltstone lenses. This unit crops out throughout the field area, forming the hills and cliff-face (Plate 1a), along the western margin of the lagoon.

A highly ferruginous palaeoweathering profile at the top of the Pandurra Formation (Plate 1b) is found at several different locations throughout the area. The upper surface, dominated by a subrounded pebble conglomerate and quartz grains set in a gritty ferruginous cement (Plate 1c), grades downwards into generally unaffected, Pandurra Formation sandstones.

The Pandurra Formation is a massive, thickly-bedded medium to coarse-grained, moderately well-sorted sandstone which contains tabular and trough cross-bedding. The azimuth of the dip, which can be presumed to be the downcurrent direction of sandstone deposition (Pettijohn et al, 1973), was consistent

throughout the area with most readings being around 174 W suggesting a north to south transport for the clastics.

Petrological examination has revealed that medium to coarse-grained, rounded quartz grains form 85% of the slide with some grains consisting of highly weathered volcanic fragments. There has been intense secondary silicification with the development of prominent quartz overgrowths and a polycrystalline silicic matrix. There has also been extensive suturing of quartz grains.

The Pandurra Formation has been interpreted to have formed in a fluviatile environment (Mason et al,1978) and is a continental sediment derived from the weathering of the volcanic rocks forming the nearby Gawler Craton.

2.2.3 McLeay Beds

Several occurrences of this unit were noted during the field work, where they were defined principally from stratigraphic interpretations, as this unit is generally observed unconformably overlying the Pandurra Formation and underlying the Woocalla Dolomite. The McLeay Beds form as a thin, ((1m to 3m) discontinuous veneer of unconsolidated sediment, deposited on the Pandurra Formation palaeosurface (Gersteling and Heape, 1975).

The McLeay Beds are found as shales, sandstones, conglomerates and carbonate facies, (Plate 1d-f). The varied nature of the unit and the presence of overlying Woocalla Dolomite, suggests that the McLeay Beds represent the initial transgressive sequence of the Tapley Hill Formation Sea, as waters invaded the Stuart Shelf and onlapped upon established sediments. The gradual increase in water depth eventually resulted in the formation of the intertidal carbonate platform represented by the Woocalla Dolomite.

2.2.4 Woocalla Dolomite

The Tapley Hill Formation on the Stuart Shelf is represented by black and grey shales and buff, thinly laminated dolomites (Johns,1968). Such occurrences are found at Woocalla, where grey, fine grained siltstones are interbedded with thin dolomite layers. However the predominant lithology of the area representing the Tapley Hill Formation is the Woocalla Dolomite. It is this unit that has the association with the manganese deposits. The Woocalla Dolomite is exposed along the western margin of Pernatty Lagoon and at Woocalla (Plate 1f), where it overlies the McLeay Beds. (Further outcrop is believed to be found near South Oakden Hill, 15 km west of Pernatty Lagoon (Johns,1968). However no outcrop was discovered in that area during this study).

The shallow water calcareous facies observed forming the Woocalla Dolomite are quite variable, indicating a number of differing environments. The Woocalla Dolomite occurs principally as stromatolite reefs (Johns,1968); however, other calcareous facies can be differentiated.

A majority of stromatolite occurrences in the Pernatty Lagoon region can be described according to Logan et al's (1964) classification, as close-laterally linked hemispheroids, designated as LLH-C. LLH-C stromatolites (Plate 1g) occur on a number of scales within the field area, ranging from small, with amplitudes and diameters of only a few centimetres, to large, with domes several metres long. Many larger domes contain microstructures of smaller LLH-C domes.

Other LLH-C stromatolites have, as a microstructure, vertically stacked hemispheroids or Type-SH stromatolite forms (after Logan et al,1964). This type consists of discrete,

columnar structures which are not laterally linked (Plate 1h), but have a surrounding fine-grained carbonate matrix.

Stromatolites are organosedimentary structures produced by the sediment trapping, binding and/or precipitation activities of microorganisms, as a result of the growth and metabolic activity of those microorganisms (Awramik and Margulis, as cited by Walter,1976, p.1). The different stromatolite forms are produced by the dynamic interaction of microbes, detrital sediment and are affected by prevailing physical environmental factors (Logan et al,1964), such as the depth, salinity and clarity of the water, the light and the temperature (Johnson,1961). Hence stromatolite morphology is excellent for palaeoenvironmental interpretations.

Once classified, the interpretation of stromatolite morphology is useful, as environments can now be tentatively assigned. Type-LLH stromatolites characteristically develop in continuous algal-bound mat sediments from the marine-intertidal mudflat environment (Logan et al,1964), although similar stromatolite forms have been described in subtidal environments (Gebelein,1969). This environment is often characterized by protected locations in bays and behind barrier islands, where wave action is usually slight (Logan et al,1964). This is the suggested environment for the formation of a majority of the Woocalla Dolomite. Hence morphological descriptions of stromatolite facies can be useful for palaeoenvironmental interpretations.

Further morphological observations can be used for palaeocurrent analysis. The elliptical nature of many of the hemispheroidal stromatolites was recorded, as the preferred elongation can be directly related to the direction of major sediment transportation during stromatolite formation

PLATE 1a: Outcropping massively bedded Pandurra Formation sandstones and minor siltstone lenses, forming a cliff-face along the south-western margin of Pernatty Lagoon.

PLATE 1b: Ferricrete cap forming along a palaeoweathering profile, which grades down into unaltered Pandurra Formation sandstones.

PLATE 1c: Part of the ferricrete cap revealing brecciated cross-bedded Pandurra Formation sandstones surrounded by a gritty iron-enriched matrix. Considered to be an insitu breccia due to the continuation of bedding and cross-bedding across clast boundaries.

PLATE 1d: McLeay Beds at Pernatty Lagoon, with lower red sandstone and upper brown carbonate-rich sandstone. Both contain dolomite fragments with this sequence representing a high energy beach environment with a progressive deepening of water.

PLATE 1e: Photomicrograph of the McLeay Beds. Subrounded quartz grains surrounded by dolomite and a large dolomite fragment. Note absence of any internal laminations in the clast.(*25)

PLATE 1f: McLeay Beds at Woocalla. Pandurra Formation sandstones are overlain by unconsolidated sands and conglomerates, finally becoming inundated with water and the formation of large subtidal stromatolite domes of the Woocalla Dolomite.

PLATE 1g: Laterally-linked hemisperoid stromatolites forming the Woocalla Dolomite. Note dark colour indicating a high manganese content.

PLATE 1h: Branching vertically stacked hemisperoids found at Pernatty Lagoon.

PLATE 1

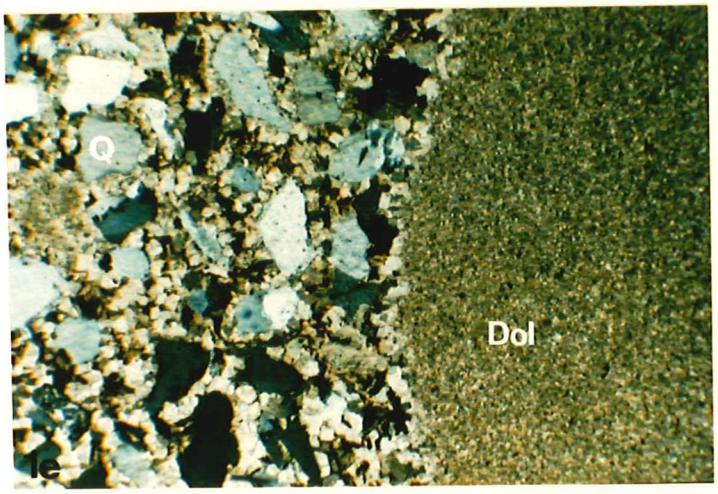

1a


1b



1c

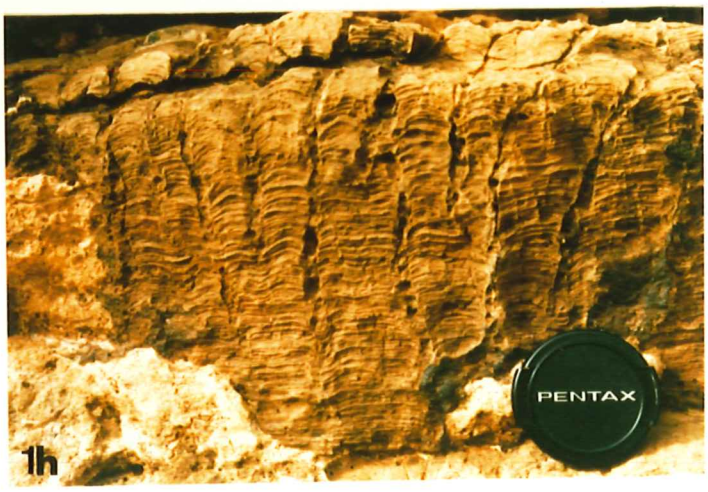

1d



1e


1f


1g



1h

(Hoffman,1976). The discovery of asymmetric hemisperoidal stromatolites gives an indication of both current trend and sense. Figure 4 indicates palaeocurrent trends and sense as established from field analysis. In the Pernatty Lagoon area, sediment movement on the flood tide was greater than on the ebb tide. Movement of the tides was perpendicular to the coastline, however behind a barrier island, movement of water and sediment was parallel to the coast.

At Woocalla the dolomitic facies consist of large LHH-C type stromatolite domes (Plate 2a), and their elliptical nature reveals an E-W trend. Figure 4 reveals that the dolomite has this form because tidal waters passed through a narrow submerged valley in the ancient Pandurra Formation palaeosurface.

These LLH-C domes are overlain by flat-lying thinly bedded dolomite layers which do not reveal any internal laminations. In many cases the contact with the underlying dolomite is irregular as the overlying dolomite forms a blanket over the existing domes (Plate 2b). This layer also has associated teepee structures which suggest that peritidal conditions prevailed. Hence the domes represent a subtidal environment which grades upwards into an intertidal-supratidal environment.

Along the margin of Pernatty Lagoon, other dolomite morphologies are found, including large, trough cross-bedded oolitic shoals which overlie the original stromatolitic carbonate platform. This facies is often associated with shoals of brecciated tabular dolomite (Plate 2c).

Ooids characteristically form in moderately low energy, shallow-marine environments, found on the outer margins of carbonate platforms. Sellwood(1978) observed that storm processes redistribute the ooid shoals across the carbonate platform; this

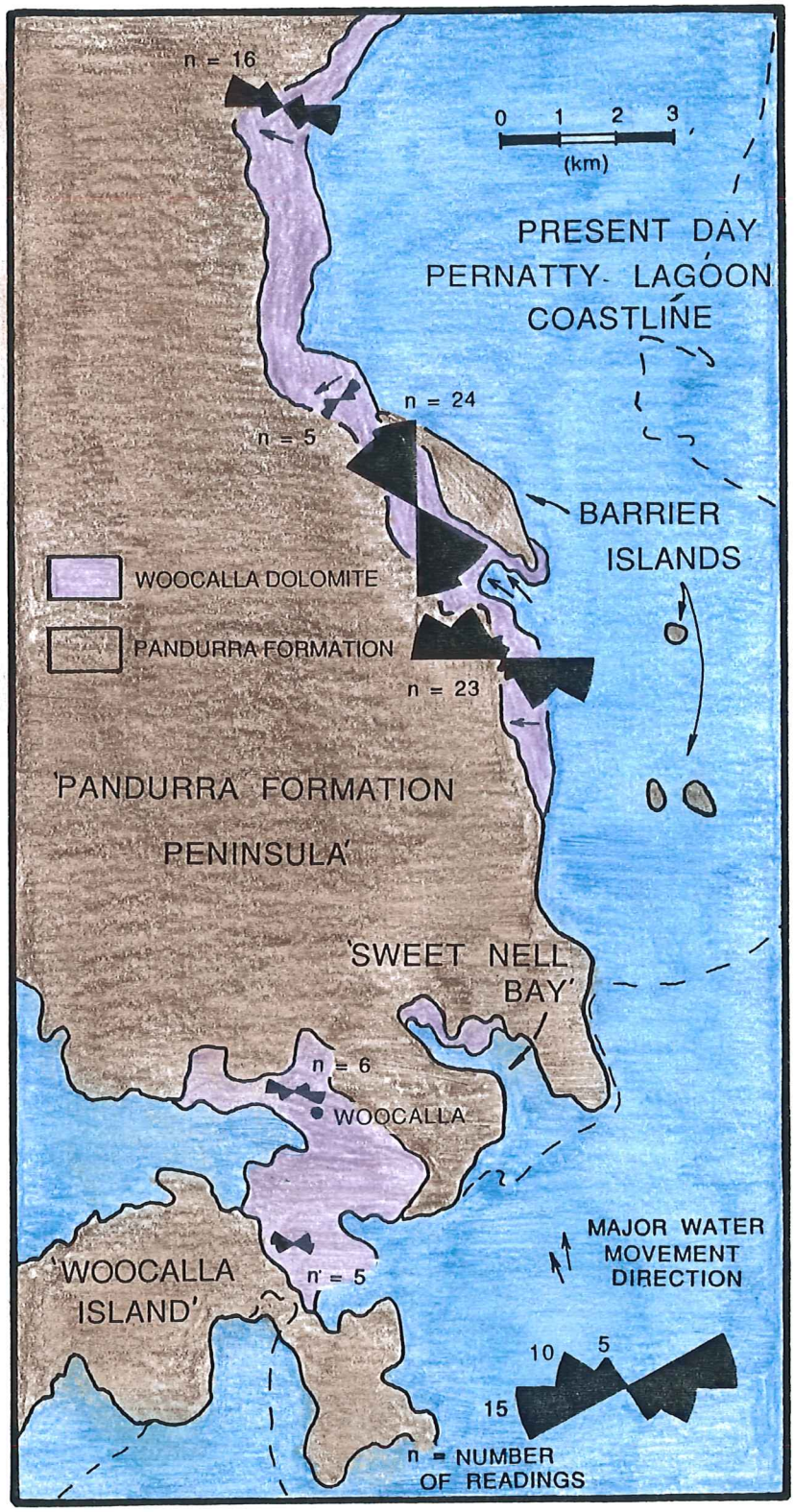


FIGURE 4 : Stromatolite Preferred Orientations Indicating Direction of Water Movement

appears justified from facies associations found within the field area. Often the ooid shoals appear to fill crevasses between, and accumulate against the boundaries of established stromatolitic reef facies. Ooids therefore appear to have been trapped within protected areas. The effect of storm processes is also seen in the presence of shoals of brecciated dolomite. They form due to the rip-up of algal mats and later deposition of the fragments in association with the ooids.

The oolitic and breccia shoals and stromatolitic carbonate platform found in the Pernatty Lagoon region represent the maximum extent of the Tapley Hill Formation transgression. The regression of the Tapley Hill Formation Sea prevented further carbonate formation in the area.

2.2.5 "Vuggy Sandstone"

This next unit is rather ambiguous, but a number of outcrops consisting of white clastic sandstones which contain angular, tabular voids were found at several different stratigraphic levels, including unconformably overlying Pandurra Formation sandstones and conformably overlying brecciated Woocalla Dolomite (Plate 2d). A similar white sandstone is found capping manganese ore at lagoon level in the Main Workings.

Petrographic studies indicate a moderately well-rounded, coarse grained, quartzose sandstone, which has undergone some secondary silicification with the formation of quartz overgrowths.

Petrologically similar to the transgressive McLeay Beds, both units probably formed in a beach environment. The McLeay Beds represent the initial Tapley Hill Formation Sea transgression, but the "Vuggy Sandstone Unit" formed later as

regressive sands extended across the area. The dissolution of ripped up calcareous algal mats, which became incorporated within the sandstone, would result in the angular voids presently observed.

2.2.6 Cattle Grid Breccia

The Cattle Grid Breccia is found to mantle fractured Pandurra Formation bedrock and is overlain by the Whyalla Sandstone. Sandstone wedges, similar to those described at Mt.Gunson, by Busbridge (1981), Tonkin and Williams (1983) and Williams and Tonkin (1985), are observed to penetrate and disrupt the Cattle Grid Breccia. This action has resulted in the lateral compaction of the breccia and formation of teepee structures, (Plate 2e).

Williams and Tonkin (1985) subdivide this breccia into two units with the uppermost unit consisting of irregular, angular to subrounded fragments of sandstone. This grades downwards into an in situ tabular breccia which overlies the Pandurra Formation.

The origin of the Cattle Grid Breccia is believed to be through brecciation of an exposed Pandurra Formation palaeosurface, by frost shattering, during the initial stages of Marinoan glaciation (Knutson et al,1983). Evidence includes the manner in which the breccia mantles the palaeosurface, with partly redeposited breccia passing down into in situ breccia, and then into fractured bedrock (Williams and Tonkin, 1985).

2.2.7 Whyalla Sandstone

The Whyalla Sandstone unconformably overlies the Cattle Grid Breccia within the field area and is a white, friable sandstone with minor low angle cross-bedding and ripplemarks. A silcrete

PLATE 2a: Large laterally-linked hemisperoidal stromatolities found at Woocalla, and believed to have formed in a subtidal environment.

PLATE 2b: Large domes are overlain by a blanket of thinly bedded, flat-lying dolomite. This sequence represents a shallowing in water depth.

PLATE 2c: A trough cross-bedded ooid shoal with angular dolomite fragments representing the rip-up of established algal mats.

PLATE 2d: Tabular dolomite fragments with a sandy matrix is overlain by a sandstone with angular voids representing the removal of carbonate fragments by dissolution. This sequence represents the regression of a sea with outwash sands becoming incorporated with angular carbonate fragments.

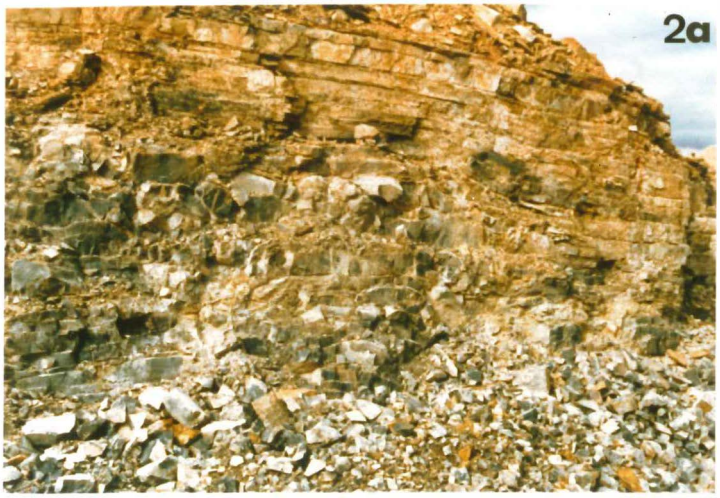
PLATE 2e: Teepee structure forming in the insitu Cattle Grid Breccia formed by a nearby disruptive periglacial sand wedge.

PLATE 2f: Flat-lying white Whyalla Sandstone including a silicified palaeoweathe ing profile.

PLATE 2g: Open periglacial sand wedge consisting of alternate coarse and fine grained laminae.

PLATE 2h: Sand involution containing subrounded Pandurra Formation clasts in a preferred orientation reflecting wedge movement.

PLATE 2


2a


2b



2c

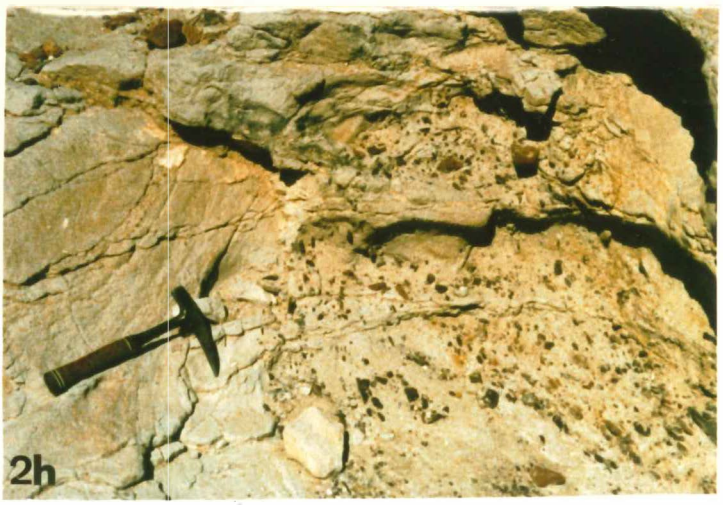


2d


2e


2f


2g


2h

cap at the top of this unit (Plate 2f) most likely represents a palaeoweathering profile.

Sandstone wedges were found which do not penetrate the Cattle Grid Breccia, but form open, shallow wedges which cut into an underlying basal sandstone (Plate 2g). These wedges have an internal fabric, composed of alternating fine and coarse grained laminae between 1mm and 2mm thick, with a white clay matrix.

The sandstone wedges also have associated tongues of sandstone which contain small, well rounded Pandurra Formation clasts (Plate 2h), which have a preferred orientation. This feature is interpreted as being a water escape structure with sandstone containing Pandurra Formation clasts, injecting upwards into established overlying sediments.

Petrographic studies indicate that quartz grains comprise 85% of the Whyalla Sandstone with the remaining 15% consisting of a fine-grained clay matrix. The quartz grains are well rounded and have a bimodal grain size distribution. That is, 80% of the quartz grains occur in a size range between 0.5mm and 2mm with the remaining 20% being of a much smaller size, around 0.1mm.

The flat-lying Whyalla Sandstone most likely formed in a low energy lacustrine environment. However it has been influenced by glacial conditions, as the sand wedges are known to form due to the repeated infilling of frost-contraction cracks, by sands (Williams and Tonkin, 1985).

2.2.8 Conclusion

The formation of each of these units was largely dependent upon the environment existing during unit formation. Study of each unit has indicated important palaeoenvironmental conditions which can be critical to interpretation. A majority of the units,

especially the manganese-related Woocalla Dolomite, are exposed within the Pernatty Lagoon region due to the Pandurra Formation basement high, known as the Pernatty Culmination (Johns,1974). This suggests that the tectonic framework of the region must have been important in the formation of each unit in the area.

3. MINERALIZATION

3.1 Introduction

The mineral occurrences in the Pernatty Lagoon region are summarized by Johns (1968), with recent investigations of copper mineralization at the Sweet Nell and Fair Nell Mines by Creelman (1976), and at Mt.Gunson, by Gersteling and Heape (1975) and Knutson et al (1983).

The barite at Pernatty Lagoon is closely associated with the Main Workings (Map C, Appendix A), where it occurs today as veins or as massive coarsely crystalline aggregates (Plate 3a). Fluid inclusions in the barite reveal similar melt temperatures, in a -17.6° C to -26.0° C range (average -19.7° C), indicating salinities of approximately 20 equivalent weight percent NaCl. However a variety of homogenization temperatures, ranging from 130° C to 360° C, indicate that a number of events have probably affected the barite since it was originally concentrated.

It is likely that the origin of the sulphur is from a marine (seawater) source, due to the positive sulphur isotope ratio, given as +23.5. Claypool et al (1980) illustrate the relationship between sulphur isotope composition of seawater sulphates and age (Figure 5), with the ratio corresponding to Late Precambrian times, around 640 Ma.

The main exercise of this study is to analyse the manganese deposits present in the study area; this objective has never previously been the basis for a major investigation.

3.2 Manganese Occurrence

Concentrations of manganese within the Pernatty Lagoon region are associated with the Woocalla Dolomite Member of the Tapley Hill Formation. The manganese is discernible from mere

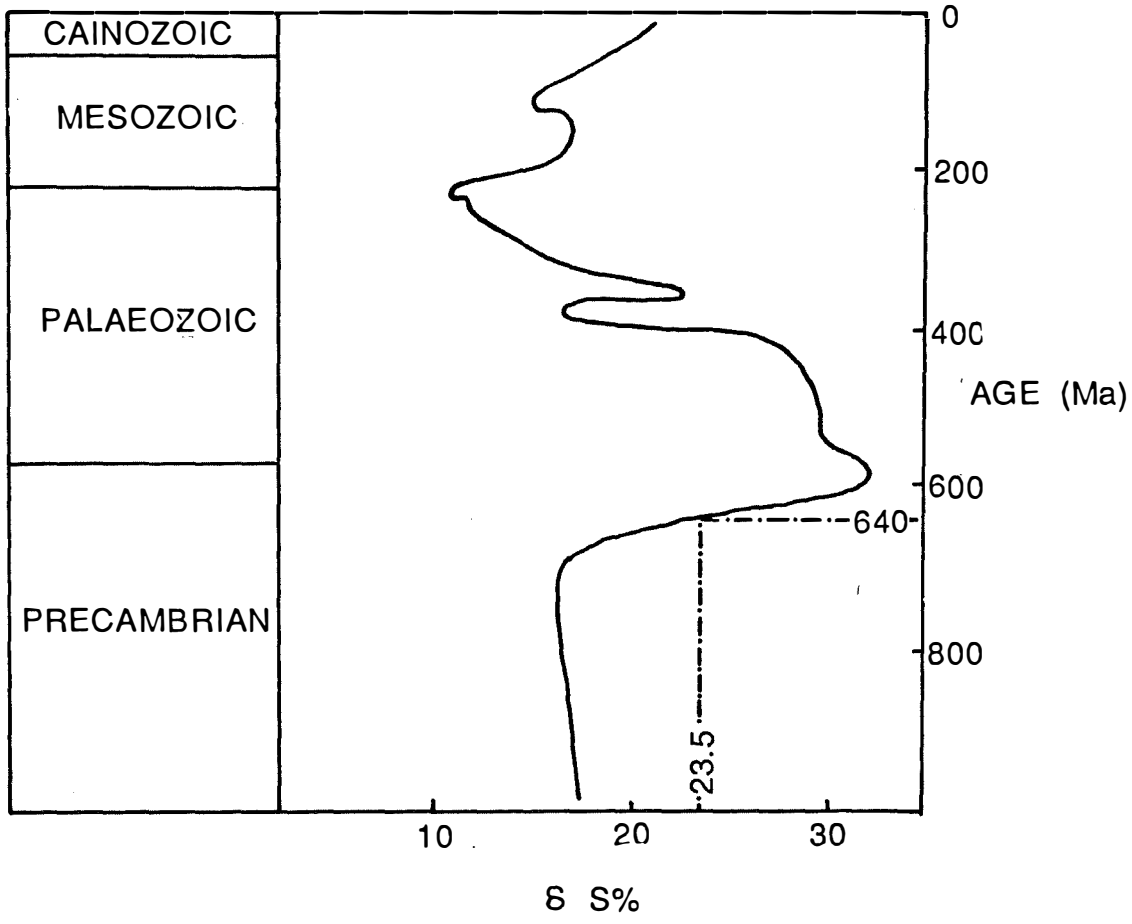


FIGURE 5: Summary Sulphur Isotope Age Curve For Sulphate (Modified from Claypool et al,(1978)).

specks and dendritic markings, up to appreciable concentrations. The three manganese accumulations, identified along the margins of Pernatty Lagoon, are designated the "Main Workings", the "Big Cut" and the "Northern Workings", with all three deposits being exploited during previous mining operations in the area.

The common association of the Woocalla Dolomite to the manganese accumulations is suggested as all three deposits occur at the boundary between outcropping Woocalla Dolomite and earlier clastic sediments. Plans and cross-sections produced from the interpretation of the deposits (Figures 6a-c) reveal this characteristic feature.

3.3 Lithological Descriptions of Manganese Deposits

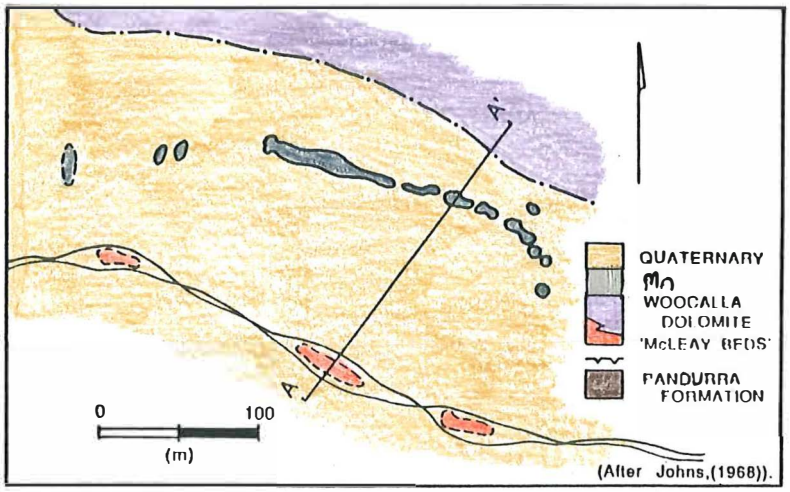
Study of the manganese accumulations within the region has revealed a number of discrete units which can be analysed and interpreted to conclude possible origins. The Main Workings contain a majority of these units, with lateral distributions highlighted on Map C (Appendix A).

3.3.1 Laminated Manganese Unit

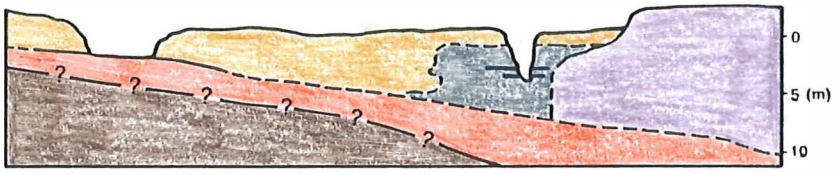
Forming in the Main Workings and Big Cut deposits in areas above the present-day water table, a friable, fine-grained, grey to black, manganese-rich laminated unit, containing ripple marks and low-angle crossbeds (Plate 3b), was observed. Later cementation of this unit has occurred with the formation of hard concretions along fracture planes, (Plate 3c).

The presence of sedimentary structures suggests a primary origin for this particular unit, with the deposition of particulate manganese-oxides in a sedimentary environment.

6a

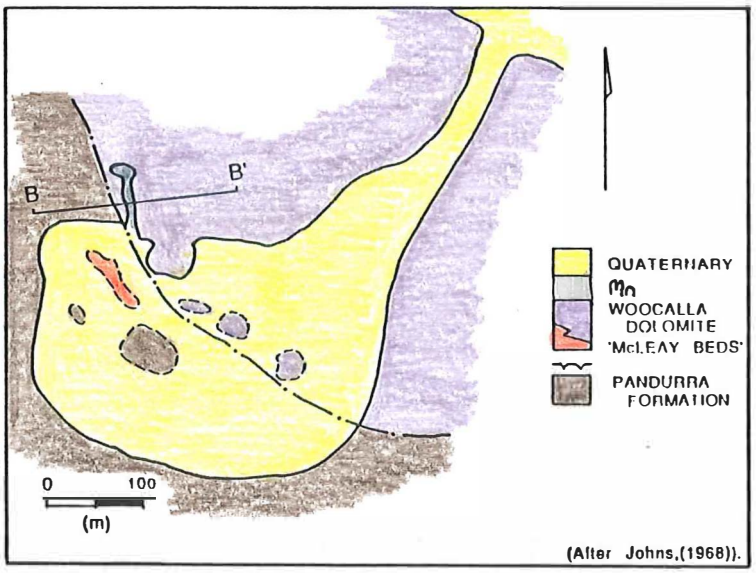


NORTHERN WORKINGS

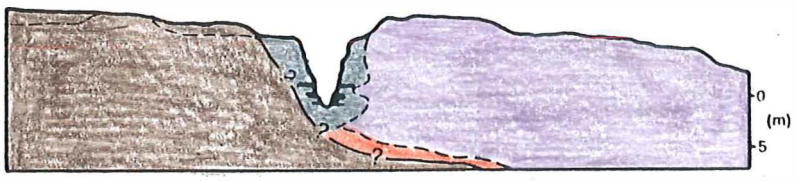


SECTION A-A'

6b

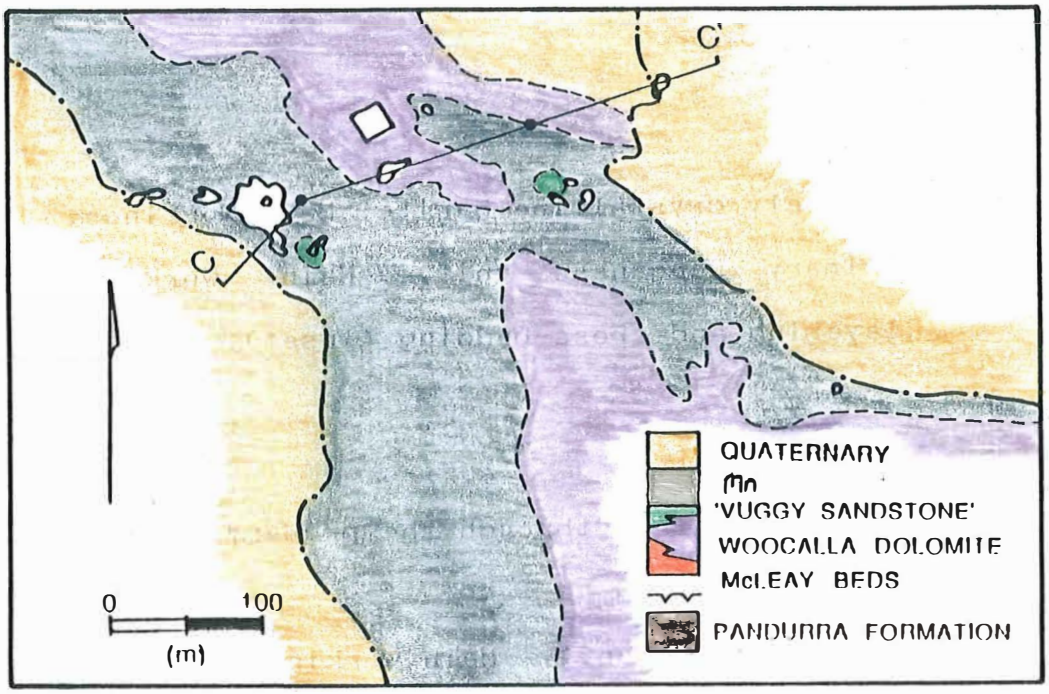


BIG CUT

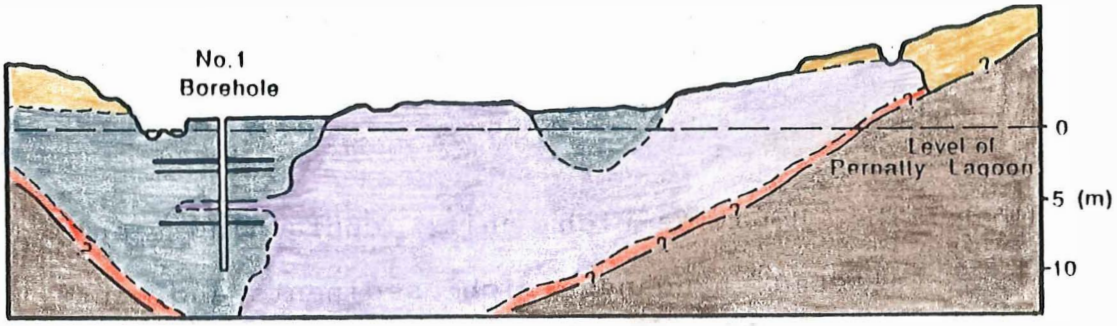


SECTION B-B'

FIGURE 6a-b: Plan and Cross-section of the Northern Workings and Big Cut Manganese Deposits.



MAIN WORKINGS



SECTION C-C'

Pernatty Lagoon, No.1 Borehole

Depth (m)	
0 → 1.4	Manganiferous sandy clay.
→ 1.8	White clay with occasional fragments of manganese ore.
→ 2.7	Manganiferous and ferruginous clay.
→ 3.3	Ferruginous manganese ore containing a little clay.
→ 3.6	Manganiferous and ferruginous sandy clay.
→ 3.9	Low grade manganese ore.
→ 4.6	Ferruginous clay and a little manganese ore.
→ 5.0	Ferruginous and manganiferous clay and dolomite.
→ 5.2	Dolomite and some manganese ore.
→ 7.3	Ferruginous clay.
→ 7.4	Lowgrade manganese ore.
→ 7.9	Ferruginous and manganiferous clay.
→ 8.4	Ferruginous clay.
→ 9.5	Ferruginous and manganiferous sandstone.

FROM: Mining Review 91, (1951) p.37

FIGURE 6c : Plan and Cross-section of the Main Workings Manganese Deposit. Includes SADME Drillhole Data

PLATE 3a: Coarsely crystalline barite, Main Workings.

PLATE 3b: Primary manganese unit, Main Workings, revealing layering and cross-bedding (inset).

PLATE 3c: Later veining through the primary layer resulting in cementation.

PLATE 3d: Hematite-rich unit, Main Workings. Forming a reaction rim along the margin of the deposit separating sands and manganese ore.

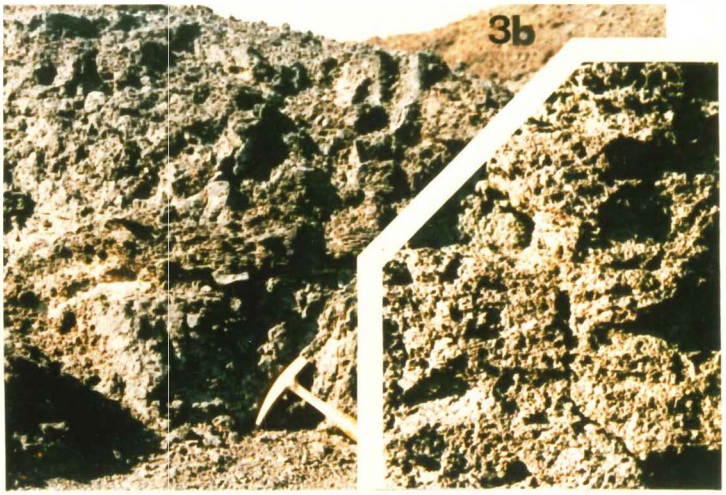
PLATE 3e: The Hematite-rich unit containing interdigitated, altered manganese-rich sediments and minor limonitic clays. Formed during secondary processes in the region.

PLATE 3f: Limonitic clay unit in the Main Workings.

PLATE 3g: Ooids from the Northern Workings with a quartz grain nucleus and an inclusion dominated, cryptomelane cortex. Surrounding matrix is relatively pure cryptomelane. (*25)

PLATE 3h: Pyrolusite crystals forming in voids, Big Cut manganese deposit.


3a


3b

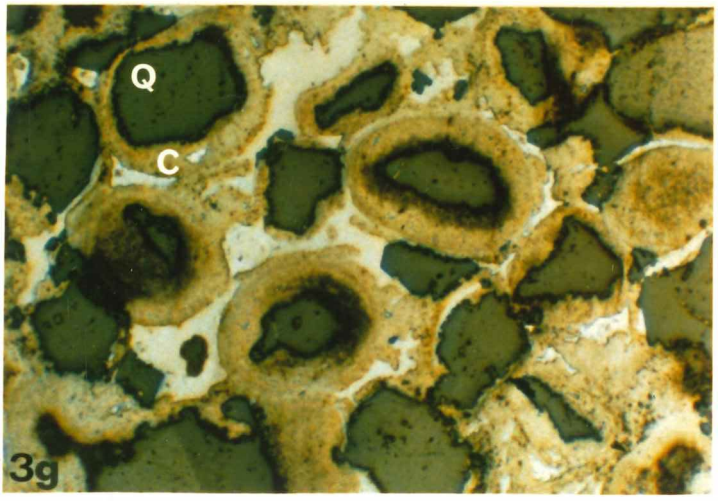


3c

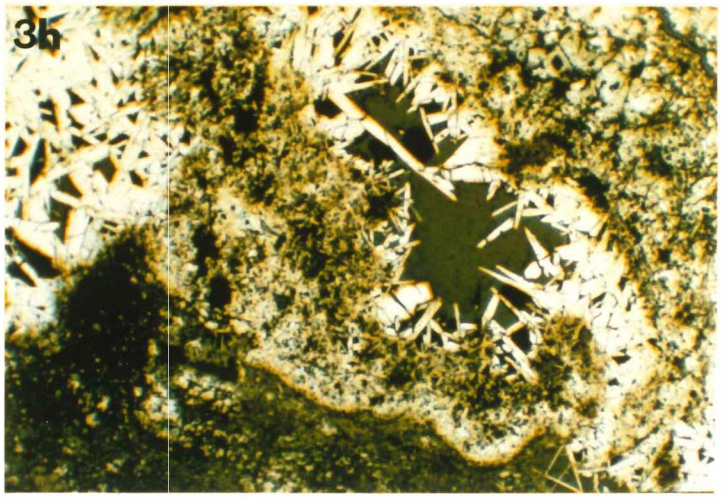

3d


3e


3f



3g


3h

3.3.2 Hematite Unit

Along the western boundary of the Main Workings, between the main manganese accumulations and the adjacent unconsolidated scree and sands, is a hematite-rich unit (Plate 3d). The ochre-red hematite dominated lithology, is often interdigitated with black lithified manganese and minor yellow limonitic clay (Plate 3e). A white crystalline material (sometimes occurring with a bladed or coffin-like habit) occurs in small veins throughout the lithified hematite and manganese members.

This iron-rich unit most likely represents a reaction front where ground waters containing ionic iron species interacts with the manganese in the deposits. The dissolved iron is oxidized to form a hard iron-rich rock and this suggests that secondary enrichment or remobilization processes are active in the area.

3.3.3 Limonite Unit

A minor amount of fine-grained, yellow limonitic clays (Plate 3f) was found outcropping in the Main Workings (Map C). This clay was often found beneath the primary manganese layer, although similar clay horizons are found at different levels throughout the deposit. This is substantiated from known drill-hole logs (Figure 6c), with Johns (1968) indicating that the largest quarry in the Main Workings reached a depth of several metres, with clay and ore horizons occupying specific horizons.

This unit most likely represents the alteration of established sediments by the influx of groundwaters along specific levels in the deposit.

3.4 Petrography

Petrological differences between the manganese occurrences in each deposit is indicated below and based on the study of

polished thin sections and the use of Scanning Electron Microscopy (SEM). A number of interesting associations can be examined which provide further information about the manganese in the region.

The Northern Workings' manganese ore is generally quite weathered, with the deposit contaminated by sands and gypsum. However petrological examination of an outcropping "manganese-rich sandstone"(Johns,1968) has revealed that the rock is dominated by ooids, but has incorporated quartz grains. The ooids have a quartz nucleus and a manganese-rich cortex and matrix (Plate 3g). Table 1 gives the results of a number of Electron Microprobe (EMP) analyses in a cross-section across an ooid, which is summarized in Figure 7. These results indicate that the manganese-rich cortex contains quite a significant number of inclusions. These contaminating elements, dominated by Fe_2O_3, must have been incorporated during ooid formation. The pure nature of the manganese matrix, can be seen with the lack of contaminating inclusions. A Scanning Electron Microscope (SEM) photomicrograph (Plate 4a) indicates the quartz grain nucleus surrounded by a fine-grained matrix.

The fine-grained particulate manganese ore within the Big Cut deposit has been influenced by secondary manganese remobilization and precipitation. This can be seen from the large manganese crystals which have formed in fractures (Plate 4b) or in voids, (Plate 3h). A further SEM photomicrograph (Plate 4c) shows the large prismatic manganese crystals.

In the Main Workings, the manganese-rich ore horizons intersected by a SADME borehole (Figure 6c) was buried beneath the surface. However this ore was intersected during this study by the drilling of DDH-4 (Map C). The study of this ore horizon

Table 1: MICROPROBE ANALYSIS OF OOIDS

	1	2	3	4	5	6	7	8	9
SiO_2	104,87	104,01	21,47	0,87	0,94	0,93	0,57	1,27	0,62
Al_2O_3	–	–	1,47	1,76	1,94	1,41	0,50	1,23	0,64
MnO	0,42	0,44	31,89	41,62	42,78	46,71	62,65	47,78	61,82
FeO	0,33	0,15	3,73	14,34	15,83	5,43	1,87	2,77	1,61
MgO	0,15	0,16	0,44	0,21	0,48	0,78	2,27	1,31	2,03
CaO	–	–	0,19	0,23	0,28	0,81	1,63	1,10	1,73
K_2O	–	–	2,35	2,87	2,98	2,16	0,91	1,61	1,08
TiO_2	–	–	0,19	0,22	0,28	0,35	0,31	0,35	0,23
V_2O_3	–	–	0,10	–	0,11	–	–	–	–
P_2O_5	–	–	–	0,18	0,26	0,21	0,19	–	–
Na_2O	0,18	0,12	0,47	0,54	0,69	0,92	2,05	1,16	1,60
Cl^-	–	–	0,10	0,10	0,23	0,29	0,38	0,55	0,51
TOTAL	105,94	104,87	67,39	62,94	67,02	59,99	73,40	59,13	71,88

Analysis No,1 to 7 represent a cross-section across an ooid,
1, Ooid nucleus,
2, Ooid nucleus near outer edge,
3, Boundary between nucleus and cortex,
4, One third of the way through the cortex,
5, Two thirds of the way through the cortex,
6, Ooid cortex at its outer boundary,
7, Matrix surrounding ooids,

8, Random analysis of an ooid cortex,
9, Random analysis of matrix,

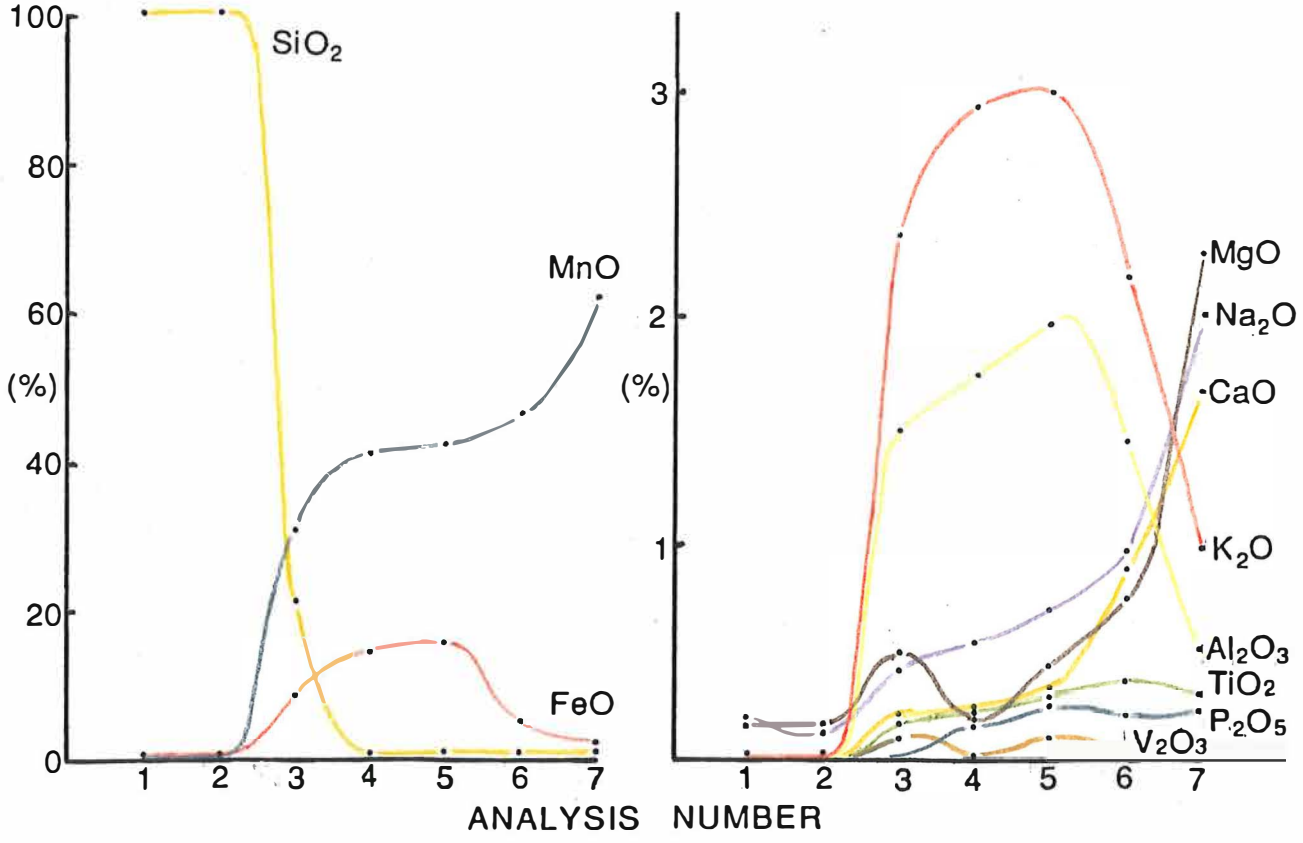


FIGURE 7: EMP Analyses in a Cross-section Across an Ooid.

using SEM indicated a number of large blade-like crystals forming in voids (Plates 4d-e).

Manganese-rich Woocalla Dolomite was also studied, to reveal the nature of the manganese within the dolomite. Voids in the dolomite often contain large amounts of euhedral crystalline material (Plate 4f) which has undergone some secondary remobilization due to alteration around grain boundaries.

3.5 Geochemistry

Geochemical analyses of rocks within the deposits may reveal further important information regarding the origin of the deposits. The use of Whole Rock Analysis (WRA), Atomic Absorption Spectroscopy (AAS) and the Electron Microprobe (EMP) can therefore be critical to interpretation. (All geochemical data is found in Appendix C).

As the Woocalla Dolomite is suggested by Johns (1968) to be the source rock for the manganese deposits in the Pernatty Lagoon area, background manganese concentrations were undertaken to determine any degree of enrichment. Handspecimens collected from Woocalla, from outcropping dolomite at Pernatty Lagoon and from Mt.Gunson, all of which contained a minimal amount of visual manganese, were selectively gouged to obtain a sample with minimal secondary enrichment. These samples were analysed using AAS with a further thin section analysis attempted using the EMP. The results obtained indicate a background manganese concentration range of between 6289 ppm (AAS) and 6900 ppm (EMP).

The manganese accumulations in the area were studied using WRA with the results revealing the nature of the deposits and the units within them. Samples of the manganese ore from all three deposits revealed high percentages of MnO ranging from 70% in the

Main Workings and the Big Cut, to 40% in the Northern Workings where the SiO_2 content approaches a high 35%. In general, Fe_2O_3 concentrations are quite low with values less than 10%. These results can be compared to other rock associations in the Main Workings, which have been assigned a secondary origin to give any geochemical evidence for their suggested origins.

The cementation along fractures and joints in the primary manganese layer is believed to be secondary. WRA reveal a higher Fe_2O_3 content, (about 30%) and an increase in trace element content. Barium, cobalt, copper, nickel and zinc contents all rise by significant amounts, suggesting that groundwaters moving through this area were enriched in both iron and trace elements.

Samples of the low-lying clay which covers most of the Main Workings indicates variable MnO and Fe_2O_3 values ranging from 7% to 35% and 43% to 80% respectively. The trend is that MnO content decreases with increasing Fe_2O_3, with the other major element analyses remaining constant. Trace element analyses show barium, cobalt, copper, strontium and zinc all seem to be anomolously high. This suggests that most of this clay has been influenced by secondary processes.

3.6 X-ray Diffraction

The mineralogy of the deposits, as determined by X-ray Diffraction (XRD) studies, has indicated that the manganese-species present in this area are manganese-oxides. The manganese-species dominant in the Northern Workings is cryptomelane ($K_{<2}Mn_8O_{16}$), whereas the Big Cut deposit consists entirely of pyrolusite (MnO_2). The manganese-species dominant in the Main Workings, is pyrolusite, but a number of other mineral species were identified, including trace amounts of psilomelane and

todorokite. The manganese ore horizon found at depth in the Main Workings is composed predominantly of manganite (ɣ-MnO(OH)).

Of all other manganese minerals in the oxidation zone, pyrolusite, together with the cryptomelane-psilomelane group of minerals, are the most common. Manganite can be sedimentary in nature although in most cases it tends not to be preserved, but instead is transformed into pyrolusite during weathering (Frenzel,1980). Hence the different manganese-species have a similar genesis, forming due to weathering processes in oxygenated sedimentary environments. The variable capacity for the incorporation of other cations into manganese-oxides results in the different mineral species.

3.7 Similarities Between Pernatty Lagoon Mineral Deposits

The manganese, copper and barite deposits found throughout the area seem to have the same basic mode of genesis. All seem to be associated with the marine environment that formed the Tapley Hill Formation sediments in the region. Knutson et al (1983) suggest that the stratiform copper deposits at Mt.Gunson were concentrated in a reducing aquatic environment. The barite seems to have some association with seawater from which sulphate was derived and barium concentrated. The manganese is associated with carbonate facies associated with this Tapley Hill Formation Sea.

The accumulation of economic concentrations of manganese in the Pernatty Lagoon area was the result of a number of independent events. The likely geological processes and phenomena which probably contributed to the formation of the deposits will be discussed and critically examined below.

4. DISCUSSION

4.1 Origin of Manganese

The initial question which must be addressed is the origin of the manganese. The manganese has been directly related to the Woocalla Dolomite, which formed in relation to the Tapley Hill Formation Sea, which transgressed across the Stuart Shelf. It is known that manganese can be introduced into this type of aqueous sedimentary environment in a number of ways.

Smirnov (1964) described how circulating waters, in the sea-floor, which are heated by localized volcanic activity, participate in the dissolution and leaching of manganese from the established sediment pile. Ascending hydrothermal fluids exhale into the aqueous environment, resulting in a gradual accumulation of manganese within the water column. However there is no indication that the manganese associated with the Tapley Hill Formation was derived from volcanic activity, as there is no known penecontemperaneous volcanism.

Hariya (1980) states that many sedimentary manganese deposits can be related to the weathering of basic and intermediate volcanic rocks. This suggestion can be applied to the Pernatty Lagoon area due to the number of basic volcanic units present in the region.

The major lithological units present on the Stuart Shelf prior to the Tapley Hill Formation transgression, which could be possible source rocks, include the Roopena Volcanics, the clastic Pandurra Formation and finally the Backy Point Beds with intertonguing Beda Volcanics. A further possible source rock could be the basaltic dykes of the Gairdner Dyke Swarm.

Drill cores reveal that these units are distributed across the Stuart Shelf, with whole rock analyses compiled by a number

of investigators. These analyses can be used to detect if there is any anomolous manganese content in these units when compared to global manganese-oxide averages for similar rock types. A summary of the results obtained is given in Table 2, with mean values for occurrences within each 1:100,000 topographic sheet revealed in Figure 8. (The data used is listed in Appendix D).

Manganese content in sedimentary rocks is at a minimum in sandstones with an average range of between 0.026% and 0.05% (Wedepohl,1969). Therefore the clastic Pandurra Formation does not have any anomolous manganese content which could contribute significantly to an aqueous reservoir.

The range of manganese-oxide averages of basaltic rocks is relatively small, irrespective of geological environment. The mean MnO concentration of tholeiitic basalts has been calculated as 0.173 percent (Wedepohl,1969) and 0.18 percent (De La Roche et al,1980). The data (Table 2) indicates that there is indeed a MnO anomaly within the Stuart Shelf volcanic units. The Roopena and Beda Volcanics have only a slight positive anomaly; however the Gairdner Dyke Swarm displays a remarkable manganese anomaly.

The Gairdner Dyke Swarm could be a possible source rock of the manganese, due to its highly anomolous MnO content. However, due to the limited number of dykes (Figure 3), it could not individually be a suitable source. However, if the dykes were feeder conduits for the Beda Volcanics, it could be suggested that the Beda Volcanics were previously quite extensive across the Stuart Shelf and may also have had a higher manganese content.

4.2 Concentration History

After the formation of the Beda Volcanics (Figure 9a), there was an extensive period of weathering of manganese-rich volcanics, which resulted in manganese dispersal with weathered clastics upon the Stuart Shelf and into the Adelaide Geosyncline (Figure 9b). The prevailing hydrologic regime may have precipitated the manganese in oxidizing environments in close proximity to the weathering zone, resulting in further manganese concentration and not dissemination amongst geosynclinal sediments.

The Tapley Hill Formation, which is the unit to which the manganese deposits are related, is represented in the Adelaide Geosyncline and much of the Stuart Shelf, by finely laminated, pyritic black shales and minor gritty dolomites. Whole rock analyses (by Sumartojo 1974) of the Tindelpina Shale, which is the basal member of the Tapley Hill Formation, reveals anomolous zones of enrichment of iron over manganese in the Adelaide Geosyncline, (Figure 10), when related to the average Fe:Mn ratio for geosynclinal shales of 80:1 (Wedepohl,1969). This implies there is an overall deficit of manganese from the system.

Any manganese, which accumulated with iron in the Tapley Hill Formation Sea in the Adelaide Geosyncline, may have been fractionated by iron sulphide precipitation. This process is important to further concentrate the manganese by the removal of iron. Fractionation can occur when a basin achieves euxinic conditions with the direct precipitation of iron sulphides in the water column, or during diagenesis when the iron is fixed in anoxic sediments and manganese is mobilized upwards (Force and Cannon, in press). The overlying seawater has a sufficiently low

TABLE 2: SUMMARY OF MnO CONCENTRATIONS IN STUART SHELF ROCKS

Lithological Unit	Number of Analyses	Mean(%)	Maximum(%)	Minimum(%)	σ (%)
Roopena Volcanics (1)	53	0,22	0,64	0,01	0,13
Pandurra Formation (2)	11	0,02	0,04	0,01	0,01
Beda Volcanics (1)	78	0,27	0,66	0,02	0,13
Gairdner Dyke Swarm (1)	45	0,78	5,37	0,12	1,15

* σ = Standard Deviation

(1) South Australian Department of Mines and Energy, (unpubl,reports)
(2) From: Knutson et al,(1983)

TABLE 3: SUMMARY OF OTHER MANGANESE OCCURRENCES ASSOCIATED WITH STROMATOLITES

Area	Age	Formation	Form of Stromatolite	Mineralogy
Oceans (1)	Recent	—	Bacterial(?) Nodules	Pyrolusite
Dead Sea (2)	Recent	—	LLH-C	Mn-oxides
Zaire,W,Katanga (3)	E,Proterozoic	Lukoshi Complex	Collenia (LLH)	Rhodochrosite
Botswana,Africa (4)	Precambrian	Transvaal System	SH	Pyrolusite/ Cryptomelane

(1) From: Monty,(1973)
(2) From: Druckman,(1981)
(3) From: Doyen,(1973)
(4) From: Litherland and Malan,(1973)

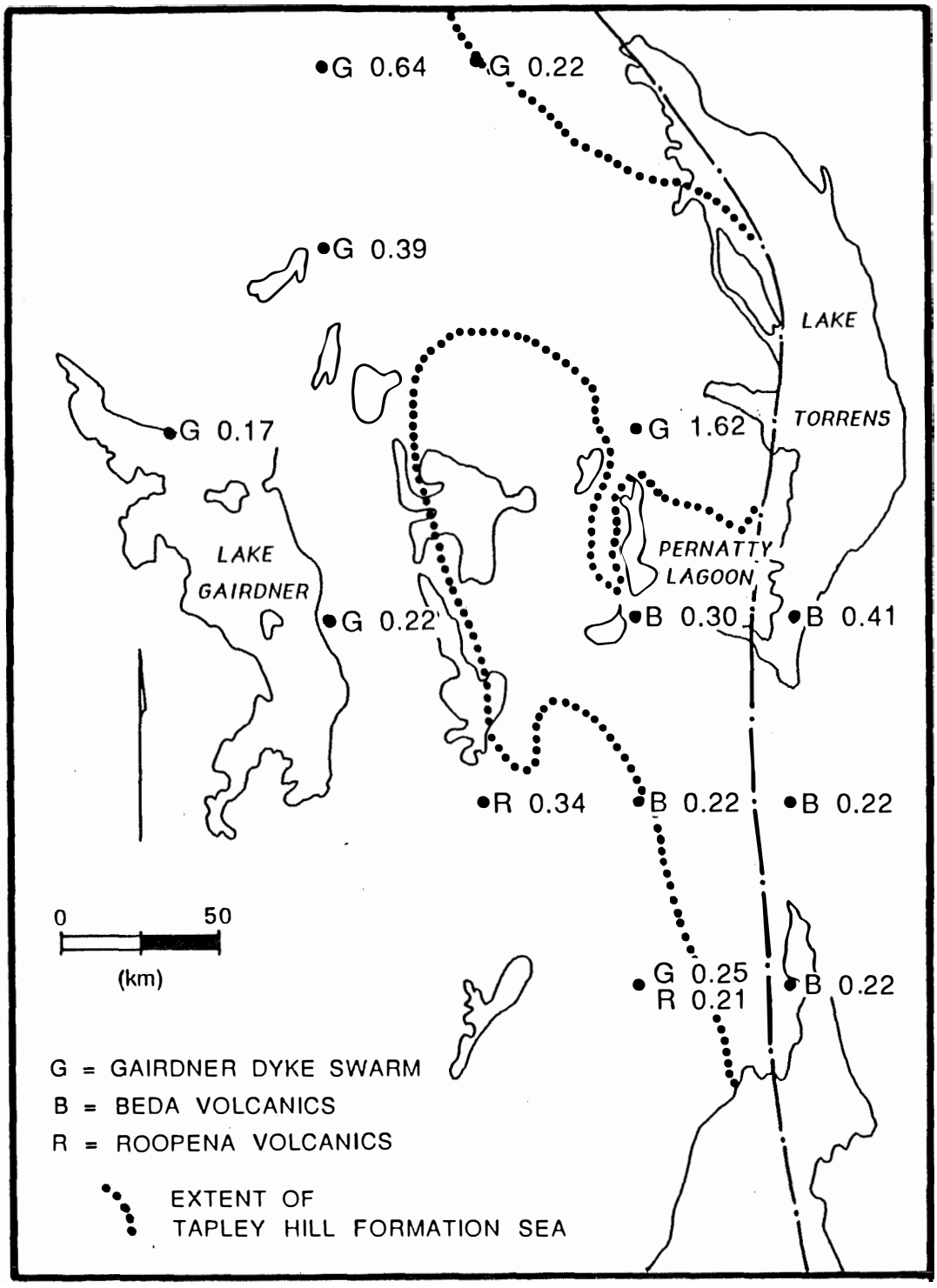


FIGURE 8: Manganese-Oxide Contents of the Stuart Shelf Volcanic Units. (Adapted from Preiss,W.,(1983) and SADME unpublished reports).

Eh to retain the manganese in the ionic state, hence contributing to the dissolved manganese reservoir.

Hence the advent of the Tapley Hill Formation Sea in the Adelaide Geosyncline resulted in the accumulation and remobilization of the manganese within a reducing aqueous system. Furthermore, the transgression of the Tapley Hill Formation Sea across the Stuart Shelf collected and allowed accumulation of any manganese in oxidized zones present in that area. The circulation pattern for the Tapley Hill Formation Sea may have been estuarine in nature, with a net seaward (eastward) flow in the upper levels and a net shelfward flow in deeper layers, (Figure 9c).

Sundby et al (1981) suggest a similar present-day model in the Laurentian Trough System (Canada), where manganese in deep waters is being caught up in the circulation pattern of the estuary. The net tidal motion of the bottom water is landward, and the repeated sweeping of manganese towards the head of the estuary is known as the 'broom effect'. Eventually forced to upwell, due to a steep sill at the head of the Laurentian Trough, manganese is brought into shallow water environments, where tidal lag could drive particulate manganese oxides further shorewards. A similar process is proposed to have occurred on the Stuart Shelf with upwelling against the Pernatty Culmination.

4.3 Deposition of Manganese

The formation of mineral deposits associated with stromatolites has been well documented (Mendelsohn,1976; Verma, 1980). This is attributed to the fact that many sedimentary mineral deposits are formed in marine areas, under shallow water conditions. This is also a zone which supports rich organic life and which, during Precambrian times, was represented by huge

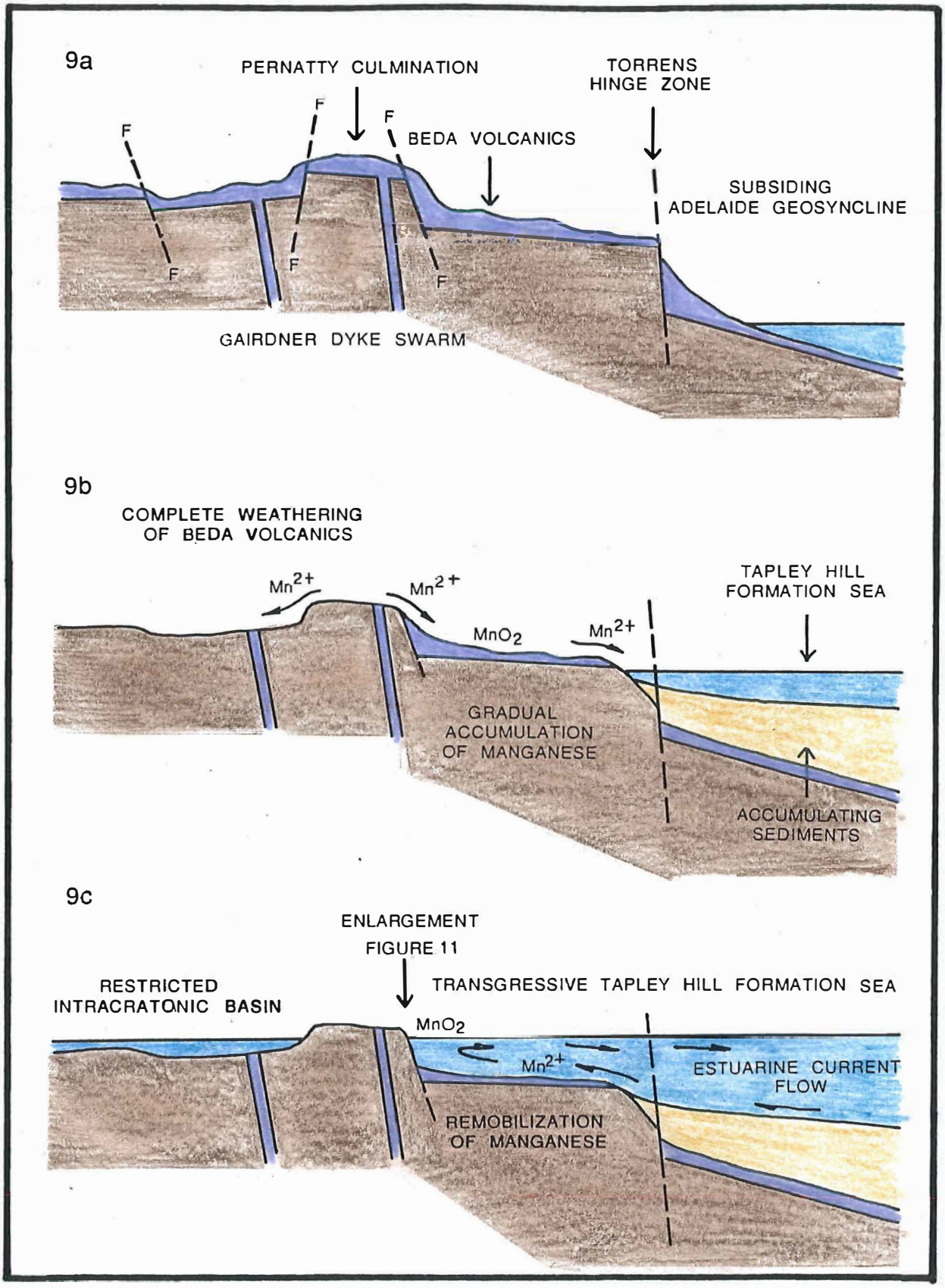


FIGURE 9: Introduction of Manganese into the Aqueous Sedimentary Environment from the Weathering of Volcanic Units, with Remobilization of the Manganese.

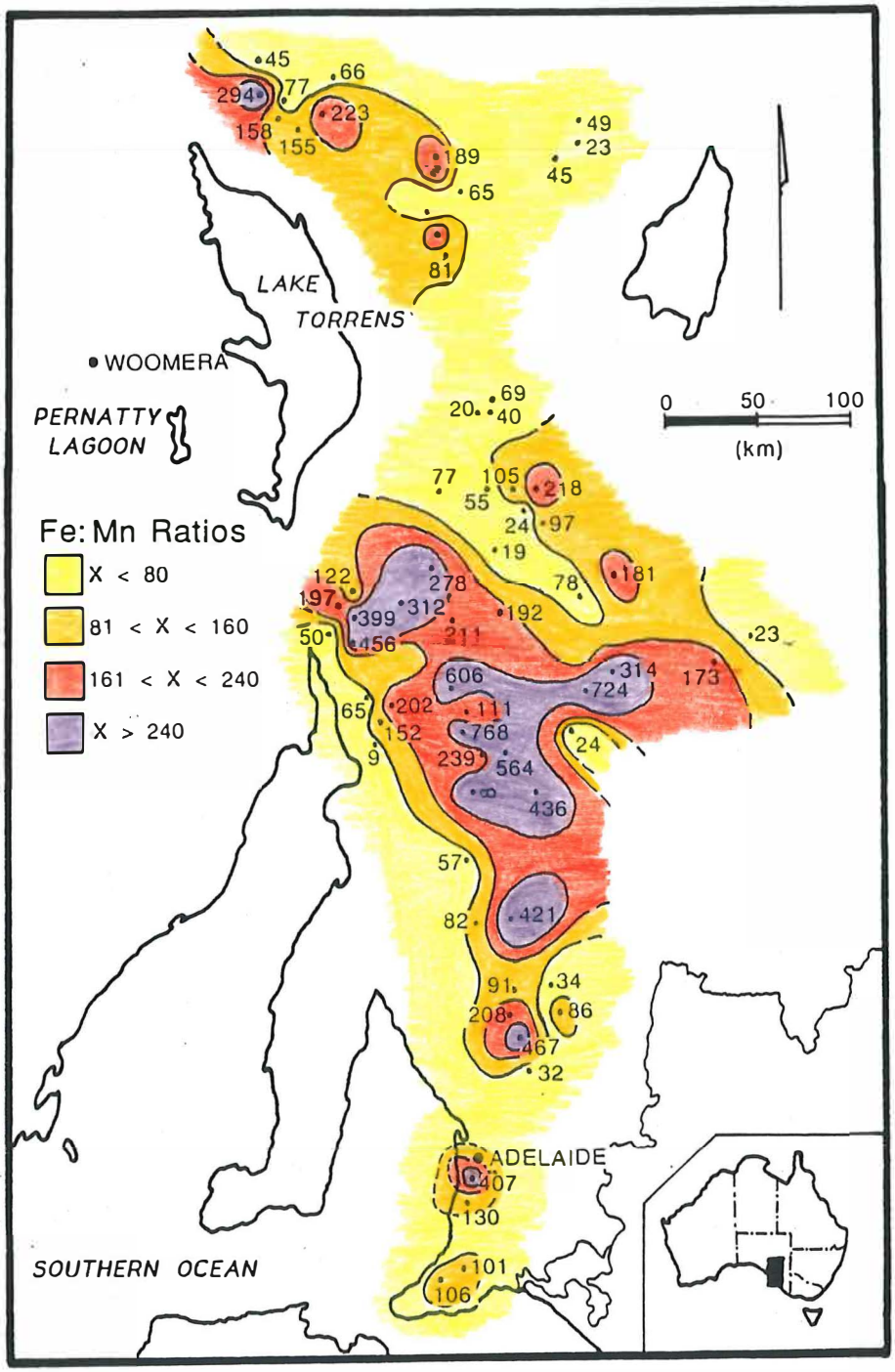


FIGURE 10: Tindelpina Shale Fe: Mn Ratios in the Adelaide Geosyncline (Adapted from Sumartojo,(1974)).

colonies of algae, (Verma, 1980). The number of stratiform deposits of manganese suggests the possibility that algal mats were at least able to grow under conditions where manganese in high concentrations was present. It therefere seems quite likely that some manganese deposits formed during, and perhaps related to, algal mat growth.

Manganese could be concentrated in a number of ways by the microorganisms which form the algal mats. First, the microorganisms could change the physical or chemical character of the sea water as a result of which the solubility of manganese will be decreased and speed up the rate of precipitation.

The removal of carbon dioxide through the photosynthetic activity of the algae may result in a significant rise in the pH of the seawater (Verma,1980) or the same process releasing oxygen which ultimately could result in an increased potential for manganese precipitation. Precipitation of the manganese can then proceed in an environment favourable to accumulation (Verma,1980).

Alternatively, the manganese may have already been precipitated and introduced into the area by tidal lag. This suggests that the organisms may have merely survived in an environment where deposition of the manganese is taking place, without actually taking part in the process (Mendelsohn,1976). This scenario seems to be the most likely; however the other factors may have contributed to some degree to concentrate the manganese in association with the Woocalla Dolomite.

The occurrence of sub-Recent stromatolites along the shore-lines of the Dead Sea have been detailed by Druckman (1981). Laminations are evident and consist of alternating white aragonitic and black manganese and iron oxide laminae.

Druckman (1981) summarizes the formation of these stromatolites as being related to the growth of algae in freshwater springs near the shoreline, which contain between 1375 and 3700 ppm manganese. This is compared to the 3 to 7 ppm manganese found in present day Dead Sea Water (Epstein et al, 1975). Hence the intervention of microorganisms in manganese enrichment remains an appealing solution. Algal mats in the intertidal zone of the study area may have helped in the precipitation and concentration of manganese in a similar method to the stromatolites in the Dead Sea.

A further possibility is the introduction of a zone of oxygen depletion containing dissolved manganese into the area. Manganese-rich waters could then directly deposit manganese on the carbonate platform and result in manganese enrichment of the sediments due to percolating waters. Such a scheme could explain the high background manganese content of the Woocalla Dolomite.

Mixed manganese-calcium carbonates have recently been found in shallow marine and lacustrine environments (Glasby,1977). These have a highly variable manganese content and also form in lagoonal environments where the precipitation of manganese-rich calcite predominates over aragonite (Flugel,1982), or in sea water with a higher than normal manganese abundance (Wedepohl,1969). The anoxic waters of the Upper Permian Kupferschiefer Sea in Central Europe is cited as an example, with calcite and dolomite containing 2000 to 6000 ppm manganese being precipitated (Wedepohl,1969). Compounds such as $CaMn(CO_3)_2$ and $MnCO_2$ might have formed from waters partly contaminated by H_2S (Sapozhnikov,1970). Rankama and Sahama (1950) state that carbonate sediments may become enriched in manganese, due to the replacement of calcium by manganese in the crystal lattice.

The precipitation of manganese oxides during transgressive/ regressive sequences has been documented by Frakes and Bolton (1984). A similar theory for deposition around black shale basins has been offered by Force and Cannon (in press), in which oxygenated waters interacting with anoxic waters result in the precipitation of dissolved manganese species. Such a process is suggested to have occurred in the area during maximum transgression and initial regression in relation to the stromatolitic carbonate platform (Figure 11a).

Shallow water features which support this model in the Pernatty Lagoon area are characteristically found in protected areas, at the disconformable boundary between Woocalla Dolomite and either McLeay Beds or Pandurra Formation sediments (Figure 11b). The laminated nature of some of the manganese ore, including cross-bedding and ripples, is further evidence for a primary origin. Particulate oxides precipitated in the zone were trapped and retained in low energy areas where they could not be influenced by further events.

Further evidence suggesting penecontemporaneous deposition of manganese-oxides and dolomite can be found in drillhole data (Figure 6c). Within the drillhole sequence there is around 30cm of dolomite which is found between clay layers. This suggests that the dolomite formed above the accumulating clay at one stage and was covered during a later period with further clay.

The occurrence of sandstones and the "Vuggy Sandstone" Unit forming above the manganese in the Main Workings (Plate 4g), represent the late regressive phase of the Tapley Hill Formation Sea and provides further support for a primary origin. The Main Workings area was subsequently covered with clastic sediments of the Whyalla Sandstone and later Tent Hill Formation sediments.

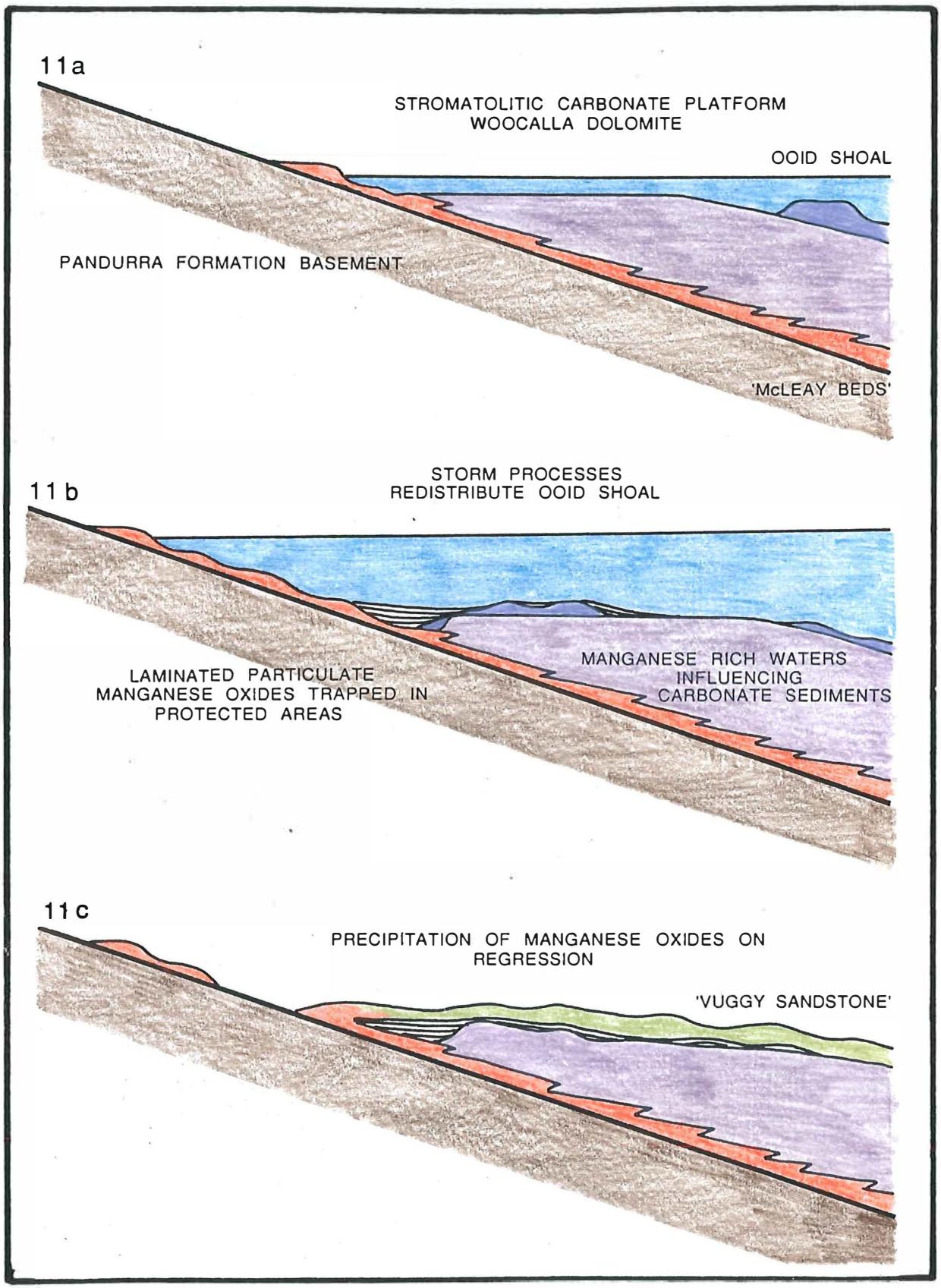


FIGURE 11: Manganese Deposit Formation in the Pernatty Lagoon Area.

4.4 Supergene History

The sediments remained until Tertiary times (Johns, 1968) when the dissection of the Arcoona Tableland by fast flowing rivers resulting in re-exposure of the Woocalla Dolomite. Once again the manganese was exposed to the aqueous environment.

Any rock with a low but significant manganese content may act as a parent rock for later supergene deposits in favourable conditions (Roy, 1981). Supergene concentration can then continue through long-lasting weathering and redeposition processes. The manganese-enriched Woocalla Dolomite may have undergone further supergene concentration due to the decomposition of the dolomite.

Lelong et al (1976) indicate that secondary enrichment processes also have negative aspects which include the washing away of dissolved manganese and the reprecipitation of manganese with iron. Hence both primary and supergene manganiferous ores located near the surface are only transitory accumulations, with the continuation of the supergene process leading inevitably to the dispersal of manganese.

The later remobilization of manganese within the area can be supported from observations revealed in the study of the deposit. An example is found marginally east of the Main Workings, where buff-coloured dolomite overlies deeply stained dolomite (Plate 4h). This layer most likely represents an old water table level where manganese has been dissolved, remobilized and eventually precipitated, staining the dolomite.

The minor amount of supposed primary ore observed in the area is dramatically surpassed by secondary manganese and iron oxide/hydroxide sediments which cover and confuse original depositional indicators (Plate 4i). The low-lying clays which

PLATE 4a: SEM photomicrograph of an ooid from the Northern Workings showing quartz grain surrounded by manganese dominated cortex.

PLATE 4b: SEM photomicrograph from Big Cut where large pyrolusite crystals form along discordant fractures in a fine manganese matrix.

PLATE 4c: SEM photomicrograph of the large pyrolusite crystals.

PLATE 4d: SEM photomicrograph of blade-like manganese crystals from the ore horizon, Main Workings.

PLATE 4e: SEM photomicrograph of manganese crystals forming in a void.

PLATE 4f: Photomicrograph of pyrolusite crystals forming within dolomite, Main Workings.(*25)

PLATE 4g: Overlying manganese layer is a sandy horizon which includes the vuggy sandstone suggesting manganese accumulation prior to the regression of the Tapley Hill Formation Sea.

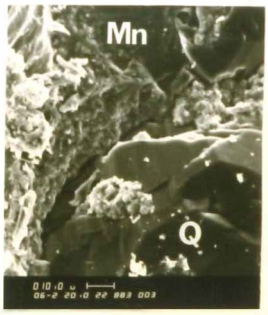
PLATE 4h: Remobilization of manganese has resulted in the staining of the Woocalla Dolomite, with this level probably representing an old water table.

PLATE 4i: Iron-contaminated low-lying clay, Main Workings.

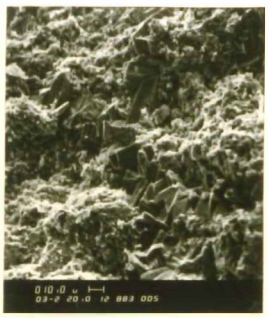
PLATE 4j: Possible supergene manganese pod, forming in elevated areas near the Main Workings.

PLATE 4k: This manganese pod overlies highly weathered Woocalla Dolomite.

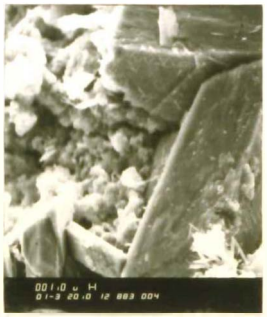
PLATE 4



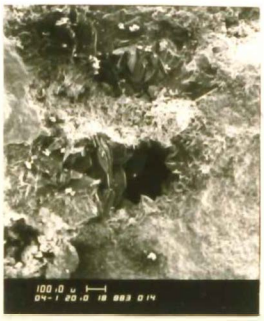
4a



4b



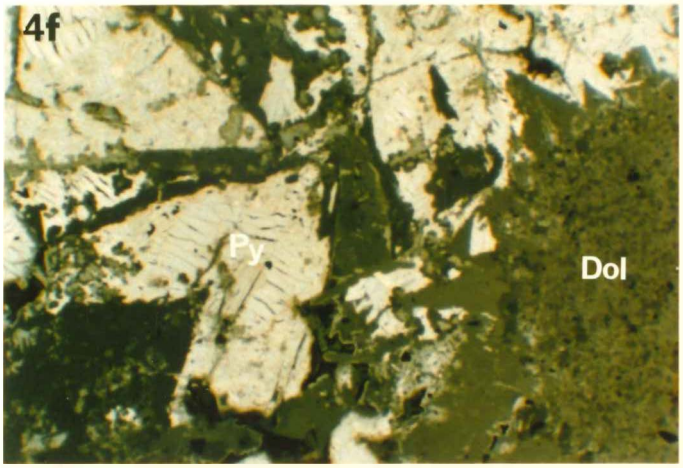
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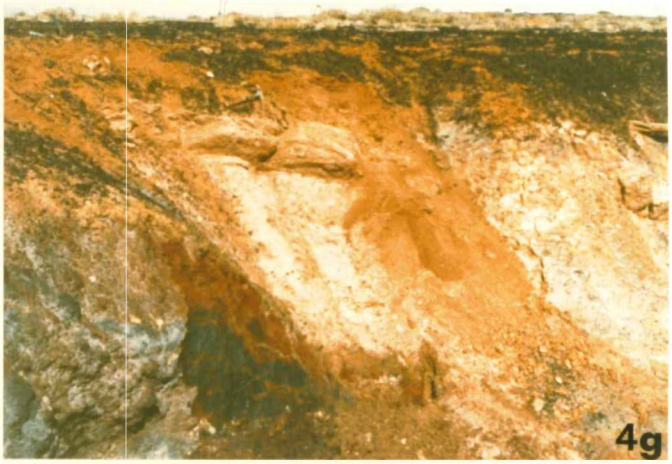


4d

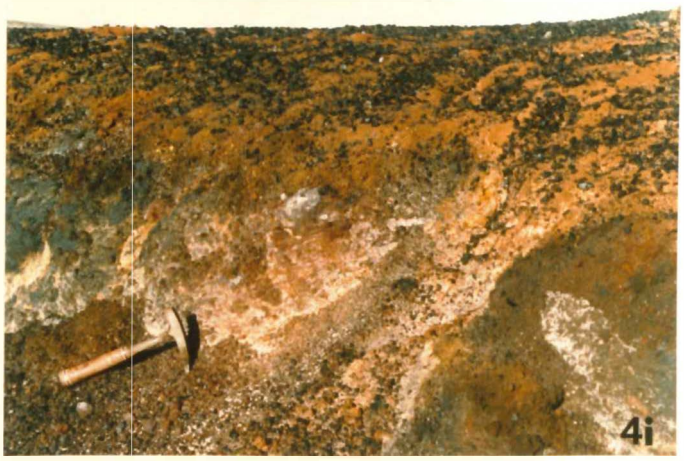


4e













dominate the Main Workings may be a supergene concentration formed by the decomposition of the manganese-rich Woocalla Dolomite. However the presence of iron enrichments in the region, forming the palaeoweathering profile on the Pandurra Formation and the Goethite Gibber, has contaminated any later enrichment which may have occurred, due to the remobilization of iron.

A number of small manganese accumulations which were not greatly affected by iron contamination are found on the eastern side of the Main Workings, usually in elevated regions. The manganese is associated with gypsum (Plate 4j), and overlies heavily weathered Woocalla Dolomite (Plate 4k). This suggests that the pod may have been derived from supergene processes.

4.5 Comparisons With Other Manganese Deposits

Now that the Pernatty Lagoon manganese deposits have been interpreted, they can be compared to a number of other sedimentary manganese deposits, to indicate any similarities.

Sapozhnikov (1970) describes how the waters of the (Miocene) Maikop Basin may have acted as a great reservoir of manganese, as the giant Nikopol and Chiatura deposits (USSR) are found around the margins of this basin. Roy (1981) suggests these deposits formed due to the upwelling of manganese rich waters, with deposition of oxide and carbonate ore horizons in a nearshore environment, on the edge of the downwarped Ukrainian Shield.

The (Cretaceous) Groote Eylandt deposit probably formed in a shallow water marine environment and lies on a tectonically stable sedimentary platform (Pracejus et al, in prep). Manganese was concentrated in the anoxic waters of an intracratonic basin which transgressed upon the stable basement. The precipitation of

manganese-oxides and carbonates in shallow nearshore environments occurred during a marine regression (Frakes and Bolton,1984).

These settings are similar to the suggested formation of the manganese deposits at Pernatty Lagoon. The anoxic Tapley Hill Formation Sea, containing dissolved manganese, transgressed across the shallow Stuart Shelf. Eventually forced to upwell against a basement high, manganese-rich waters precipitated manganese-oxides in a nearshore environment.

Other manganese deposits, including the Kisenge-Kamata (Zaire), and Kgwakgwe Hill (Botswana) deposits, have stromatolites associated with manganese. Table 3 indicates these and other manganese occurrences associated with stromatolites. Both deposits have been assigned a sedimentary origin due to this association.

Identification of laterally-linked hemisperoidal stromatolites, (Doyen,1973) in the Kisenge-Kamata deposit and the vertically-stacked hemisperoids (Litherland and Malan,1973) in the Kgwakgwe Hill deposit, indicates that there is an association between manganese accumulations and stromatolites forming in a shallow marine environment. This is similar to the environment believed to have been present in the Pernatty Lagoon region.

Hence a number of analogous manganese deposits can be applied to the manganese accumulations at Pernatty Lagoon, including the origin and mode of formation of the deposits. Many large manganese deposits have formed in shallow nearshore environments, which also is the environment favourable to stromatolite growth. Therefore it could be suggested that the association, between manganese accumulations around restricted basins and stromatolites, may be quite common.

5. ECONOMIC CONSIDERATIONS

5.1 Pernatty Lagoon Manganese Deposits

The preceding chapter indicates the series of events which brought about the formation of economically viable manganese deposits associated with the Woocalla Dolomite at Pernatty Lagoon.

More recent geological history has, however, been unfavourable to further accumulation, due to the chemical weathering of the exposed Woocalla Dolomite. Although, in principle, decomposition of the dolomite would result in the release of manganese which could then accumulate in nearby favourable environments, iron enrichments forming in the area during the Tertiary, have resulted in the contamination of any later enrichments due to iron precipitation in association with manganese.

The deposition of primary manganese (and possibly barium and copper) within a restricted lagoonal environment, against the basement high, resulted in concentrations suitable for economic exploitation on a small scale. Any future economic potential of the known manganese accumulations in the Pernatty Lagoon area is discouraging, as the small amount of available uncontaminated tonnage could not justify the high costs of production and establishing the required infrastructure.

5.2 Stuart Shelf

Any search for similar deposits on the Stuart Shelf should concentrate on looking for similar environmental conditions to those displayed at Pernatty Lagoon, as these are vital for manganese accumulation.

The manganese-rich Gairdner Dyke Swarm is found right across the Stuart Shelf as most probably were originally the Beda Volcanics (now only concentrated east of Pernatty Lagoon). The extent of the Tapley Hill Formation Sea is also quite extensive (Figure 3).

Further outcropping basement highs similar to the Pernatty Culmination are not evident upon the Stuart Shelf. Since the basement sequence is block faulted, there may be further occurrences of upthrust basement blocks. However they may not have reached an elevation in which manganese could be precipitated, and remain trapped within a shallow marine facies. Most were probably completely inundated by the Tapley Hill Formation Sea, with subsequent loss of manganese due to remobilization.

Further accumulations could occur at the extreme margins of the transgression, where the Tapley Hill Formation Sea onlapped upon established Pandurra Formation sediments and even other earlier volcanic units. Shallow lagoonal facies may have formed along the westerly extent of the Tapley Hill Formation Sea, with conditions similar to those seen at Pernatty Lagoon. If so, similar deposits may have been formed within this zone. Unfortunately there is minimal outcrop of Tapley Hill Formation sediments on the Stuart Shelf, other than those occurrences at Pernatty Lagoon.

The formation of a restricted intracontinental basin, to the west of the Pernatty Culmination, could have provided a trap for manganese. Manganese introduced into this basin due to the weathering of volcanics or remobilized from other areas during the maximum extent of the transgression could very well have

eventually precipitated and accumulated in favourable areas throughout this basin.

As the environment became much more arid and the sea regressed due to an approaching ice age, the basin may have become cut-off from the Tapley Hill Formation Sea. This basin would then become stagnant, even more restricted, with a considerable quantity of manganese and other metallic rich waters trapped in the area.

Drill hole data known in the region (Preiss,1983), indicate that the inlet, beween this intracontinental basin and the Adelaide Geosyncline, has the thinnest sequences of Tapley Hill Formation sediments. The sediments seem to progressively thicken towards the Geosyncline and into the basin behind the Pernatty Culmination. This suggests that a possible manganese rich basin could have formed in the latter region.

Hence further exploration could be undertaken, including analysis of core and geochemical work, to determine if there is additional manganese present in economic quantities, associated with the Tapley Hill Formation, within and around the margins of this restricted palaeobasin.

6. CONCLUSION

The nature and origin of the manganese deposits found along the margin of Pernatty Lagoon has been discussed, suggesting initial source rocks and how the manganese has been concentrated. This study has detailed the Proterozoic rock units outcropping in the Woocalla and SW Pernatty Lagoon area, with a comprehensive analysis of each unit used to derive the environment in which each unit formed. This palaeoenvironmental interpretation must be made, especially with respect to the Woocalla Dolomite, due to the association between this unit and the manganese accumulations. That is, both seem to have formed during the same period, in association with the transgressive Tapley Hill Formation Sea.

The environment, that was present during the formation of the Woocalla Dolomite, can be interpreted as a shallow tidal-lagoonal-mudflat environment, where large colonies of algal mats can grow. This oxidizing, nearshore environment is also an environment where remobilized manganese present in the nearby anoxic sea can be precipitated. Tidal processes could then drive the particulate manganese shoreward, where it can be trapped in protected areas in association with algal mats and concentrated within the carbonate sediments.

With the Woocalla Dolomite being enriched in manganese, it could then be considered to be a suitable source rock for the formation of supergene manganese accumulations. Evidence indicates that a number of secondary supergene processes have influenced the manganese deposits in the area. However, since the formation of the manganese deposits, a number of iron enrichments in the area, have contaminated the deposits. This includes the

palaeoweathering profile at the top of the Pandurra Formation and the goethite gibber caps which blanket areas near the dolomite.

Supergene processes have formed the iron-rich units presently found in the Main Workings, due to the remobilization of iron in the local aqueous system. These units testify to the fact that iron has contaminated and altered the original sediments. The low-lying clay, which covers a wide area in the Main Workings, has a high iron and manganese content suggesting it too has formed by remobilization. Hence, the decomposition of the manganese-rich Woocalla Dolomite has not formed any large supergene manganese deposits in the area.

Finally, the mode of formation of these deposits can be used to suggest areas and environments where other economic concentrations could be discovered on the Stuart Shelf. The conditions required for the concentration, remobilization and precipitation of manganese-oxides, may have resulted in the formation of other sedimentary manganese deposits. Further study and research may reveal new manganese deposits which may have formed in association with Tapley Hill Formation sediments.

ACKNOWLEDGEMENTS

My sincere thanks must go to my supervisors, Prof.L.A.Frakes and Mr.B.R.Bolton, for initiating this project and for supplying experienced guidance throughout the year. Thanks must also go to Mr.B.Pracejus for his interest in the project.

Financial assistance during the field work and preparation of this thesis was generously provided by B.H.P. Company Limited and was greatly appreciated.

The Technical Staff of the Department of Geology and Geophysics must be thanked due to their outstanding help throughout the year. Mr.P.McDuie and Mr.J.Stanley for their help during geochemical analyses; Mr.G.Trevelyan and Mr.W.Mussarad for the manufacture of thin and polished sections; Mrs.C.Badcock for XRD work; Mr.E.Bleys for help with fluid inclusions; Dr.K.Turnbull for conducting a sulphur isotope study of my barite; Mrs.F.DeLaine for help with drafting and Mr.R.Barrett for the photography.

Thankyou All.

Finally my love and my deepest appreciation must go to my two families. The first being my family at home; Thanks to Mum, Dad, Nigel and Donna for supporting my University career. All those years of study have now finally paid off.

My second family is the other nine Honours Geology Students who I saw nearly every day in the Geology Department. Melissa, Louise, Bob, Phung, Bruce, Brett, Steve, Alison and Justin. Thanks for your company, your support, and your insanity.

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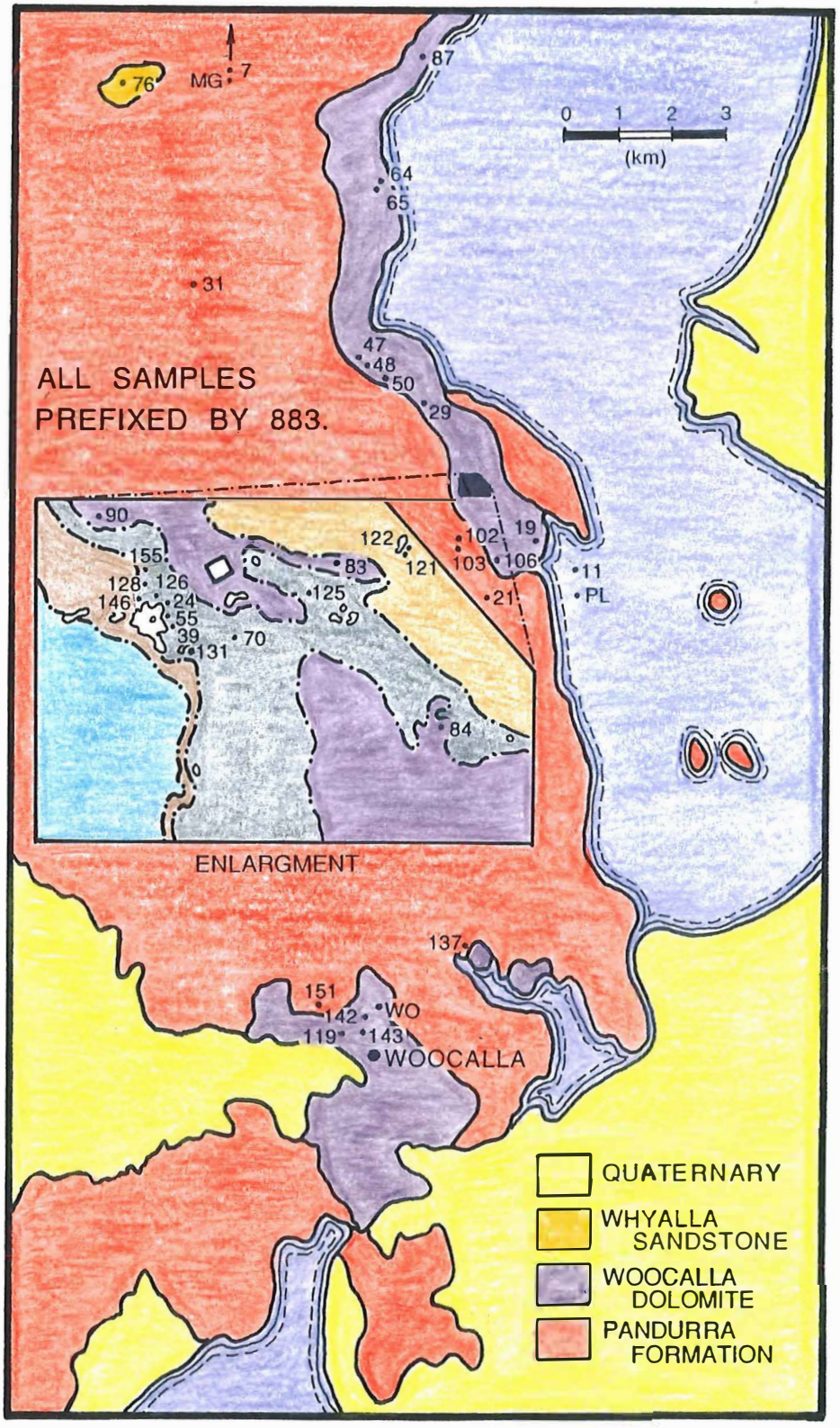
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Sample Locality Map



APPENDIX B

HANDSPECIMEN AND THIN SECTION DESCRIPTIONS

I. SAMPLE IDENTIFICATION

883.102 PANDURRA FORMATION, PERNATTY LAGOON

II. FIELD RELATIONS

This specimen is from a major outcrop of red sandstones/ quartzites, which form extensive cliffs down the southern section of the mapping area, adjacent to the lagoon. The outcrop consists of a massive, thickly bedded sandstone which contains distinct cross-bedding and graded bedding and minor siltstone layers, (refer Part VI below). Each bed has a large lateral extent and in general is flat-lying. The quartzite has undergone later iron-enrichment with the formation of extensive liesigang banding in most outcrop profiles. This banding transects the original bedding at acute or oblique angles and is formed by variations in iron-oxide contents as groundwaters perculate through the sandstone layers.

III. HAND SPECIMEN DESCRIPTION

A red, fine to coarse grained sandstone. Graded bedding is present with quite good sorting within the bands. Medium grained sands compose a majority of the rock. All grains are subrounded. The quartzite is sutured, however there is a small content of white cement infilling between grains.

IV. THIN SECTION DESCRIPTION

The texture of the thin section reveals large, rounded quartz grains somewhat sutured together. Overgrowths on the quartz grains are quite extensive, with the original grain margins marked by the occurrence of inclusions or iron oxide "dust". Many have overgrowths in optical concordance with individual crystal members of the quartz grain. The grains are also surrounded by some extent by a cement. Grain size varies from 0.1mm to 3mm, however the average is approximately 0.5mm to 1mm.

The mineralogy consists of two main elements. The major component is quartz. The uniaxial, positive mineral appears grey in plane polarized light and reveals undulose extinction. Suturing is quite evident. The percentage of quartz in the slide is approximately 75 to 85 percent, with a increased percentage in coarse grained layers and a smaller percentage in the finer grained layers.

The other main mineral fills the gaps around the quartz grains. It has (under plane polarized light) a mottled texture which seems to be composed of a multiple of smaller grains. This is probably a secondary silicification of the rock with polycrystalline quartz filling in the gaps of the sandstone. The large amounts of silcrete found in this area, indicates that a great deal of secondary silicification has occurred to all the rock types present in the Pernatty Lagoon area.

V. INTERPRETATION

This red sandstone represents a mature sandstone deposited in a fluvial environment. During the lithologies latter history it has been influenced by a number of processes resulting in suturing and overgrowth formation.

VI. ASSOCIATED HANDSPECIMEN DESCRIPTIONS

883.31 PANDURRA FORMATION WITH CLAY, PERNATTY LAGOON

This handspecimen differs from the rock type described above. Overall it consists of a red, sandstone with fine to coarse, subangular to subrounded grains. There may be minor graded bedding. The difference is its large content of clay. The white-pinkish clay comprises approximately 5 percent of the handspecimen, where it infills the voids between the quartz grains, hence it may be some type of cement. It is not calcareous. It is concentrated in the coarser layers, obviously due to the lack of compaction and the increased porosity of larger grained sediment.

883.103 SILTSTONE FROM PANDURRA FORMATION, PERNATTY LAGOON

The handspecimen is part of the outcrop described in full above. Forming a number of minor layers through the Pandurra Formation sandstones is a fine grained siltstone. It is yellowish in colour and very friable. Minor, low angle cross-bedding was found however a majority of the siltstone consists of flat-lying beds.

Mineralogy consists of very fine grained silt and quite a large proportion of muscovite, subsequently resulting in the fine bedding of the rock.

I. SAMPLE IDENTIFICATION

883.21 FERRICRETE, PERNATTY LAGOON

II. FIELD RELATIONS

Outcropping at the top of the Pandurra Formation, at one particular stratigraphic level throughout the field area is a heavily iron-stained hardground. To the south it can be seen to grade down into Pandurra Formation sandstones. The ferricrete is sometimes composed of Pandurra Formation pebbles up to 10cm which show original cross-bedding and have a limonite cap. Other outcrops consist of sand grains all cemented by ferricrete.

III. HAND SPECIMEN DESCRIPTION

Small, rounded Pandurra Formation pebbles ranging in size up to 3cm are quite altered by iron enrichments. The pebbles are surrounded by a gritty, heavily iron-stained matrix which completely invades the rock.

IV. THIN SECTION DESCRIPTION

The iron-stained matrix consists of fine-grained quartz (0.1mm to 0.4mm) fragments which are quite angular but moderately well sorted. All these quartz grains are completely surrounded by hematite rinds with only minor amount of suturing. A number of grains have undulose extinction.

The altered Pandurra Formation pebbles consist of moderately well-rounded quartz grains which do reveal overgrowths and suturing. However the grains are surrounded by a fine-grained, highly altered, brown to yellow matrix.

V. INTERPRETATION

This rock initially represented a palaeoweathering profile where weathered Pandurra Formation pebbles and sands accumulated on the surface. Iron-enrichment most likely occurred due to iron-rich groundwaters perculating through sediments, eventually cementing the pebbles and sand grains together. The water must have been trapped within the sediments to get the hematite rind around the unconsolidated quartz grain matrix. Further perculation through the sediment resulted in the alteration of the clay matrix in the Pandurra Formation pebbles resulting in the altered appearence today.

I. SAMPLE IDENTIFICATION

"McLEAY BEDS", PERNATTY LAGOON

883.64 RED SANDSTONE
883.65 CONTACT BETWEEN RED SANDSTONE AND OVERLYING DOLOMITIC BROWN SANDSTONE

II. FIELD RELATIONS

Outcropping in a creek bed in the northern section of the mapping area, is a red sandstone (883.64) which contains subrounded dolomite clasts. Overlying this is a darker brown sediment (883.65) again containing dolomite clasts. This whole sequence is overlain by massive brecciated and oolitic Woocalla Dolomite. The sandstone has a gently undulating surface and is nearly flat-lying with only a shallow dip towards the east.

III. HAND SPECIMEN DESCRIPTIONS

883.64

As indicated above, the underlying red sandstone does contain dolomitic fragments. The dolomite fragments however, differ from the clasts in the upper sandstone unit. In this lower sandstone they appear more angular and grey in colour.

The reddish sandstone unit is a medium to coarse grained, well rounded sandstone. The occasional larger grain is present with some angular fragments ranging in size up to 3mm. The sandstone also contains a number of red and orange coloured grains, which are volcanic fragments interpreted as Gawler Range Volcanic equivalents, (A.Purvis, pers.comm.).

883.65

The hand specimen reveals the contact between the underlying red sandstone and the overlying brown, dolomitic sediment.

The contact with the brown, dolomite-clast sandstone is quite dramatic and sudden. Similar coarse sand grains are present in this upper sandstone unit, however a darker, fine grained sediment predominates. The upper sandstone is less well sorted than the underlying sandstone. It includes large, fine grained pinkish-red dolomite clasts (with no obvious internal laminations) which range in size from 0.5cm to 3cm. They are well rounded, and occupy particular levels within the unit. The clasts are sometimes underlain by calcareous crystal growths.

IV. THIN SECTION DESCRIPTIONS

883.64

This sandstone consists predominantly of coarse grained quartz sands ranging in size from 0.5 mm to 1 mm. These grains are very well rounded and have large and extensive quartz overgrowths which fill in the voids between neighbouring grains and have optical concordance with their parental quartz grains.

The subangular dolomite fragments consist of microcrystalline dolomite that appear to have some basic internal laminations. They also contain ooids and other dolomitic

intraclasts. The contact with the quartzose sandstone is interesting as the quartz grains seem to be bedded into the dolomite with microcrystalline dolomite infilling nearby voids and fractures.

883.65

The lower red sandstone, next to the contact with the brown dolomitic sandstone, is a poorly sorted sandstone with constituent grains ranging in size from 0.2mm to 1mm. It appears bimodal in nature with a large number of moderately well rounded grains less than 0.1mm The other quartz grains range in size from 0.5mm to 1mm, these show undulose extinction and the occasional quartz overgrowth and are generally well rounded. There is minor suturing of these quartz grains. There is a minor amount of calcareous cementation. Other clastics present include microcline feldspar (minor) and the weathered volcanics found as iron-altered grains seen in hand specimen. There are only a few opaques present.

The dolomite clasts are pinkish and consist of fine grained polycrystalline material which has some minor internal layering, including the occasional quartz grain. This material is generally very finely grained however the occasional clast may have a slightly coarser texture.

Surrounding the dolomite clasts is a matrix of quartz grains and calcareous cement. The quartz grains range in size from 0.1mm to 0.3mm, however a majority of the grains are in the upper size range (i.e. 0.3mm). Some quartz grains do show overgrowths and undulose extinction. The quartz grains make up around 50 percent of the matrix. The other 50 percent of the area is composed of calcareous fragments which have cemented the quartz grains. This cement is predominantly dolomite crystals. There is some multiple twinned plagioclase feldspar.

V. INTERPRETATION

The interpretation of this outcrop is important as it most probably represents a period of sedimentation just prior to the formation of the Woocalla Dolomite. The sequence indicates the transgression of the ancient Woocalla Sea onto the stable Pandurra Formation shelf.

The red sandstone layer initially has one mode of quartz grain size than much closer to the contact where it becomes bimodal with the introduction of finer sediments. This indicates the reworking of Pandurra sediments in a possible beach environment. Dolomite is forming elsewhere with fragments and oolites washed inshore. The transgression of water over this unit resulted in the brecciation of the dolomite and the deposition of dolomite clasts and sand. The brown calcareous sandstone indicates a mildly reducing environment, possibly within shallow water.

The outcrop is overlain by classical Woocalla Dolomite suggesting a further transgression of the Tapley Hill Formation Sea.

VI. ASSOCIATED HANDSPECIPEN DESCRIPTIONS

883.137 "McLEAY BEDS", FAIR NELL

Similar to the other occurrences of this sandstone, at Fair Nell a thin unit of reworked Pandurra (or pre-Woocalla Sandstone) existed between the Pandurra and the overlying Woocalla Dolomite. The handspecimen consists primarily of subrounded, red quartz grains. These grains are poorly sorted with no evidence of graded bedding. Grain size ranges from fine to gravel size and includes a small number of red sandstone pebbles.

883.151 "McLEAY BEDS", WOOCALLA

A weathered and generally loosely consolidated sandy and silty unit which has been cemented by iron to a small extent. This unit also contains subangular quartzite clasts representing reworking of weathered Pandurra Formation sediments.

I. SAMPLE IDENTIFICATION

The following three WOOCALLA DOLOMITE specimens were taken from around the main manganese working at PERNATTY LAGOON, to try and determine any mineralogical differences between different areas.

883.11 OUTCROPPING ON LAGOONAL ISLAND 2 KM SOUTH OF THE MAIN WORKINGS
883.84 OUTCROPPING MARGINALLY DOWNSTREAM FROM WORKINGS
883.90 OUTCROPPING UPSTREAM FROM WORKINGS

II. FIELD RELATIONS

The yellow-brown, buff or grey dolomite outcrops around the margin of the workings, and elsewhere in the field area. However at the main manganese workings it is only half a metre above the lagoon level where clays occur in the low lying areas of the lagoon. The dolomite reveals a strong stromatilitic nature, with crenulations and small domes containing a minor amount of manganese. The outcrop is generally flat-lying.

III. HAND SPECIMEN DESCRIPTIONS

883.11

Small buff-coloured LLH-C stromatolites, with a small quantity of manganese concentrated along particular layers.

883.84

A crenulated stromatalitic dolomite which seems to have a slightly increased manganese concentration. Areas that have a high number of voids seem to be stained darker than areas without voids, resulting in a banded nature.

883.90

A crenulated stromatalitic dolomite that appears buff-brown in colour with dark black clays revealed in particular internal laminae and within minor fractures which cut the specimen. Dolomite fine grained but does contain many small (0.2mm to 1mm) voids within the structure. These holes are occasionally filled with a dark manganese clay especially when fractures cut the dolomite, suggesting that water perculating through the dolomite result in precipitation of manganese in fractures and porous void areas.

IV. THIN SECTION DESCRIPTION

883.11

Polycrystalline dolomite that has been stained along fractures by iron and manganese. Voids contain manganese-oxide precipitation around the perimeter and in some cases are completely filled with opaque materials. Manganese rich voids all

seem to occur along one particular level in the crenulated dolomite. Darker layers seen in the handspecimen, is fine-grained dolomite whereas light layers are composed of larger dolomite crystal growths.

883.84

Microcrystalline dolomite. A large amount of opaques is observed in particular layers especially where voids are present. Reflected light reveals an off-white mineral species, identified as pyrolusite.

883.90

The texture of the thin section reveals the polycrystalline nature of the dolomite and the amount of opaques (20 to 25 percent). Similar features to those described in the hand specimen can be seen in this section. A majority of the opaques occur in cross-cutting fractures and veins and within larger, rounded pods. (Suggesting infill of voids). Some of the voids are only partly infilled by the opaque material, only occurring around the circumference of the void. Areas which have more opaques (or where opaques are present), the dolomite appears slightly bleached. Minor amount of quartz (< 1%).

Reflected light reveals the nature of the opaques. Disseminated throughout the entire slide is a white mineral. In veins it sometimes appears in a fibrous nature. A darker grey mineral is also present suggesting further remobilization of manganese has occurred.

V. INTERPRETATION

The Woocalla Dolomite is generally a microcrystalline dolomite that has been influenced by varying degrees, by groundwaters circulating through the area. Manganese minerals have precipitated in fractures and voids within the dolomite, due to the increased porosity and permeability of voids which dominate along particular bedding-planes.

I. SAMPLE IDENTIFICATION

883.47 OOLITIC DOLOMITE, PERNATTY LAGOON

II. FIELD RELATIONS

Forming above the stromatolitic carbonate platform is oolitic shoals, which represent the redistribution of ooids, across the platform by storm processes. Many were observed in protected areas suggesting they were trapped in protected environments. This is the situation for this sample, as it is found near the Northern Workings at the contact between the Woocalla Dolomite and McLeay Bed sandstones.

III. HAND SPECIMEN DESCRIPTION

The sample has a speckled appearance with a number of white minerals being surrounded by a dark black matrix. The rock is highly porous and only slightly calcareous. The white minerals present are quartz grains, which are medium to fine grained, well sorted, and moderately well rounded.

IV. THIN SECTION DESCRIPTION

Observing the thin section through a transmitting microscope a number of different minerals are present. The first most noticable feature is the amount of quartz occurring in the thin section. This accounts for 50 to 60 percent of the area. The rest of the area is dominated by opaque minerals. Under the reflecting microscope it can be noted that some quartz grains form the nucleusof the ooids and are surrounded by a manganese-rich cortex. All ooids and quartz grains are surrounded by a manganese-rich matrix. Larger quartz grains in the slide do not seem to have any affinity towards the ooids but are obviously mixed up with the original ooid shoal.

Mineralogy of the opaque materials is revealed by the use of the reflecting microscope and X-ray diffraction work, with cryptomelane comprising the manganese-rich cortex and matrix. The ooid cortex has a greenish tinge, which is due to the high inclusion content. This forms 80 percent of the opaque matter in the slide, with the other 20 percent also composed of cryptomelane, which fills in the voids between ooids and quartz grains, but does not have the inclusion contaminants.

V. INTERPRETATION

The interpretation of ooids suggests they form in a high energy tidal environment where strong water currents wash the rounded ooids around, precipitating carbonate. The large amount of quartz indicates a mixing of intertidal zones and beach sands.

The manganese is present as cryptomelane which forms in specific environments. Described by Frenzel (1980), as being a supergene mineral formed under the influence of oxygen, evolving directly from weathering of other manganese mineral species.

Ostwald(1975) indicates that under the microscope the material is variable in form and optical properties, due to variations in chemical composition and degree of crystallinity.

This suggests that the manganese-rich ooids could probably be formed from the alteration of carbonates as manganese-rich waters perculated through the sediments. Alternately the ooids could be the product of colloidal precipitation in a shallow sea.

VI. REFERENCES

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OSTWALD,J.,(1975): Mineralogy of Manganese-oxides from Groote Eylandt. Mineral. Deposita, Vol.10, p.1-12

I. SAMPLE IDENTIFICATION

883.87 BRECCIATED WOOCALLA DOLOMITE, PERNATTY LAGOON

II. FIELD RELATIONS

This specimen is from the north-east section of the study area. The outcrop was sampled because of the brecciated nature of the dolomite and the obvious manganese content. The outcrop was only a few metres in length and 30cm in vertical relief. This outcrop is stratigraphically important because overlying this unit is a manganese-strained sand unit which contains dolomite fragments. Tabular voids are created in the sandstone, due to the dissolution of the dolomitic fragments.

III. HAND SPECIMEN DESCRIPTION

Differential weathering reveals the flat-lying tabular fragments of dolomite which compose the outcrop. The average thickness of the tabular clasts is 1cm with a number of fragments becoming brecciated. The dolomite contains internal laminations. The breccia is surrounded by a dark (possibly manganese-rich) clay.

IV. THIN SECTION DESCRIPTION

Transmitted light reveals the texture of the slide. Opaques surround and fill the voids between the brecciated dolomite fragments. Opaques also occur within the dolomite clasts, where they appear to fill any voids present. Fractures cutting the dolomite are also filled with the opaque materials.

Study under reflected light reveals the nature of the opaque minerals. A white mineral which has a distinct cleavage and consists of a number of individual crystals, is identified as pyrolusite. Fractures cutting through this mineral reveal a darker, pleochroic mineral replacing the first. This slightly anisotropic mineral has a dendritic mineral growth pattern which replaces initial mineral occurrence.

V. INTERPRETATION

The formation of this brecciated rock was either contemperaneous with the formation of the Woocalla Dolomite, or during a post-Woocalla stage. The latter scenario is the most probable theory due to the field evidence found. After the formation of calcareous algal mats, a high energy event ripped up and redeposited the breccia with subsequent infilling of voids with manganese-rich clays and weathered sands. A further outcrop in the area revealed the same tabular clasts of dolomite, surrounded by sandstone.

Still further up-sequence is a medium to coarse grained sandstone which has tabular, angular voids. It is suggested that these voids were originally dolomite fragments but in the

outcrop's latter history, the clasts have been slowly dissolved and weathered away. The sandstone unit is found elsewhere in the field area and hence has an important consequence to the overall stratigraphy.

This sandstone unit (defined as the "Vuggy Sandstone") may be correlated to the "Yudnapinna Beds" and probably represents a phase of sedimentation after the formation of the Woocalla Dolomite, indicating a beach (or similar environment), where sands wash over weathered, fragmented dolomite.

I. SAMPLE IDENTIFICATION

883.7 WOOCALLA DOLOMITE, MT.GUNSON

II. FIELD RELATIONS

The dolomite outcrops marginally above lagoon level and forms the typical Woocalla Dolomite occurrence at Mt.Gunson. Towards the west this unit unconformably overlies the Pandurra Formation basement.

III. HAND SPECIMEN DESCRIPTION

Buff-brown dolomite containing a large number of small ooids. There is also a small amount of other angular dolomite fragments which are mixed in with the ooids. Some manganese enrichment has occurred in the handspecimen with the occasional deeply stained section.

IV. THIN SECTION DESCRIPTION

The dolomite is composed of ooids (0.2 to 0.5 mm) within a dolomitic matrix. The ooids are polycrystalline dolomite whereas the matrix is much coarser grained. The nucleus of the ooids is generally absent however the occasional ooid may have a quartz grain as its nucleus. In some cases the matrix is an opaque material and it appears to stain the usually light brown ooids a slightly darker brown colour. The slide also has an area where only opaques predominate. They only get the occasional (<5%) quartz grain within this area.

Under reflecting light the opaque material found in the slide is composed of two mineral species. The ooids have a concentric nature with manganese-species predominating at particular levels in the ooids.

V. INTERPRETATION

Ooids form today in shallow marine environments where movement by tides results in the gradual accretion of calcite or aragonite around a nucleus. This results in the concentric nature of the ooid cortex. Manganese alteration may have occurred, resulting in the replacement of calcium by manganese ions in the crystal lattice.

I. SAMPLE IDENTIFICATION

883.29 MANGANESE ORE, BIG CUT MINE, PERNATTY LAGOON

II. FIELD RELATIONS

The Big Cut manganese deposit is found at the boundary between the Woocalla Dolomite and the Pandurra Formation sandstone basement. Forming marginally below the present-day land surface, the ore was exposed during mining operations in the area.

III. HAND SPECIMEN DESCRIPTION

A dense, manganese rich pod which contains layering (2mm to 3mm thick) and small metallic crystals within the specimen along particular layers and surrounding void areas. Minor yellow clays in the specimen tend to concentrate along particular layers. Some layers appear more competent than others, with metallic minerals forming the harder, more competent layers. The sample has a very high density due to the large amount of metallic elements within it.

IV. POLISHED SLAB DESCRIPTION

The polished slab reveals alternating layers of medium-grained white material and fine-grained darker material. Cutting through both units are veins of larger whitish crystals, probably suggesting remobilization of manganese-rich solutions and precipitation of manganese minerals. X-ray diffraction work has revealed that the major mineral species present is pyrolusite.

V. INTERPRETATION

This specimen represents the ore originally mined from the Big Cut Mine. The concentration of particulate manganese-oxides in an oxidizing environment would result in the layering observed in the specimen. Latter history has resulted in manganese remobilization along fractures. The pure nature of the sample suggests it has not been contaminated a great deal during the time since deposition.

I. SAMPLE IDENTIFICATION

883.67 "VUGGY SANDSTONE", PERNATTY LAGOON

II. FIELD RELATIONS

Outcropping throughout the field area this unit was identified due to the angular vugs in the sandstone. It is generally only found as minor outcrops and found at many different levels.

III. HANDSPECIMEN DESCRIPTION

The handspecimen reveals the clastic nature of this specimen with the dominant constituent being moderately well-rounded quartz grains. A number of angular, tabular vugs are found and this rock also contains the occasional well-rounded red quartzite pebble.

IV. THIN SECTION DESCRIPTION

The thin section reveals that a majority of the rock is composed of well-rounded, moderately well-sorted, medium to coarse grained quartz grains. There has been a small amount of silicification and suturing in this sample. A number of weathered, well-rounded volcanic fragments are also found, including a green mineral identified as tourmaline (A.Purvis, pers.comm). A number of larger pebbles consist of highly sutured quartz grains which also have extensive quartz overgrowths.

V. INTERPRETATION

The similarities between this sample and the McLeay Beds suggest that both were formed with the same environment and the same source. The Pandurra Formation pebbles incorporated in this specimen and the weathered volcanics are very similar to the other clastic sediments in the area. The presence of the tabular vugs suggests that dolomite fragments formed from the rip-up of established calcareous algal mats,were mixed into the sands in a beach environment. This sequence most likely represents the regressive sands which washed over the Woocalla Dolomite, on regression of the Tapley Hill Formation Sea.

I. SAMPLE IDENTIFICATION

883.76 WHYALLA SANDSTONE, PERNATTY LAGOON.

II. FIELD RELATIONS

This specimen, from the north-west section of the study area, is an example of the Whyalla Sandstone. In outcrop the sandstone is predominantly flat-lying with minor, low-angle cross-bedding and ripple marks. The outcrop forms extensive cliff faces, with the silcrete cap forming a plateau surface. This rock type is only found in one location of the field area.

III. HANDSPECIMEN DESCRIPTION

The handspecimen reveals the sandstone characteristic of the Whyalla Sandstone in this area. The quartz dominated sandstone reveals moderately well sorted, coarse grained sands. The quartz grains are surrounded by a white clay, which comprise approximately 10 percent of the specimen.

IV. THIN SECTION DESCRIPTION

The thin section reveals the mineralogy described above, with quartz grains make up a majority of the slide. There appears to be a bimodal nature to the quartz grain occurrence. Most grains are 0.5 to 2.0 mm in size, well rounded with no quartz overgrowths and only the occasional grain with undulose extinction. Some larger grains, up to 3 mm consist of heavily sutured grains, hence suggesting a previous quartzite being weathered and eroded, with some of its fragments forming this sandstone unit. The other grain size mode is around 0.1 mm with these smaller grains comprising approximately 20 percent of the slide.

Surrounding all the grains, is a very fine grained clay matrix which fills all the gaps and voids in the slide. It is brownish under ordinary light and slightly birefringent under cross-polars.

V. INTERPRETATION

The Whyalla Sandstone is generally considered to be aeolian in origin with large scale cross-bedding forming due to sand dunes. However this exposure of the sandstone is basically flat-lying and suggested by Williams and Tonkins (1985) to be the basal sequence. Its low angle cross beds and minor ripple marks suggest it was probably formed in a lacustrine environment adjacent to ancient sand dunes.

VI. REFERENCES

WILLIAMS,G.E. and TONKIN,D.G.,(1985): Periglacial Structures and Palaeogeographical Significance of Late Precambrian Block Fields in the Cattle Grid Copper Mine, Mt.Gunson, South Australia. Aust.Jour.Earth Science, Vol.32, p.287-300

I. SAMPLE IDENTIFICATION

883.31 SILCRETE, PERNATTY LAGOON

II. FIELD RELATIONS

The silcrete residuals found in the mapping area, are very similar to the classical Terrazzo-type silcrete described by Smale (1978). That is, it takes the form of quartz grains of varying shape and roundness, surrounded by a cement of cherty, polycrystalline silica.

However this specimen was chosen as it is a varient on this standard silcrete type. It was found associated with the classical silcrete and suggests a similar and possibly synchronous formation. It has the same surface expression as the ordinary silcrete, however this specimen contains red quartzite gravels instead of coarse quartz grains.

III. HAND SPECIMEN DESCRIPTION

The hand specimen is dominated by red, medium to coarse grained quartzite clasts, which are iron stained. These clasts are subangular to subrounded and range in size from 3mm to 1cm. The clasts are surrounded by an uneven texture of very fine grained polycrystalline silica and coarse quartz grains.

The silica cement is disseminated throughout the hand specimen, however most of the cement is found around the quartzite clasts. The coarse quartz grains that infill around the quartzite clasts are also cemented by the silica cement.

IV. THIN SECTION DESCRIPTION

The larger red quartzite clasts consist of quartz grains from 0.3mm to 0.6mm, with others having quartz grains up to 1mm. The quartz are completely sutured together within the clast, they have extensive and complete quartz overgrowths and undulose extinction. Another grain appears to be composed of two quartz growths. That is, a majority of the clast undergoes extinction at one particular angle, whereas the blebs which cover the clast all undergo extinction at another angle. This suggests that the blebs are a secondary growth and formed in one discrete event. Other clasts contain polycrystalline cements formed from earlier cementation. Hence the clast was weathered from a previous silicified rock, redeposited and finally involved with the formation of the present silcrete.

The matrix surrounding the quartzite clasts consists predominately of quartz grains ranging in size from 0.05mm to 1mm. There is an obvious bimodal nature of the grains. A majority of the grains are 0.1mm in size, they are angular and undergo undulose extinction. The other grain size mode is 0.3mm to 0.4mm, however they tend to be rounded. All the grains are surrounded by a polycrystalline silica cement, with opaques approaching a slide concentration of approximately 5 percent.

V. INTERPRETATION

As stated above, the silcrete forms as a result of silica cementing of the landscape. Terrazzo-type silcrete forms as silica cements weathered sands. This rock forms from the same silicification process, but has cemented both sand and small, rounded quartzite clasts.

VI. REFERENCES

SMALE,D.,(1978):Silcretes and Associated Silica Diagenesis in Southern Afica and Australia. In, T.Langford-Smith and S.H.Watts (eds) Silcrete in Australia. Publ.Uni.New England, p.261-267

I. SAMPLE IDENTIFICATION

883.106 MANGANESE-RICH STROMATOLITE, PERNATTY LAGOON.

II. FIELD RELATIONS

This specimen is found in the southern section of the lagoon and is important due to the very high concentration of manganese. It outcrops just above lagoon level.

III. HAND SPECIMEN DESCRIPTION

This fine grained specimen is part of a domal stromatolite, stained almost completely black. However the stromatolitic internal layering can still be seen.

IV. THIN SPECIMEN DESCRIPTION

Under transmitting light the large percentage of opaque can be seen. They however, are concentrated into certain layers. The rest of the slide contains microcrystalline dolomite with a mottled brown texture.

Under reflecting light the mottled texture is evident. Two different manganese mineral types are present. The majority of the opaques consist of a manganese-mineral that appears white. It has been altered to some extent. This white mineral is disseminated right throughout the slide, infilling gaps between the fine calcareous material.

V. INTERPRETATION

The manganese-rich areas in the dolomite generally occur in particular layers. They predominate in areas with a large number of voids and the suggested formation is due to ionic manganese percolating through the dolomite. Individual layers which contain the voids, have a higher porosity and permeability than the rest of the rock and so this is where the manganese is most likely to be found. The precipitation of manganese in the voids results in the manganese-enrichment of the dolomite and stains it black.

APPENDIX C

GEOCHEMICAL ANALYSES

ANALYSIS OF MANGANESE SAMPLES

A. WHOLE ROCK GEOCHEMICAL ANALYSIS

1. Weathered rock surfaces were removed and larger samples were crushed in a jaw crusher. The crushed sample was finely ground using a Siebtechnik tungsten carbide mill.

2. The whole rock analysis continued with approximately three grams of finely ground sample ignited at 960° C overnight, to determine the percentage loss of volatiles.

3. 280 mg of ignited powder was weighed out with 20 mg of sodium nitrate and 1.5 grams of lithium tetraborate flux. The mixture was heated in a platinum crucible by Mr.P.McDuie, to form a fused disk.

4. This fused disk was then analysed on the Siemens SRS X-ray Spectrometer by Mr.J.Stanley.

5. Na_2O determination was achieved by taking approx. 30 mg of each sample and digesting it in an acidic solution of 50% H_2SO_4 and 50% 0.1M HF, within teflon beakers. The digested solutions were then made up to 100 ml volumes using a volumetric flask.

6. The Na_2O concentration was then determined using the AAS against known standards.

B. DIGESTION PROCEDURE

1. After weighing out 0.5 grams of dried, unignited sample into a clean dry 50 ml teflon beaker, wet the sample with a few ml of deionised water and then add 5 ml of conc.HCl acid.

2. Cover the beakers and place on a hotplate and heat them for 1 hour at 180 C. Remove covers after washing residue back into the beaker and place back on hotplate to reduce volume.

3. Remove from the hotplate and add 2 ml of conc.$HClO_4$ acid and 10 ml of conc.HF acid, then reheat at 180 C until the solutions have evaporated completely away.

4. Take beakers from the hotplate and add 10 ml of conc.HCl, then add to each 10 ml of La/Zr solution (20,000ppm La/ 10,000ppm Zr). The solutions are now ready to be made up to volume (100 ml).

5. Transfer the contents of the beaker into a 100 ml volumetric flask, adding 2 ml of 6 w/v K solution, then make the solution up to the mark with deionised water.

6. Transfer solution to a 100 ml plastic bottle with this solution now being ready for Atomic Absorption Spectroscopy (AAS).

C. OPERATING CONDITIONS FOR AAS

ELEMENT	LAMP CURRENT(mA)	LINE(nm)	SBP(nm)	FLAME TYPE
Fe	8	372.2	0.2	N_2O/Acet
Mn *	5	279.5	0.2	N_2O/Acet
Ba	20	553.6	0.2	N_2O/Acet
Sr	10	460.7	0.2	N_2O/Acet
Cr	5	357.9	0.2	N_2O/Acet
Co *	8	240.7	0.5	Air/Acet
Ni *	8	232.0	0.5	Air/Acet
Cu *	3	324.7	0.5	Air/Acet
Pb *	10	217.0	1.0	Air/Acet
Zn *	5	213.9	0.5	Air/Acet

* - Denotes background correction used.

PANDURRA FORMATION - Pernatty Lagoon

Sample No. 883.102

Major Elements (%)		Trace Elements (ppm)	
SiO_2	93.87	Ba	189
Al_2O_3	4.24	Co	354
Fe_2O_3	0.14	Cr	< 10
MnO	0.00	Cu	7
MgO	0.22	Ni	< 14
CaO	0.11	Pb	13
Na_2O	0.05	Sr	152
K_2O	0.29	Zn	16
TiO_2	0.15		
P_2O_5	0.07		
Loss	(1.96)		
TOTAL	99.14		

FERRICRETE - Pernatty Lagoon

Sample No. 883.21

Major Elements (%)		Trace Elements (ppm)	
SiO_2	84.78	Ba	783
Al_2O_3	1.02	Co	139
Fe_2O_3	13.51	Cr	13
MnO	0.02	Cu	5
MgO	0.23	Ni	< 14
CaO	0.09	Pb	< 10
Na_2O	0.05	Sr	29
K_2O	0.10	Zn	21
TiO_2	0.19		
P_2O_5	0.05		
Loss	(2.31)		
TOTAL	100.04		

BACKGROUND TRACE ELEMENT ANALYSIS OF THE WOOCALLA DOLOMITE

1. Using AAS

Sample Location	883.WO WOOCALLA	883.PL PERNATTY LAGOON	883.MG MT.GUNSON
Mn (ppm)	4807	7203	6856
Fe (ppm)	6203	8185	13191
Ba (ppm)	112	238	71
Co (ppm)	< 6	1957	117
Cr (ppm)	19	< 10	< 10
Cu (ppm)	8	12	18
Ni (ppm)	< 14	23	23
Pb (ppm)	< 10	< 10	< 10
Sr (ppm)	71	136	93
Zn (ppm)	20	30	101

2. Using EMP

	Analysis No.					
	1	2	3	4	5	6
Major Elements (%)						
SiO_2	0.37	0.11	0.24	0.23	0.23	0.31
Al_2O_3	0.22	0.20	0.39	0.27	0.32	0.17
Fe_2O_3	0.18	0.95	1.66	1.97	0.24	-
{ Fe (ppm)	0.13	0.66	1.16	1.38	0.16	- }
MnO	0.56	0.63	0.89	0.81	1.27	1.21
{ Mn (ppm)	0.43	0.49	0.69	0.63	0.98	0.93 }
MgO	21.28	20.66	20.25	20.04	20.33	20.53
CaO	28.49	28.57	27.87	27.51	29.35	28.62
SO_3^{2-}	-	-	-	0.13	0.30	-
Cl^-	-	-	-	0.06	0.09	-
P_2O_5	0.11	0.14	0.19	0.26	0.24	-
TOTAL	51.21	51.26	51.50	51.28	52.36	50.84

Mn x = 6900 ppm o = 2100 ppm

Fe x = 7000 ppm o = 5100 ppm

WOOCALLA DOLOMITE

Sample No.	883.19	883.83	883.106	883.142	883.143
Major Elements (%)					
SiO_2	1.56	2.40	1.97	10.73	8.56
Al_2O_3	0.87	0.71	0.30	2.84	2.08
Fe_2O_3	22.91	10.92	1.80	2.52	2.60
MnO	66.58	9.64	29.20	3.20	2.95
MgO	1.01	31.42	26.01	32.72	34.37
CaO	0.59	42.37	34.33	45.66	47.76
Na_2O	0.90	0.01	0.24	0.01	0.00
K_2O	0.05	0.02	0.03	0.21	0.03
TiO_2	0.03	0.04	0.03	0.21	0.18
P_2O_5	0.11	0.12	0.16	0.13	0.10
Loss	(14.51)	(40.85)	(36.54)	(42.25)	(43.34)
TOTAL	94.61	97.63	94.06	98.22	98.65
Trace Elements (ppm)					
Ba	3422	na	928	2312	na
Co	112	46	53	7	na
Cr	29	17	17	14	na
Cu	759	8	66	26	na
La	70	na	23	9	na
Ni	31	43	8	8	na
Pb	11	< 8	29	23	na
Rb	3	na	1.1	16	na
Sc	25	na	6.9	na	na
Sr	828	na	527	146	na
V	109	na	71	77	na
Zn	133	132	85	16	na
Zr	36	na	16	28	na

PRIMARY MANGANESE LAYER

Sample No.	883.24	883.126
Major Elements (%)		
SiO_2	3.21	15.19
Al_2O_3	1.09	5.57
Fe_2O_3	6.07	8.27
MnO	80.06	41.62
MgO	1.02	2.24
CaO	0.74	0.30
Na_2O	0.75	1.97
K_2O	0.05	0.06
TiO_2	0.02	0.28
P_2O_5	0.15	0.13
Loss	(13.66)	(21.19)
TOTAL	93.15	75.61
Trace Elements (ppm)		
Ba	108	v.high
Co	26	na
Cr	17	na
Cu	26	na
La	117	72
Ni	48	99
Pb	11	na
Rb	2.3	25
Sc	13.5	13.1
Sr	489	883
V	149	76
Zn	252	na
Zr	23	80

BIG CUT AND NORTHERN WORKINGS MANGANESE ORE

Sample No.	883.29	883.48	883.50
Major Elements (%)			
SiO_2	0.99	34.09	34.99
Al_2O_3	1.02	5.63	4.73
Fe_2O_3	11.58	6.41	5.84
MnO	76.08	37.76	42.49
MgO	0.83	1.29	0.76
CaO	0.26	1.13	1.91
Na_2O	0.31	7.79	1.77
K_2O	0.07	1.00	2.61
TiO_2	0.03	0.15	0.27
P_2O_5	0.06	0.06	0.08
Loss	(11.45)	(23.02)	(9.87)
TOTAL	91.23	95.31	95.45
Trace Elements (ppm)			
Ba	6780	4941	679
Co	165	359	493
Cr	26	9	17
Cu	18	19	15
La	922	22	45
Ni	122	42	134
Pb	< 8	8	< 8
Rb	2.8	19	30
Sc	24	18.3	10.4
Sr	529	551	372
V	100	39	45
Zn	405	187	355
Zr	41	46	108

CEMENTATION THROUGH PRIMARY LAYER

Sample No.	883.55	883.128
Major Elements (%)		
SiO_2	7.67	6.01
Al_2O_3	3.62	5.64
Fe_2O_3	13.92	32.58
MnO	60.62	35.97
MgO	3.52	2.54
CaO	0.50	0.45
Na_2O	2.30	2.26
K_2O	0.05	0.05
TiO_2	0.11	0.09
P_2O_5	0.10	0.09
Loss	(22.34)	(24.34)
TOTAL	92.41	85.67
Trace Elements (ppm)		
Ba	high	high
Co	854	747
Cr	17	17
Cu	1124	318
La	198	56
Ni	278	588
Pb	< 8	< 8
Rb	15	14
Sc	6.4	4.6
Sr	1060	926
V	29	30
Zn	827	1122
Zr	22	22

LIMONITE UNIT (MAIN WORKINGS) AND LIMONITE AT WOOCALLA

Sample No.	883.119	883.146	883.155
Major Elements (%)			
SiO_2	12.88	58.80	17.18
Al_2O_3	4.99	1.53	1.77
Fe_2O_3	61.56	37.26	64.98
MnO	0.91	0.15	4.28
MgO	2.54	0.57	0.92
CaO	0.11	0.34	5.32
Na_2O	3.13	0.25	0.12
K_2O	0.15	0.34	0.42
TiO_2	0.23	0.11	0.12
P_2O_5	0.13	0.09	0.13
Loss	(13.84)	(5.85)	(11.79)
TOTAL	86.63	99.44	95.24
Trace Elements (ppm)			
Ba	high	3632	3660
Co	63	55	na
Cr	14	29	na
Cu	310	47	na
La	11	7	24
Ni	49	13	31
Pb	< 8	< 8	na
Rb	6	13	11
Sc	14.3	4.4	6
Sr	1273	70	345
V	42	50	54
Zn	239	91	na
Zr	74	41	24

WEATHERED LOW-LYING CLAY (MAIN WORKINGS)

Sample No.	883.39	883.70	883.125	883.131
Major Elements (%)				
SiO_2	5.78	9.02	9.74	4.07
Al_2O_3	3.51	2.16	1.94	1.32
Fe_2O_3	66.51	51.30	43.28	80.24
MnO	14.44	30.42	34.30	7.40
MgO	1.60	1.45	2.99	1.20
CaO	0.14	0.20	1.70	0.13
Na_2O	2.33	2.16	2.25	1.09
K_2O	0.16	0.28	0.20	0.05
TiO_2	0.25	0.12	0.13	0.05
P_2O_5	0.28	0.21	0.22	0.21
Loss	(14.46)	(13.44)	(14.87)	(95.76)
TOTAL	95.00	97.33	96.73	95.76
Trace Elements (ppm)				
Ba	4734	2337	na	na
Co	152	229	129	113
Cr	83	< 8	29	35
Cu	592	25	24	308
La	21	10	na	na
Ni	154	233	184	86
Pb	80	17	11	< 8
Rb	19	20	na	na
Sc	11	20	na	na
Sr	258	297	na	na
V	117	150	na	na
Zn	1304	2027	1290	340
Zr	60	35	na	na

WEATHERED PRIMARY LAYER

Sample No.	883.121	883.122
Major Elements (%)		
SiO_2	3.45	19.48
Al_2O_3	2.51	8.94
Fe_2O_3	6.23	28.22
MnO	72.24	27.49
MgO	3.61	4.25
CaO	0.91	0.60
Na_2O	1.92	7.72
K_2O	0.08	0.26
TiO_2	0.05	0.50
P_2O_5	0.04	0.15
Loss	(17.83)	(21.70)
TOTAL	91.03	97.61
Trace Elements (ppm)		
Ba	327	112
La	254	58
Ni	132	219
Rb	7	30
Sc	27	22
Sr	1265	30
V	374	268
Zr	46	149

Diamond Drill Hole No.4

	DDH4-1	DDH4-2	DDH4-3	DDH4-4
Depth (m)	0.35	1.40	1.60	2.15
Major Elements (%)				
SiO_2	16.87	25.06	54.47	1.80
Al_2O_3	3.95	8.86	15.44	1.03
Fe_2O_3	23.35	56.08	23.12	2.23
MnO	39.03	1.24	1.70	84.56
MgO	1.80	1.85	1.24	0.80
CaO	0.22	0.07	0.04	0.06
Na_2O	2.65	1.44	1.42	0.68
K_2O	0.38	0.57	0.60	0.01
TiO_2	0.18	0.53	1.07	0.14
P_2O_5	0.07	0.07	0.05	0.03
Loss	(14.54)	(12.95)	(10.72)	(13.55)
TOTAL	88.50	95.77	99.15	91.34
Trace Elements (ppm)				
Ba	54557	13276	2736	4277
Co	231	22	8	153
Cr	23	26	70	< 10
Cu	201	97	78	219
Ni	66	48	40	40
Pb	< 10	< 10	< 10	< 10
Sr	973	1778	142	223
Zn	147	73	257	294

APPENDIX D

MnO CONTENT OF STUART SHELF ROCK UNITS

Pandurra Formation - Mt.Gunson (11 samples)

	Mean(%)	Max(%)	Min(%)	σ(%)
SiO_2	86.40	93.31	58.67	9.85
TiO_2	0.30	1.25	0.06	0.33
Al_2O_3	7.20	24.04	3.75	5.86
Fe_2O_3	0.87	2.50	0.01	0.70
FeO	0.28	1.28	0.04	0.36
MnO	0.02	0.04	0.01	0.01
MgO	0.38	1.11	0.03	0.33
CaO	0.11	0.35	0.03	0.10
Na_2O	0.18	0.76	0.03	0.20
K_2O	1.56	4.42	0.09	1.18
P_2O_5	0.04	0.07	0.02	0.02
CO_3	0.30	0.70	0.05	0.22
SO_3	0.36	1.09	0.03	0.38
C	0.05	0.10	0.02	0.03

From:Knutson et al,(1983),(Table 1).

Gairdner Dyke Swarm - SADME Analyses

1:100,000 Map Series	Number of Analyses	MnO Readings for samples 100% Volatile Free (%)
6035	4	0.17, 0.17, 0.14, 0.18
6134	2	0.23, 0.20
6136	7	0.36, 0.45, 0.55, 0.33, 0.29, 0.46, 0.30
6137	4	0.92, 1.14, 0.21, 0.28
6237	10	0.29, 0.25, 0.17, 0.20, 0.20, 0.12, 0.31, 0.21, 0.28, 0.20
6332	2	0.18, 0.31
6335	16	0.42, 0.21, 0.45, 0.60, 0.68, 2.44, 4.33, 3.57, 2.59, 5.37, 2.44, 0.25, 1.05, 0.66, 0.36, 0.47

TOTAL MnO Samples 45 Mean 0.78 σ 1.15

Beda Volcanics - SADME Analyses

1:100,000 Map Series	Number of Analyses	MnO Readings for samples 100% Volatile Free (%)
6333	27	0.23, 0.22, 0.22, 0.21, 0.22, 0.24, 0.21, 0.22, 0.21, 0.24, 0.24, 0.20, 0.17, 0.20, 0.18, 0.18, 0.23, 0.21, 0.26, 0.24, 0.20, 0.22, 0.29, 0.19, 0.24, 0.26, 0.27
6334	25	0.11, 0.12, 0.14, 0.18, 0.18, 0.32, 0.18, 0.31, 0.32, 0.54, 0.55, 0.43, 0.43, 0.55, 0.65, 0.44, 0.44, 0.45, 0.04, 0.12, 0.18, 0.19, 0.02, 0.24, 0.48
6432	15	0.27, 0.26, 0.24, 0.24, 0.24, 0.22, 0.23, 0.25, 0.24, 0.22, 0.23, 0.21, 0.16, 0.18, 0.22,
6433	1	0.22
6434	10	0.58, 0.53, 0.34, 0.66, 0.50, 0.41, 0.31, 0.33, 0.25, 0.20

TOTAL MnO Samples 78 Mean 0.27 σ 0.13

Roopena Volcanics - SADME Analyses

1:100,000 Map Series	Number of Analyses	MnO Readings (%)
6233	6	0.22, 0.14, 0.64, 0.38, 0.28, 0.38
6332	48	0.12, 0.19, 0.15, 0.21, 0.13, 0.14, 0.23, 0.24, 0.25, 0.46, 0.13, 0.25, 0.46, 0.39, 0.17, 0.21, 0.15, 0.19, 0.12, 0.10, 0.22, 0.50, 0.20, 0.19, 0.47, 0.12, 0.19, 0.15, 0.21, 0.16, 0.16, 0.26, 0.18, 0.28, 0.35, 0.19, 0.57, 0.07, 0.05, 0.01, 0.21, 0.07, 0.15, 0.19, 0.26, 0.19, 0.15, 0.18
TOTAL MnO	Mean 0.223	σ 0.126

MAP A: THE GEOLOGY ALONG THE SOUTH-WESTERN MARGIN OF PERNATTY LAGOON, SOUTH AUSTRALIA.

INFERRED BOUNDARY
OUTCROP BOUNDARY
TRACK
CREEK
FENCE
MINE
TANK ; RUIN
OPEN CUT MINE
POWER TRANSMISSION LINE AND TRACK
BEDDING ; STROM. PREFERRED ORIENTATION
SAND DUNE

N
MN

0 1 2
(km)
SCALE

CAINOZOIC
QUATERNARY
ALLUVIUM: Gravels and sands in major drainage channels and alluvial fans.

LAKES: Salt, gypseous clays and silts.

TERTIARY
GIBBER SCREE: Pandurra Formation quartzite scree. Including undifferentiated silcrete residuals (inset).

GOETHITE GIBBER: Ironstone gravel cap.(Age uncertain).

LATE PROTEROZOIC
STURTIAN
MARINOAN
UMBERATANA GROUP
WHYALLA SANDSTONE: Flat-lying, white, minor cross bedded, friable sandstone with well rounded grains surrounded by white clay. Includes duricrust along exposed surface.

CATTLE GRID BRECCIA: Brecciated Pandurra Formation sandstones.

VUGGY SANDSTONE: White to pinkish vuggy sandstone or quartzite.

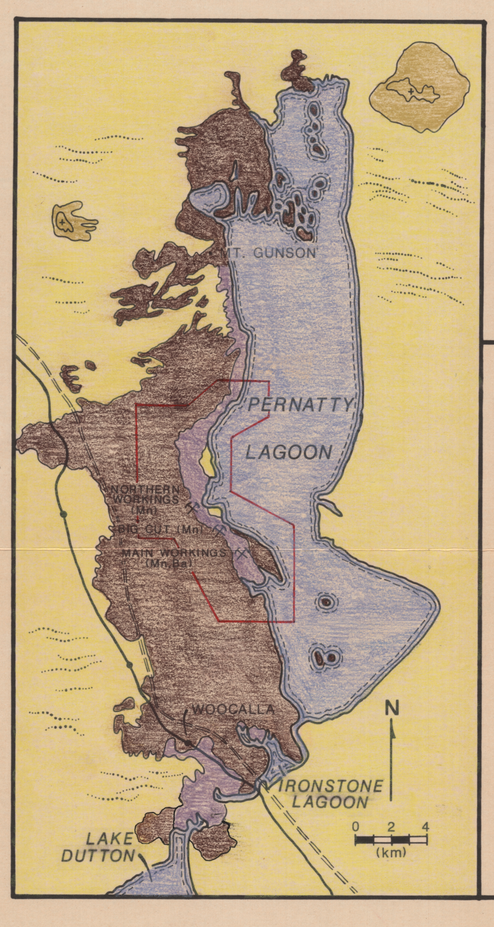
WOOCALLA DOLOMITE: Yellow-brown,oolitic and stromatolitic, manganese-rich dolomite.

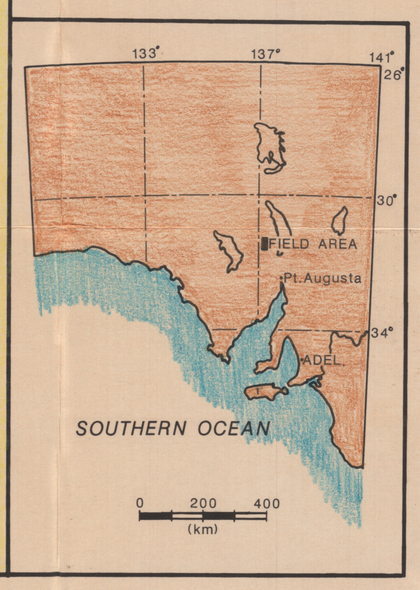
McLEAY BEDS: Red and brown sandstone containing rounded dolomite clasts.

PRE-ADELAIDEAN
PANDURRA FORMATION: Red,cross-bedded quartzites, sandstones,grits with occasional siltstone lenses. Includes Deeply iron-stained duricrust along ancient weathered surfaces (inset).

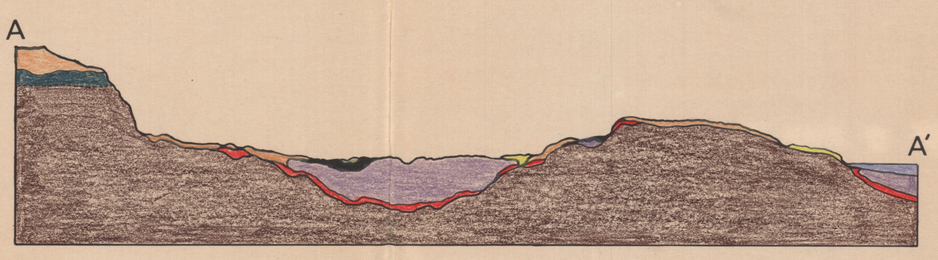
WOOCALLA DAM

LOCALITY MAPS





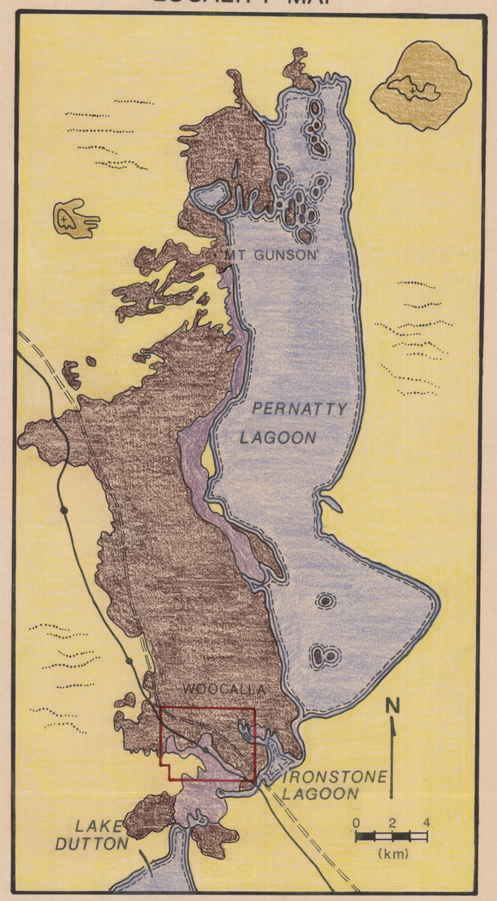
SCHEMATIC SECTION A-A'

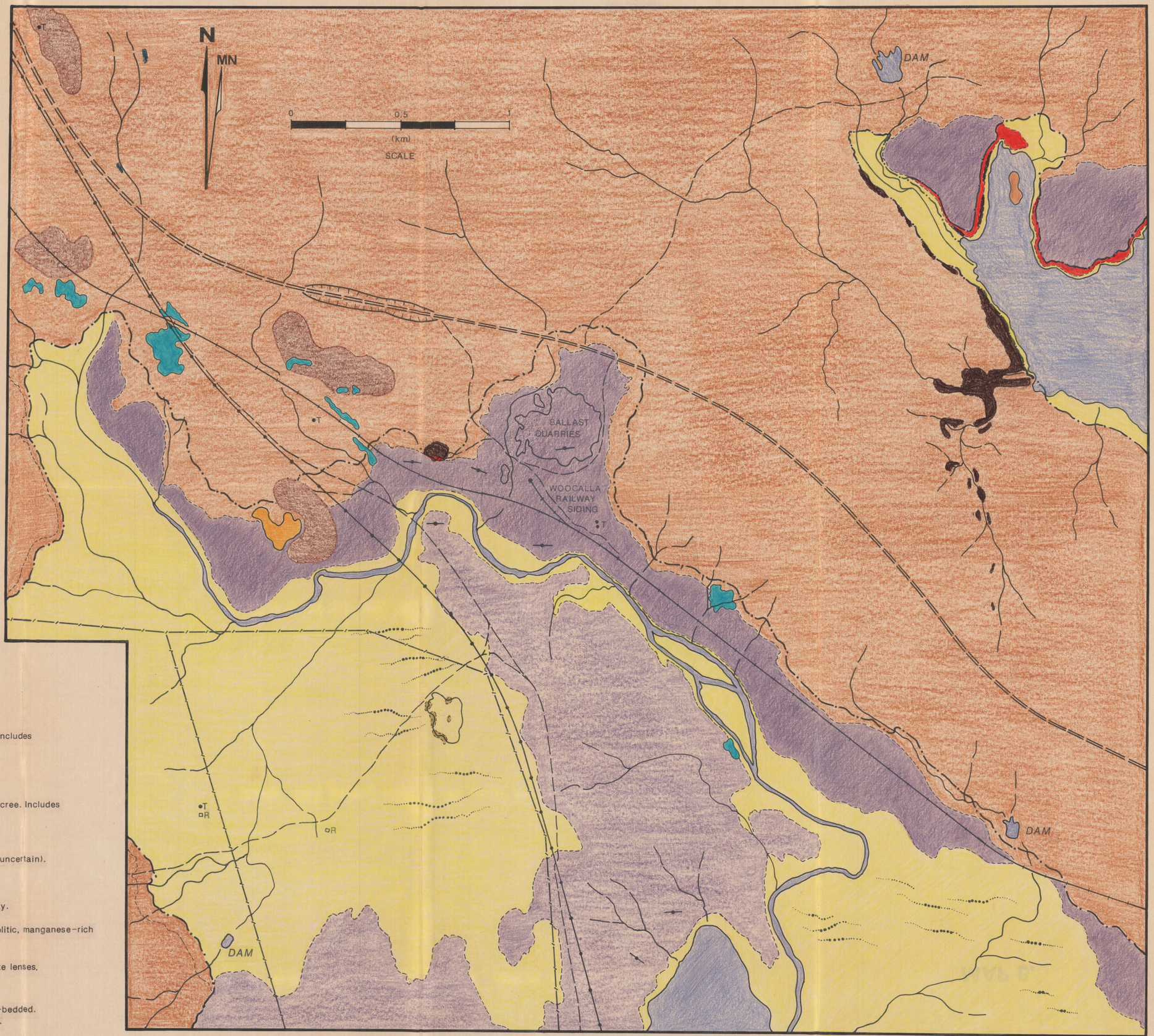


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MAP B: THE GEOLOGY AT WOOCALLA, SOUTH AUSTRALIA.

LOCALITY MAP





TRACK; ROAD
FENCE
RAILWAY LINE
PIPELINE
CREEK
RUIN ; TANK ●R ●T
OUTCROP BOUNDARY
SAND DUNES
STROMATOLITE PREFERRED ORIENTATION
INFERRED BOUNDARY

CAINOZOIC
TERTIARY QUATERNARY

ALLUVIUM: Sands in major drainage channels. Includes sand dune system.

LAKES: Salt, gypseous clays and silt.

GIBBER SCREE: Pandurra Formation quartzite scree. Includes undifferentiated silcrete residuals (inset).

GOETHITE GIBBER: Ironstone gravel cap. (Age uncertain).

LATE PROTEROZOIC
PRE-ADELAIDEAN STURTIAN MARINOAN

MAGAZINE HILL CLAY: White-grey kaolinite clay.

WOOCALLA DOLOMITE: Yellow-brown, stromatolitic, manganese-rich dolomite. Includes grey shale (inset).

McLEAY BEDS: Red sandstone and conglomerate lenses.

PANDURRA FORMATION: Red quartzites, cross-bedded. Includes deeply iron stained duricrust (inset).

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MAP C: MAIN MANGANESE WORKINGS, PERNATTY LAGOON.



SADME No.1.
FROM: Mining Review 91, (1951) p.37

Depth (m)

- 0 – Manganiferous sandy clay.
- 1 – White clay with occasional fragments of manganese ore.
- 2 – Manganiferous and ferruginous clay.
- 3 – 24.6% Mn: Ferruginous manganese ore containing a little clay.
- 4 – Manganiferous and ferruginous sandy clay.
- 4 – 38.6% Mn: Low grade manganese ore.
- 5 – Ferruginous clay and a little manganese ore.
- 5 – Ferruginous and manganiferous clay and dolomite.
- 6 – Dolomite and some manganese ore.
- 7 – Ferruginous clay.
- 8 – 27.8% Mn: Lowgrade manganese ore.
- 8 – Ferruginous and manganiferous clay.
- 9 – Ferruginous clay.
- 9 – Ferruginous and manganiferous sandstone.

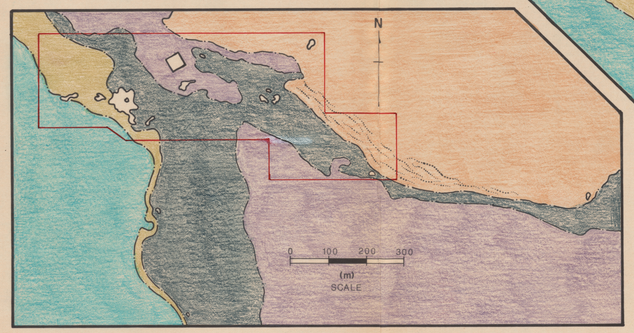
9.46 EOH

DDH-4
(This Study)

- 0 – Manganiferous and ferruginous sandy clay.
- 0 – 39.03 Black manganiferous clay.
- 1 – Yellow clay.
- 1 – Black clay.
- 1 – 1.24 Yellow clay.
- 1 – 1.70 Yellow clay with minor white clay.
- 1 – White clay with brown clay.
- 2 – Yellow clay.
- 2 – 84.56 Hard manganese ore.

2.17 EOH

ALL VALUES MnO(%)
FOR COMPLETE ANALYSIS
REFER APPENDIX C.



CAINOZOIC

- SECONDARY CLAY: Iron, manganese and silica rich clay formed by remobilization. Forms in low lying areas. High sand content (inset).
- LIMONITE UNIT: Representing the gradual replacement of manganese
- HEMATITE UNT: Lithified hematite/manganese unit with minor crystalline barite veining.
- GIBBER SCREE: Pandurra Formation quartzite scree.

ADELAIDEAN

- GOETHITE GIBBER: Subrounded black pebbles.
- SANDSTONE UNIT: White unconsolidated sandstone and lithified vuggy sandstone with minor red sandstone clasts.
- BARITE: Massive and forming in veins. Coarsely crystalline cutting through existing terrain.
- PRIMARY MANGANESE UNIT: Friable black cross-bedded and ripple marked, manganese. Includes later cementation along fractures.
- WOOCALLA DOLOMITE: Stromatolitic, crenulated to domal, buff-brown dolomite.

SURFACE LITHOLOGY BOUNDARY .....
PIT AND OUTCROP .....
INTERMEDIATE STOCKPILE AND DUMP .....
STROMATOLITE PREFERRED ORIENTATION .....
SAND DUNE .....

0 25 50 75 100 125 150
(m)
SCALE

N
MN

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