DIAPIR RECOGNITION AND MODELLING

with examples from the LATE PROTEROZOIC

ADELAIDE GEOSYNCLINE, CENTRAL FLINDERS RANGES,

SOUTH AUSTRALIA.

by

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ABSTRACT

A large number of irregular breccia bodies have been mapped in the late Precambrian and Early Cambrian sediments of the Adelaide Geosyncline. Although a diapiric origin was suggested in 1960, the complex internal history and varied settings of these bodies has lead to numerous interpretations as to their origin and the subject is still controversial. The interaction of a syn-sedimentary diapir with surrounding sediments creates a number of diagnostic features and a catalogue of these features has been assembled from literature studies. Sandbox modelling of the complete intrusive history of salt-type diapirs, a new technique applied to this study, has confirmed many of the previously recorded diagnostic features and added to the list.

Detailed mapping and section measurement around seven breccia bodies in the Central Flinders Ranges, and comparison with more regional mapping, has found specific evidence of synsedimentary diapirism. In particular, the Enorama Diapir shows facies irregularities throughout 4000m of adjacent sediments. Many of the features described in the literature were found and several new features added to the list. Reconnaisance mapping around another seven breccia bodies has confirmed that, while some cannot specifically be called diapirs, all are diapirically associated breccias.

A geochemical signature has been found in sediments around several of the diapirs studied and this has led to the proposal of two models of sedimentation patterns around exposed diapirs at times of high and low sea level.

Some of the diapirs in the Flinders Ranges have been grouped into "families" based on their mode of initiation and tectonic setting. Although there is no direct evidence as such, extensive circumstantial evidence suggests that the diapirism is related to widespread evaporite deposits near the base of the Adelaidean sequence. Shale movement may have also been associated with the salt diapirism. The salt moved during the deposition of the Adelaidean sequence, during the subsequent Delamerian Orogeny and in a few cases, has been remobilized during the Mesozoic and may still be potentially mobile. It is suggested that, as diapirs are areas of relatively incompetent rock, they are the focus of later tectonic activity.

STATEMENT OF ORIGINALITY

This thesis contains no material which has been accepted for the award or any other degree or diploma in any university and, to the best of my knowledge and belief, it contains no material previously published or written by another person, except where due reference is made in the text.

N.M. Lemon.

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CHAPTER 1

INTRODUCTION

The Nature of the Problem

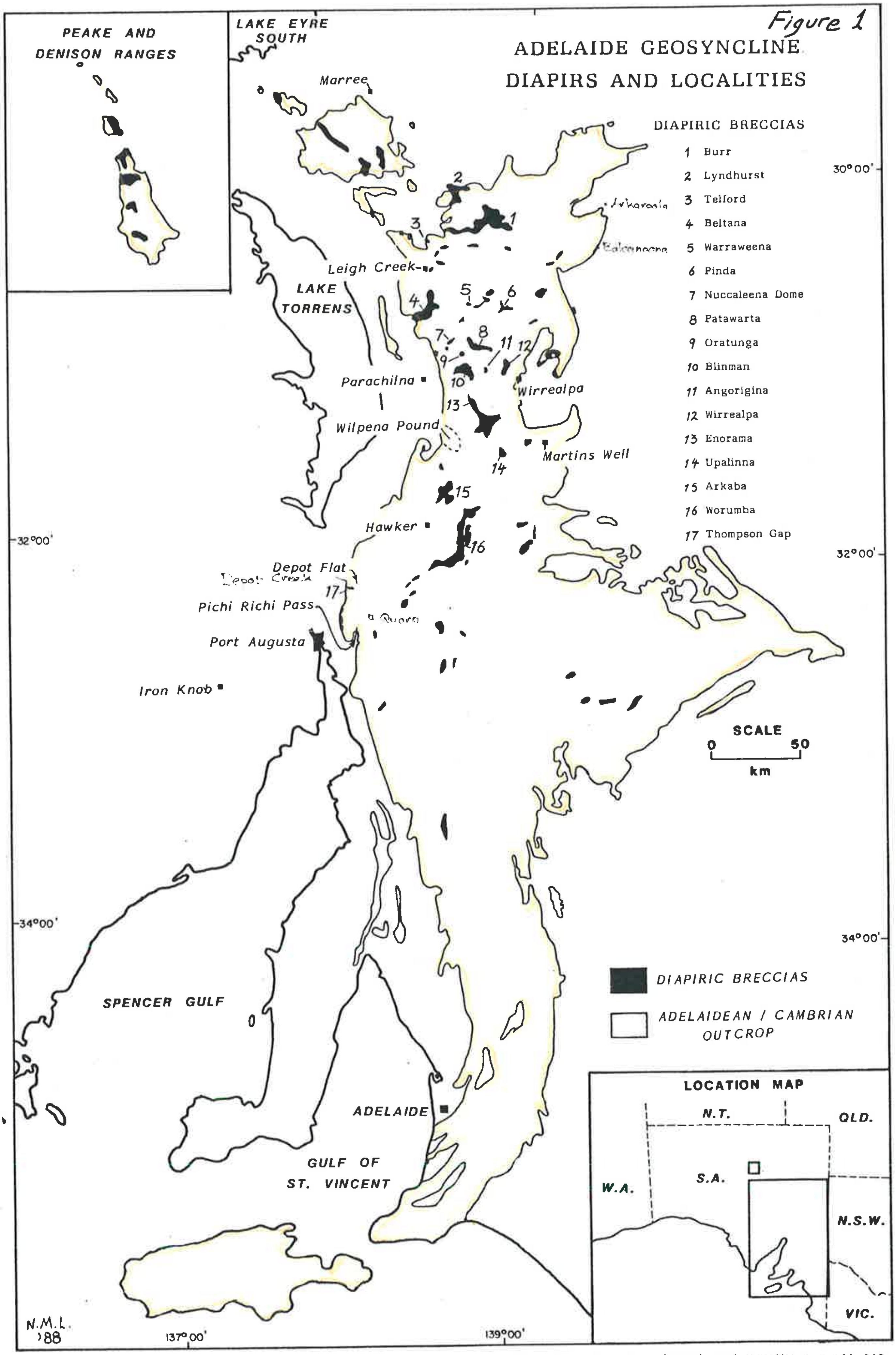
Early geological workers in the Central and Northern Flinders Ranges recognized zones of brecciated rock which did not appear to be part of the general sedimentary sequence and were difficult to put into stratigraphic context. Howchin traversed the Flinders Ranges from Parachilna to Wirrealpa through Blinman in 1906, (Howchin, 1922), and remarked that "one of the features of the district is the great amount of crush-rock that is developed, at intervals, over scores of square miles." He also noted that the crush features are "in greatest evidence where the igneous rocks are in close proximity." He ascribed the formation of this breccia to crushing during both vertical and lateral faulting.

Mawson, in his 1942 paper on the structural character of the Flinders Ranges, recognized these "core rocks" in the vicinity of Oraparinna and Blinman. He described them as regions of "slates, dolomite and basic igneous rocks" unconformably overlain by the tillite equated with that at Sturt Gorge. The tillite and the overlying sedimentary sequence up to the base of the Pound Sandstone, which he then regarded as Cambrian, was called the Upper Adelaide Series with a suggested Late Proterozoic age. The older rocks, those "much disturbed and faulted", were assigned to the Lower Adelaide Series of suggested Middle Proterozoic age.

Since that paper of Mawson's, hundreds of geologists have worked in the Flinders Ranges and there have been many interpretations on the origin of the breccias. At least 180 breccia bodies of similar appearance have now been mapped, (Fig.1), (Haslett, 1976). Sprigg was in charge of regional mapping for the South Australian Government Geological Survey during the 1950's and many of the maps of that period showed the breccias as crush zones. Sprigg (1949), suggested that they may be thrust complexes.

The first suggestion that the breccias may be of diapiric origin came from Webb in 1960. This idea was followed up diligently by Coats (1964(b), 65, 73) and Dalgarno and Johnson (1968). These workers recognized that some of the breccias were emergent during sedimentation as the sediments surrounding those breccias contained entrained debris derived from the breccias.

Mount (1975), mapped the breccia bodies at Thompson Gap and Arkaba for his Ph.D and concluded that the breccias were diapirically



Map modified from Morrison (1988) and SADME 1:2,000,000 Geological Map of South Australia, (1982) emplaced after Adelaidean sedimentation, during the Delamerian Orogeny.

The confusion surrounding these breccias still remains. At a recent symposium on the sedimentary environments and tectonic settings of the Adelaide Geosyncline, (Dalgarno 1983), no less than five possibilities were put forward for breccia origin, with several variations on some of the themes. The following is a list of those possibilities drawn from the abstacts of that symposium.

1/. Diapirs.

(a). During sedimentation.
(b). Post sedimentation during the Delamerian orogeny.
(c). Mud islands and mud lumps.

2/. Block faulting of previously deformed sediments and high angle block faulting.

3/. Emergent anticlinal cores.

4/. Synsedimentary slump brecciation.

5/. Carbonatite intrusions.

Add to this list the following:

1/. Thrusts and thrust complexes (Sprigg, 1949)

2/. Tectonic decollements (Burns et al., 1977)

and it can be seen that the breccias in the Flinders Ranges have confused many workers for a considerable period of time.

There are several reasons for the wide variety of interpretations. These include the wide variety of rock types incorporated in the breccias, the variety of structural situations in which they occur, the fact that there are no known thick beds of evaporites in the Adelaidean sequence to initiate diapirs driven by salt bouyancy, gravity lows have not been observed in association with most of the breccias and some of the breccias may involve more than one mechanism of emplacement or formation. Many interpretations are based on a study of only one or two areas. They are very complex areas of disrupted and mobile beds which often only preserve evidence of the last stage of movement. It is quite possible that various types of breccia bodies do not have a common origin although most of them seem to be composed of a similar suite of rocks.

A Solution to the Problem

This thesis is an attempt to resolve some of the obvious problems associated with the origin of the breccias. The work is based on the premise that the emplacement of a body of breccia have will some effect on the surrounding rocks, whether that breccia was derived as a result of folding, faulting, crushing, collapse, slumping or intrusion.

Several of the breccia bodies, both small and large, in the Central Flinders Ranges, are surrounded by Adelaidean sediments containing clasts of the breccia. This clearly implies that those breccias were emergent at the time of sedimentation. Detailed mapping around these areas should give specific answers on the nature of the emplacement mechanisms as each emplacement style will induce specific sedimentation patterns, facies and thickness variations and geometrical considerations diagnostic of that emplacement style.

This thesis describes such detailed mapping in the Central Flinders Ranges around the Oraparinna, Enorama, Blinman and Oratunga breccia bodies together with observations from a number of other bodies and compares the results with sedimentation around known salt and shale diapirs. This comparison is enhanced by the author's development of a sand-box model designed specifically to study sedimentation adjacent to active diapirs and block faults.

The geochemical and geophysical signature of an emergent diapir is investigated and a comparison made with diapirs in the study area where the data is available.

The results and implications of all the investigations are then extended to many of the other breccia bodies mapped throughout the Flinders Ranges to see if they agree or disagree with the proposed emplacement models.

CHAPTER 2

DIAPIR RECOGNITION AND MODELLING

The intrusive nature of salt and other evaporites has long been recognized. The conceptual model of Posephny, drawn in 1871 and shown on the title page of Braunstein and O'Brien (1968), is testimony to this. Both salt and overpressured, or uncompacted, shale can behave diapirically. The common properties that allow them to do so are their low density with respect to most clastic and carbonate sediments and their mobility or low shear strength. However, in the following discussion, the diapirs described are salt diapirs, except where specifically referred to as shale.

The features associated with diapirs fall into two categories,

1/. Internal characteristics, those features diagnostic of the diapiric mode of intrusion which are found within the salt or breccia remaining after dissolution,

2/. External characteristics, those features to be found in the surrounding sediments which were formed by the movement and intrusion of the diapir.

Internal features tend to be very complex, with each stage of movement overprinting the previous records. Usually only the last stage of movement can be clearly delineated although recent work by Talbot and Jackson (1987), has detailed some of the controls on salt flow to predict the internal characteristics. Dissolution of the carrier material, salt, will leave a breccia of the insolubles and make interpretation of the internal characteristics vastly more difficult. The Flinders Ranges breccias are just that, breccias with no salt known, even from the entire Adelaidean sequence. For this reason, this thesis has steered away from the internal characteristics of the breccias to concentrate on the external features.

By contrast, there is sedimentation concurrent with many of the diapiric structures. This records various stages of diapir movement, spreading the record vertically through the stratigraphy and thereby, not only allowing discrimination of the stages of movement, but placing an approximate time frame on them.

Diapirs are often an oddity in otherwise regular sedimentary sequences and thereby provide a focus for attention. Geological literature contains hundreds of descriptions of various diapiric structures. A catalogue of the various external characteristics can be accumulated by thumbing through this mountain of paper. Fortunately, summary papers on various diapir provinces have already been written. Trusheim (1960), summarized the features from the diapirs of northern Germany and was the first to outline the sequential growth of these features and provide a descriptive terminology. Murray (1968), reviewed the salt structures of the Gulf of Mexico Basin under such headings as shape, relationships between domes, composition, internal structure, associated faulting, etc.. Kent (1979), and Ala (1974), provided detailed descriptions of many of the salt plugs in southern Iran. Particular attention was paid to the appearance of the plugs themselves and their internal characteristics. Seni and Jackson (1983a), described many of the diapirs of the East Texas Diapir Province using copious drillhole data and the descriptive terminology of Trusheim (op. cit), to outline their sequential growth. These papers provide a basis for the catalogue of features in this thesis together with additional information gleaned from papers on individual diapirs.

Laboratory modelling has also provided much information on the types of structures which are to be expected in the vicinity of diapirs. Ramberg (1967, 1981), used mediums of varying densities to model diapirism. Medium viscosity liquids, such as heavy syrups and oils, displayed the shapes of diapirs when allowed to interact under gravity. High viscosity materials, such as silicon putties, which are relatively stable under normal gravitational forces, were forced to deform by centrifuging. By increasing the length of time of deformation of a series of models, the various stages of diapirism could be "frozen" for detailed study. Dickson (1974, 1975), divided these models into individual elements to measure the finite strain.

Parker and McDowell (1955), used asphalt rising through more brittle material, layers of sand and mud, to investigate the formation of domes, the fracture pattern associated with them and the disturbance of beds around the intrusion. They also investigated the buckling of sand layers by the forceful intrusion of a rigid plug. Similar experiments were conducted by Tanner and Williams (1968). The experiments of Parker and McDowell and of Ramberg only showed the effects of diapiric intrusion on a previously deposited sedimentary section. Currie (1956), constructed a more interactive model in which layers of coloured barite were added to the model during deformation to simulate the development of graben structures over rising salt domes.

Mathematical modelling of diapirs by Bishop (1978), treated the mobile substrate of clay or salt as a fluid which hydraulically intrudes the overburden through a pressurized hole. This explained the difference between shale and salt and predicted that salt would be able to extrude to the surface under almost any conditions. Salt extrusion cannot be explained using a bouyancy theory, such as that followed by Mount (1975) to describe the intrusion of the Thompson's Gap Diapir in the Flinders Ranges.

The author has expanded on Currie's model to simulate the interaction of sediments with a rising salt dome throughout the intrusive history of a salt plug. Stratigraphy is built up by adding successive layers of coloured sand while a rubber membrane, representing the boundary between the intrusive material and the surrounding sediments, changes shape through the three stages of diapir movement, the pillow, diapir and post diapir stages of Trusheim (op. cit). Details of some of the model experiments are shown in Lemon (1985), included as Appendix II of this thesis.

Before the sand box experiments were done, the medium density liquid experiments of Ramberg were repeated to investigate the change in shape of the diapir-sediment boundary. Heavy sugar syrup and heavy oil were sealed in a jar and inverted and the shapes of the rising oil photographed. A variation on this was tried using clear syrup and very slightly diluted coloured syrup. The shape of the "diapir" varied with both density contrast and viscosity contrast of the two liquids. High density contrast-low viscosity runs produced pronounced mushroom shapes as the drag between the phases caused both liquids to circulate. The mushroom became less pronounced with lower density contrast and higher viscosity. Very high viscosity and minimal density contrast produced a plug-like intrusion. This may approximate the natural state as suggested by Seni and Jackson (op. cit). However, Talbot and Jackson (1987), suggest a moderate mushrooming effect is common. Figure 2 shows the changes in shape with changing parameters.

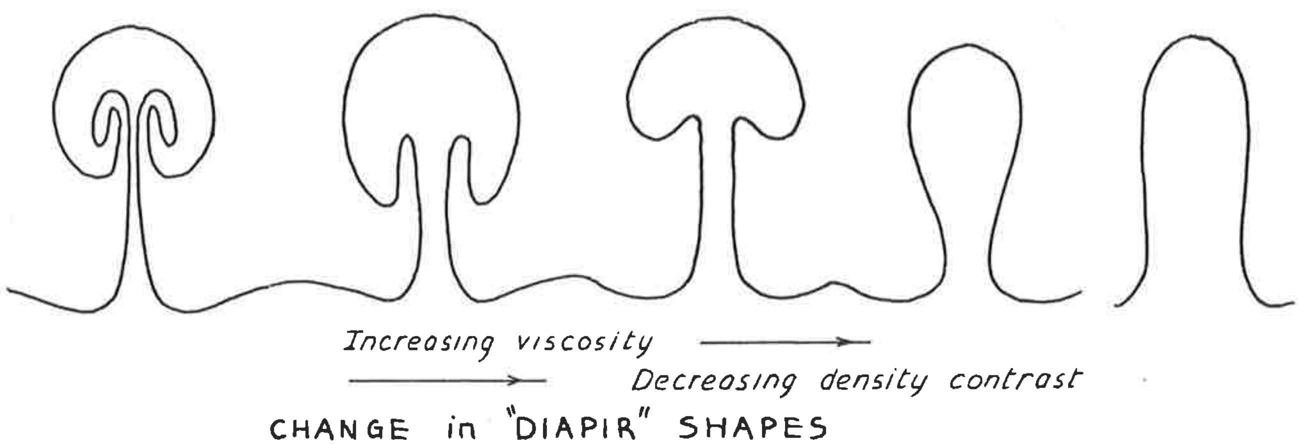


Figure 2. The change in shape of a rising "diapir" with a variation of density and viscosity parameters.

The thickness of the rubber membrane in the sand box experiments was chosen to simulate the pillow, diapir and post-diapir stages of movement together with moderate bulging of the top of the intrusion. This could be associated with either a plug-like or slightly mushroomed diapir.

The following catalogue of features is derived mainly from Trusheim (1960), and Seni and Jackson (1983a) except where there is other acknowledgement. The features are grouped according to the stage of development of the salt structure and shown in Plate 1 and Figure 3.

The Pillow Stage

A salt pillow is a plani-convex dome, a laccolithic structure with any amplitude to wavelength ratio. Sediments dip away from the axis of the structure. A pillow may be initiated by sediment loading over a source bed with thickness or boundary irregularities or tectonically, with salt flowing updip on a tilted fault block or into the core of an anticline in a compressive or wrench regime. Growth occurs initially by migration of salt from the source bed and later from migration from the outer edges of the dome toward the centre. This arguement is somewhat semantic as it is the source bed that thickens to form the pillow so that it could be argued that the movement is always from the source bed.

Growth is maintained by deposition off the pillow and by erosion, thinning or non-deposition over the crest. The position of thickening of sediments off the flanks of the pillow is called the primary peripheral sink. This is thought to migrate toward the axis of the dome as the flanks deflate. The development of this sink enhances salt migration by actively loading the source areas. The primary peripheral sink is a diagnostic but less obvious feature of the pillow stage. It is a broad, shallow basin, subparallel to, and 10-20 km from, the pillow crest. The thickness of sediments in the sink is related to the thickness of the source layer. The sink may be concentric around a single dome or elongate near a line or series of domes.

Thinning over the crest of the dome is the most characteristic feature of the pillow stage, varying from 10-100%, but typically around 25%. Lithostratigraphic variation is common as the environment shallows over the crest. The pillow may be "frozen" if it is "undernourished", ie., if the source bed is thin or becomes cut off by faulting.

The Diapir Stage

As the central part of the pillow grows, the structure grades into the diapir stage. The flanks of the pillow steepen with near vertical migration. A diapir is defined as a steep sided intrusion. The increasing height of the salt column increases the natural bouyancy of the body and the diapir rises relatively rapidly until equilibrium is reached against the confining force of the overburden. If the supply of material is great enough and the overburden not too thick, the diapir will surface. In rare cases, in arid subaerial conditions, the salt itself will surface and may flow down the flanks of the structure as salt glaciers or "namakiers", (Talbot and Jarvis, 1984). Usually there is dissolution near the surface by meteoric waters. This leaves a breccia or caprock of the insoluble components of the evaporite sequence over the diapir or as a moraine associated with a namakier. Caprocks are particularly thick if the diapir develops in subaqueous areas. The shape, size and development of a diapir is dependant on the amount and thickness of the source material and the nature and thickness of the overburden.

There is marked thickening into the secondary peripheral sink as the flanks of the original pillow deflate. This is the most characteristic feature of the diapir stage and is a deep sediment filled sink that surrounds the diapir as a rim syncline. Pillow flank collapse inverts the dips of sediments deposited against the pillow to form a turtle structure anticline. This usually encompasses the primary peripheral sink. The secondary sink forms much closer to the axis of the structure than the primary sink and dips of the surrounding sediments are generally toward the diapir axis except close to the diapir, where they are dragged steeply upward.

Thickening up to 215% has been reported into secondary peripheral sinks. These sinks are equidimensional to elongate and their axial traces usually intercept the associated domes. Factors controlling the secondary sink include the orientation of the early salt anticline, the effect of crestal depression, interference folding of the salt layer and regional basement faulting.

The rapid rise of diapirs leads to marked thinning over the crest. Depending on sedimentation rates, this may be manifest as numerous unconformities and crestal erosion. Such erosion may lead to the incorporation of caprock or diapiric breccia in the surrounding sediments. **Diapir movement or "halokinesis" is irreversible.**

PLATE 1

SANDBOX MODELLING OF A SYN-SEDIMENTARY DIAPIR

(Terminology is explained in Figure 3)

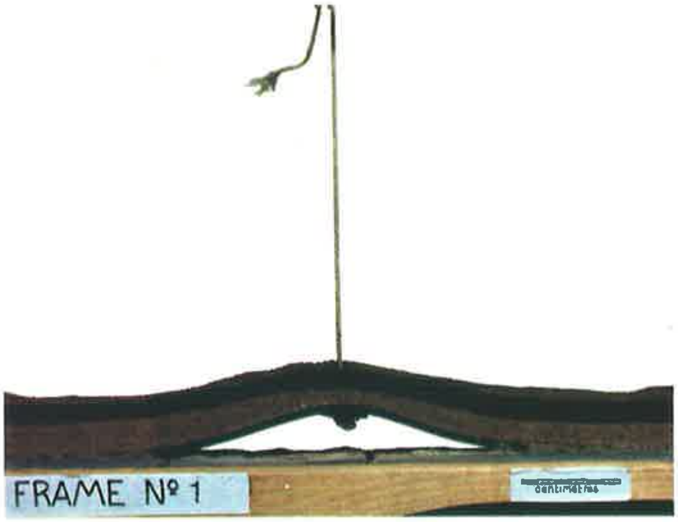
Frames 1-8 show a few of the progressive stages in an experiment where sand is added to a model box and the rubber membrane, simulating the boundary between a lower mobile layer and the surrounding sediments, is raised. The sand surface is levelled at each stage as any projection above a surface of sedimentation would tend to be eroded by transporting currents or other factors in the environment of deposition.

Frames 1-4 model the pillow stage of movement. A broad dome inflates, causing thinning of sediments over the dome. If the rate of rise outstrips the rate of sedimentation, unconformities develop over the dome. The position where beds pinch out beneath the unconformity begins close to the dome, moves out as the dome inflates, then back in as the flanks of the dome become more vertical. The sediments thicken away from the dome into the primary peripheral sink, created as salt flows into the dome.

Frames 5-7 show the diapir stage of movement. As the edges of the intrusion move to vertical, the flanks of the earlier pillow deflate and the collapse of the pile of sediments above creates a depression at the surface, a rim syncline. Marked thickening of sediments in this area shows the secondary peripheral sink. Listric faults grow upward from the evacuation area to encompass the secondary peripheral sink. The earlier sediments, then dipping off the pillow, invert to dip toward the axis creating a turtle-structure anticline in the area of the primary peripheral sink. Sediments against the diapir are pulled upward to vertical. Unconformities develop in the sediments depositing close to the diapir and there is some incorporation of sediments, originally deposited over the dome, into the adjacent sink.

Frame 8 shows the post-diapir stage of movement. The rising structure becomes isolated from the source bed but continues to move under its own buoyancy. Minor readjustments in the sedimentary pile create a small tertiary peripheral sink, with minor thickening, close to the axis of the structure. The force of salt pushing towards the surface creates a few high angle reverse faults over the crest.

This run of the experiment was interesting in that the accommodation for the secondary peripheral sink was dominantly by folding on one side of the structure and by faulting one the other side.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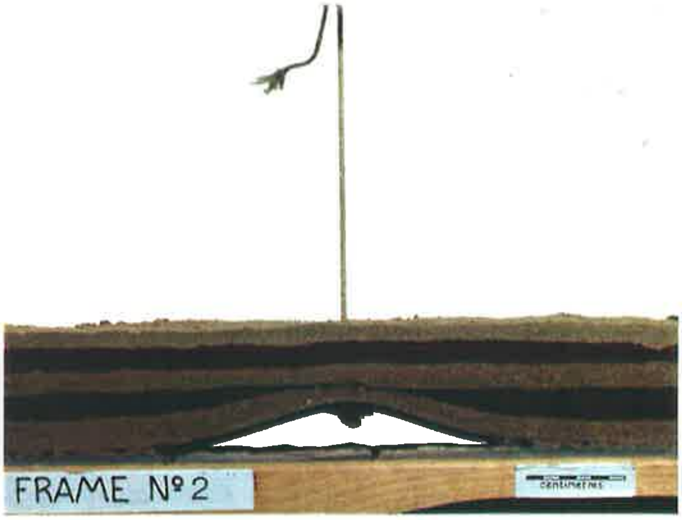
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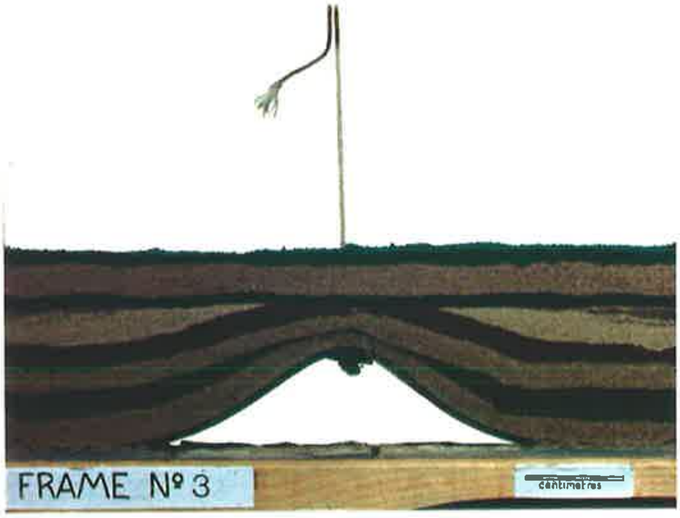
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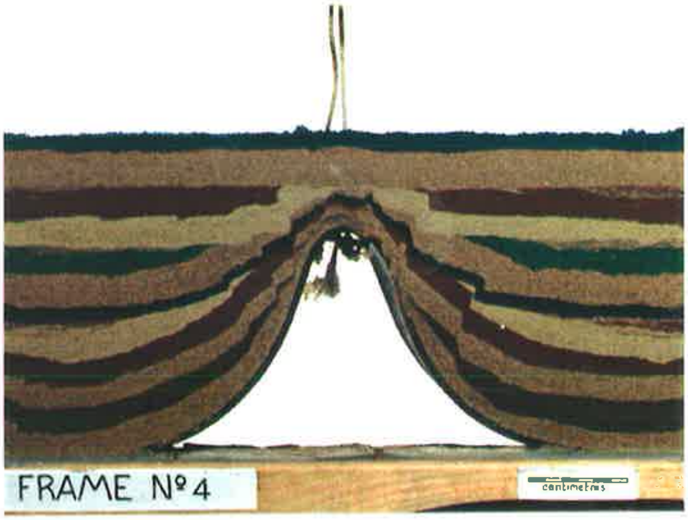
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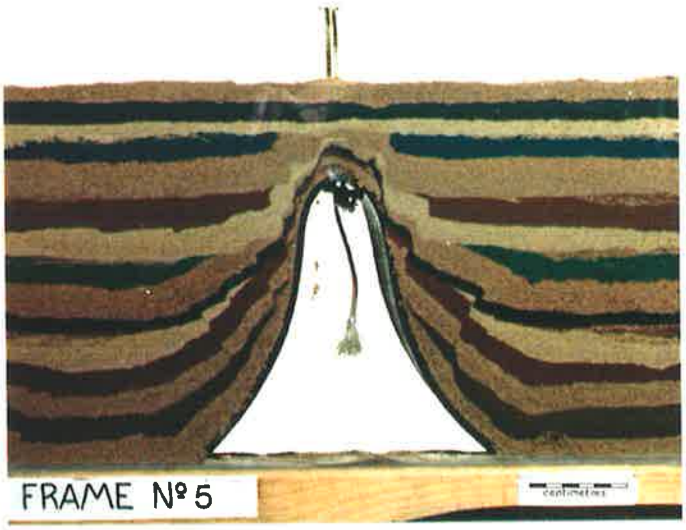
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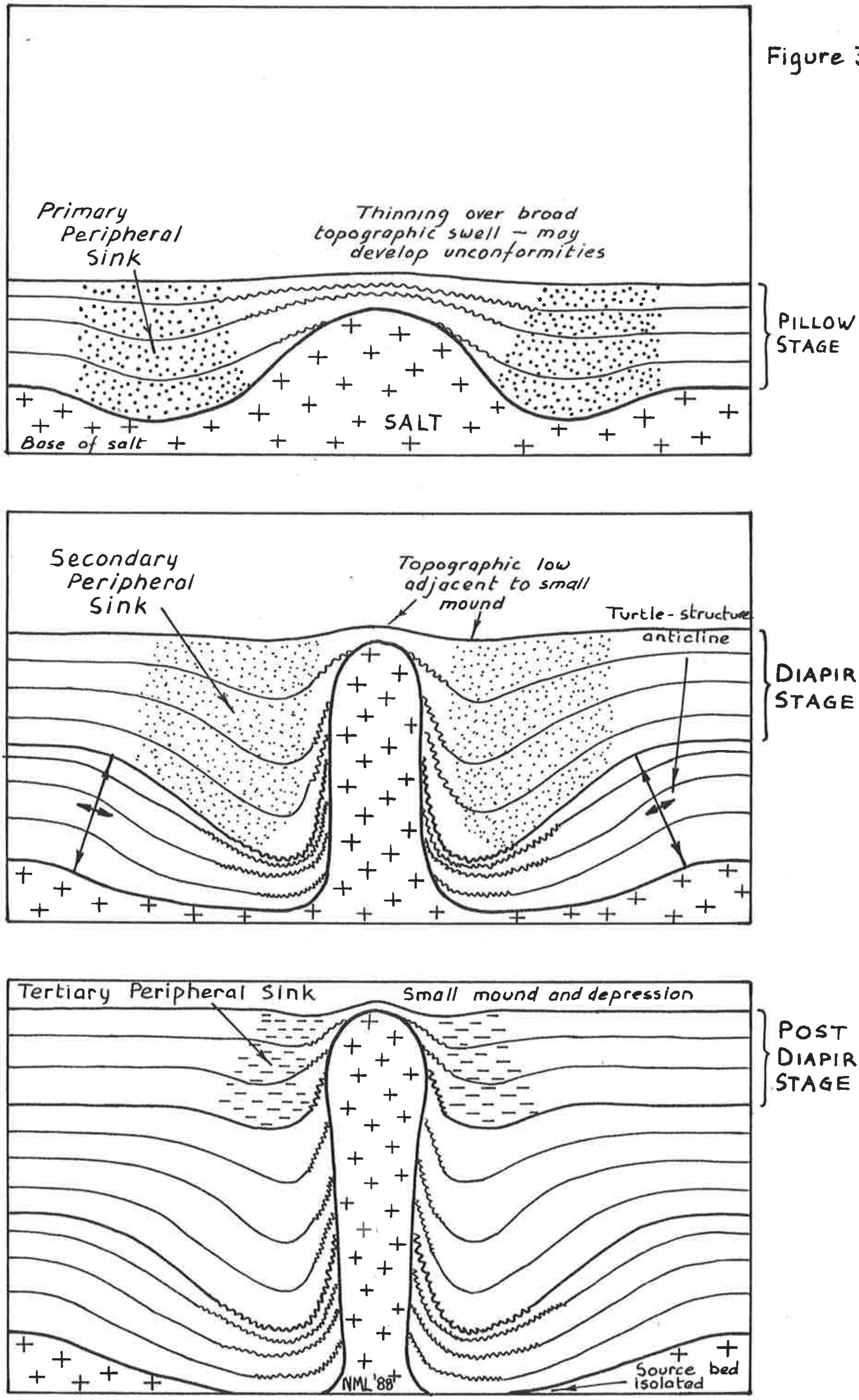
Figure 3



Three stages of salt movement

Post Diapir Stage

The post diapir stage of movement is defined as that stage when the rising body no longer receives material from the source bed. The diapir may become physically separated from the source or the supply may cease. Additional sediment loading leads to continued movement caused by the bouyancy of a now very thick column of salt. This stage may be long lived, particularly when compared to the diapiric surge. A small, shallow, tertiary peripheral sink forms close to the flanks of the dome and the minor uplift creates a small topographic rise over which different lithofacies may form. These are likely to be preserved as the rise is minimal. Consequently, exposure of the caprock and inclusion of diapiric detritus in the sediments is unlikely during this stage. Thickening into the tertiary peripheral sink is in the order of 8-40%.

Additional Observations from Modelling

Sandbox modelling by Lemon (1985), has suggested a number of other features that may be observed around diapirs.

The position of the maximum rate of thinning against the growing structure, which may be expressed as the position of pinch out of units beneath the crestal unconformities, moves throughout the history of the dome. At first it is close to the axis of the structure during the early pillow stage. This point rapidly moves away as the pillow inflates then shifts back toward the axis of the structure as the pillow flanks deflate. The same point remains near the axis during the diapir stage so that unconformities, although perhaps numerous, are only locally developed. This point is virtually over the dome during the post diapir stage.

Upturning of sediments is more pronounced near the base of a diapir because salt movement at that level has been active over a longer time. The steepness of dip increases down along the margin of the diapir so that the earliest deposited sediments above the source may be vertical to overturned. There is likely to be a sharp change in dip at the level of development of the secondary peripheral sink.

Collapse of the pillow flanks may lead to accommodation by faulting rather than by downfolding. These faults are listric, concave toward the diapir and sole out into the mobile source layer. The faults grow upwards from depth to encompass the secondary peripheral sink. Faults over the crest of the rising structure are extensional during the early pillow stage but may become compressional during the late pillow and early diapir stage as the package of sediments over the crest is pushed upwards. These reverse faults are relatively high angle and curved with the convex side toward the diapir axis.

Trusheim (1960), reported migration of the primary peripheral sink toward the pillow axis but the experiments agree with the observations of Seni and Jackson (1983a), that there is no migration until the development of the secondary peripheral sink. However, there is some migration of the position of maximum thickening within the secondary peripheral sink towards the diapir axis with time.

The early stages of the sand box model mirrored the experiments of Currie (1956). A crestal graben was formed but the preservation potential was low, especially if the dome developed beyond the pillow stage. Uplift led to erosion of most of the sequence over the crest of the diapir. Evidence presented later in this thesis from the Blinman Diapir suggests that, although most of the crestal graben may be removed, the fracture pattern developed at that stage may control the position of the secondary peripheral sink.

Features associated with diapirs generally

A topographic rise on the sediment surface occurs at all stages of salt movement. This leads to shallow water facies developing on the flanks and over the crests of domes. This may be seen as local carbonate facies such as reefs, carbonate clastics or ooid shoals, (Laudon, 1984, Seni and Jackson, 1983a, Purser, 1973 and Brown and Fisher, 1977). During regressive phases, the topographic rise will control the fluvial systems. Channels avoid the highs and so stack sands in the peripheral sinks adjacent (Seni and Jackson, 1983a). Drainage over presently active diapirs is locally radial, (Laudon, 1984). Where diapirs are active under deeper water, the topographic bumps control the position of turbidite flows and their associated deposits, (Pautot et al., 1984, Cashman and Popenoe, 1985, Bertagne, 1984 and Lehner, 1969). Laudon (1984), makes the observation that "the large vertical extent of facies peculiarities near piercement features" is testimony to their longevity.

Purser (1973) and Kent (1979) reported on the presently active salt diapirs of the Hormuz Formation in the Persian Gulf and southern Iran. Yas Island, in the southern Persian Gulf off Abu Dhabi, is a topographic rise over an active diapir. Drilling has shown that the top 80m of the rise is caprock or breccia, the insoluble remnants of the evaporite sequence below. Detritus from the island is only spread some 500m from the present shoreline. The island is, however, protected by a coral reef which diminishes the strength of possible dispersive currents.

Many of the salt plugs of southern Iran are positive features, some have little or no relief and some, in more humid terrains, are negative features. The descriptions are mainly of the internal characteristics of the plugs and show many similarities with the diapirs of the Flinders Ranges. Although most of the extrusive domes consist predominantly of halite with some gypsum, anhydrite and minor potash salts, the evaporites carry with them a vast array of exotic blocks arranged as a breccia and as large rafts within the intrusions. These blocks consist of dolomite, limestone, quartz arenite, conglomerate, chert and cherty dolomite, as well as crystalline basement rocks, migmatitic granite, gabbro, mylonite and numerous igneous rocks. The igneous suite consists of diabase, which is dominant, together with tuffs, ignimbrites and pillow lavas.

The majority of the sedimentary rocks are thought to have been interbedded with, or overlying the evaporite sequence. Many of the dolomites show inclusions of gypsum and anhydrite. It also appears that underlying basement rocks have been dragged from the floor of the evaporite sequence and carried upwards. Some of the rafts are up to 4 km by 1.5 km and consist of sediments still in a recognisable sequence. This implies that the vent through which they passed must have been at least as big.

Some diapiric features which show little or negative relief contain little salt at the surface but are represented as a brecciated mass of the insoluble inclusions with the salt all but leached away.

The Onion Creek salt diapir of Utah described by Colman (1983), shows a caprock of insoluble and less soluble residue forming the top of the diapir. Overlying Tertiary gravels have been infolded with the caprock to such an extent that the gravel-caprock contacts are subvertical to vertical. Sediments deposited adjacent to the rising diapir have been upturned around the margin. Subsidence in the adjacent basin of deposition is approximately equalled by the rise of the diapir. It also appears that the salt flow into the diapir occurred in a series of pulses.

Salt stocks or diapirs also form families, groups of diapirs genetically related to each other. Trusheim (1960), suggests that different salt stock styles can form in relation to the original thickness of salt available in the source bed. In the situation where salt movement is due to even vertical loading alone, the sediment load into the secondary peripheral sink of the first formed diapir will squeeze salt away from the root zone of that structure to create new pillows away from the "mother" diapir which eventually grow into diapirs. This process is repeated until the movement shifts to an area without enough salt to form a diapir, (Sannemann, 1968). In the case where loading of the source bed is unidirectional, the source bed is squeezed ahead of the prograding wedge of sediments to progressively form younger diapirs in the direction of progradation, (Kingston et al., 1983, Murray, 1968).

Salt will form extensive walls where the source bed is thick enough to supply the volume of material necessary, (Trusheim, 1960). Elongate salt intrusions can also result from from eruption in fault zones and by later squeezing of an intrusion along a fault, (Kent, 1979).

Shale will also act diapirically, especially where active tectonics squeeze a shale sequence to mobilize it. This can happen in wrench regimes, such as the Trinidad mud volcanos formed along anticlines associated with the right lateral El Pilar Fault, (Higgins and Saunders, 1973, Bonini et al., 1984), or in compressional regimes such as a trench basin melange, (Becker and Cloos, 1985) or other plate boundary areas like Irian Jaya, (recent unpublished BMR mapping). Chapman (1974), describes clay diapirism from between breaks in gliding slabs of sediment, supported by over-pressured shales.

While salt and shale have common properties which allow them to behave diapirically, their behaviour tends to be different. Part of shale behaviour is due to high fluid pressures. This can cause shale diapirs to be very active over a short period of time but as the shale moves to a zone of lower pressure, it loses its driving mechanism and movement tends to be short lived. Shale will eventually dewater, either through leakage and migration, compression or metamorphism. Salt, by contrast, will maintain its potential mobility indefinitely and will tend to react any time enough stress is placed upon it.

Salt and shale may act diapirically together. Early rift settings may collect evaporites and mud together in a series of playas and salinas along a sediment starved rift floor. This may become a site of very rapid sedimentation so that loading may mobilize the salt and shale together. Mixed diapirs are known from Louisiana, (Atwater and Forman, 1959) and Mexico, (Laudon, 1984). Many of the diapiric breccias in the Flinders Ranges have a grey siltstone/shale as their matrix. It appears that salt played a major role in the activity of the Flinders Ranges diapirs. Reasons for this statement will be discussed later in the thesis. However, it is not unreasonable to expect shale to have actively contributed to the diapirism.

The Location of Diapirs

Salt and shale diapirs can occur anywhere the neccessary source beds exist. In the case of salt, thick evaporites most commonly occur in basins in extensional regimes. These include grabens, half grabens, rifts, aulacogens and passive margins or geosynclines. As this group is virtually a series arranged in order of size and one grows into another if the extensional regime prevails, rift, graben and half graben style sediments will be found at the base of an aulacogen, passive margin or geosyncline. Exceptions can be found to most rules and a major exception in this case is the Messinian salt of the Meditteranean region which formed in unusual conditions during a compressional event.

Evaporites can be found at two levels in an extensional basin. Heating and uplift are inherent in all models of extensional basin formation. The uplifted rift shoulders are one of the main contributing factors to the distinctive early rift sediments. The main drainage near a rift is away from the crestal grabens. This means that the earliest sediments are usually arid alluvial fan type with a local and restricted source area. Lack of water along the basin floor, except in very humid climates, sees the alluvial fans grade into playa lakes and salinas, sometimes with accompanying aeolianites. Rifts, by their nature, are intracontinental so that marine conditions are nearly always absent early in the development. The arid continental sediments are nearly always redbeds. Evaporites in the early salinas, as well as containing gypsum and halite, often contain unusual salts such as the sodium carbonate series, trona-nahcolite-shortite etc.. The East African Rift, despite containing some of the worlds largest and deepest lakes, also has a number of highly saline soda lakes and salinas.

Volcanic input at this level in the developing sequence is common. Crustal fracturing allows the eruption of volcanoes, with intermediate to basic compositions most common. Basic lavas may cover the rift floor as extension continues.

The sediment starved rift continues to drop, eventually to below sea level. The rift will also open up through the continental margin to the sea. At this stage marine waters flow into the basin, often evaporating to form thick salt deposits, (Crawford et al., 1985). These salts are of the marine type, dominated by gypsum, halite and anhydrite, (Dean and Schreibner, 1978). Evaporite sedimentation is extremely rapid and may fill the rift up to sea level from where carbonate precipitation takes over the still clastically starved basin. This is about the stage of extension where oceanic crust is generated and the whole character of the basin changes. The rift shoulders relax and thick wedges of either clastic or carbonate sediments prograde into the basin.

Diapirs can be categorized by the tectonic and/or sedimentary position in which they form and by their method of initiation. One such classification is as follows:-

1/. Within tectonically quiet basins, eg. northern Germany, (Trusheim, 1960, Sannemann, 1968) and East Texas, (Seni and Jackson, 1983a, b).

2/. In front of a prograding wedge,
2a/. On continental margins, (Kingston et al., 1983, Cashman and Popenoe, 1985, Emery, 1980, Lehner, 1969).
2b/. Associated with deltas, (Morgan, Coleman and Gagliano, 1968, Pautot et al., 1984, Kingston et al., 1983).

3/. Along wrench systems, (Higgins and Saunders, 1973, Kingston et al., 1983, Baars and Stevenson, 1982).

4/. Activated by compression, (Kent, 1979, Ala, 1974).

5/. Beneath a thrust, (Assaad, 1983).

6/. In a trench slope basin, (Becker and Cloos, 1985).

7/. Around basin edges, (Jenyon, 1985).

8/. Basement fault controlled, (Ala, 1974, Kent, 1979).

9/. Behind listric faults, (Lowell, 1985).

10/. Over tilted fault blocks, (Boess, 1984, Guery et al., 1986).

A simpler classification can be arranged for the diapirs and provinces mentioned above by dividing them into three groups based on the mode of initiation.

i/. Even loading of a basin, diapirs from 1/. above.

ii/. Uneven loading of the source bed; diapirs from 2a, 2b, 4, 5, 6 and 7 above.

iii/. Fault initiated; diapirs from 3, 8, 9 and 10 above.

CHAPTER 3

REGIONAL GEOLOGICAL SETTING

Historical Background.

Although the geology of the Adelaide Hills and of South Australia in general has interested many workers since the time of the first European settlement, it was not until Professor W. Howchin began his research that geology of the Adelaide Foldbelt / Adelaide Geosyncline was understood to any degree. His two papers on "The geology of the Mount Lofty Ranges", published in 1904 and 1906, determined the succession and lithologies of the sequence in the area around Adelaide. Howchin also made preliminary geological traverses in the area around Blinman, from Parachilna to Wirrealpa. He intended to expand on this initial survey but was unable to complete any further work in the northern areas and eventually wrote up early work on the Blinman area in 1922.

Mawson succeeded Howchin at the University of Adelaide and widened his field of study to include the entire region. Continued work in the Flinders Ranges led to a succession of papers on the geology of the area. He saw the sediments of the Adelaide Foldbelt as a type location for the Late Proterozoic and fostered the use of the term "Adelaide Series" as proposed by David (1922).

Sprigg was the head of the Regional Mapping section of the Geological Survey of South Australia from 1946-53 and in that position started the systematic mapping of the foldbelt. Following remeasurement of Howchin's original sections, Sprigg wrote a paper with Mawson (Mawson and Sprigg 1950), proposing a standardized subdivision of the Adelaide Series and the overlying Cambrian. That subdivision was time oriented and used the terms "Willouran", "Torrensian", "Sturtian" and "Marinoan" as divisions of the Adelaide Series. Sprigg also developed the first model for sedimentation in the Geosyncline as a whole (Sprigg 1952).

Since Sprigg's time, the Geological Survey has continued the regional mapping and subdivision of the rock units in the geosyncline. A major revision of the stratigraphy and nomenclature was done in 1964 under the supervision of B.P. Thomson (Thomson et.al. 1964). The lack of fossil data and the problems of correlation within the Adelaide Geosyncline made mapping easier using a lithological subdivision. The sequence below the Cambrian was divided into the Callanna Beds and the Burra, Umberatana and Wilpena Groups. Distinct mappable horizons were recognized between the groups such as:- an unconformity between the Callanna Beds and the Burra

Group, an unconformity at the base of the Umberatana Group, the distinctive Nuccaleena Formation dolomite at the base of the Wilpena Group and another unconformity above the Wilpena at the base of the Cambrian section. The subdivision by groups gave consistency to the series of 1:250,000 scale geological maps produced around that time and was a big step forward in regional mapping.

Since 1964 there have been several papers redefining sections of the statigraphy in light of new information from detailed mapping. Many of these revisions were summarized and added to in a major publication of the Geological Survey, "The Handbook of South Australian Geology (Parkin 1969).

Major advances in the overall knowledge and understanding of sedimentation and development of the Adelaide Geosyncline since 1969 have come with the release of the COPLEY 1:250,000 scale map, (Coats 1973), the excursion guide for the 25th. International Geological Congress, (Thomson et.al. 1976), the 1:1,000,000 scale geological map of the state (Thomson 1980) and the 1:600,000 scale map of the Adelaide Geosyncline and the Stuart Shelf (Preiss 1987). The Callanna Beds have been given "Group" status following detailed work in the Willouran Ranges (Forbes, Murrell and Preiss 1981).

The stratigraphic nomenclature and subdivisions used in this thesis are those developed by Dalgarno and Johnson (1964a) for the Parachilna 1:250,000 scale map, collated by Thomson et.al. (1964), used and modified by Coats (1973) and summarized by Preiss (1987). A brief summary of the nomenclature used is shown in Fig.4.

The regional mapping of the geosyncline has provided information to allow concepts of sedimentation in tectonic regimes to be developed. Rutland et.al. (1981) produced a paper summarizing the entire Precambrian of South Australia. Von der Borch, (1980), suggested that sedimentation in the geosyncline could well have begun as a result of initial rifting. This idea was expanded upon by Preiss (1983) with a comparison of the Adelaide Geosyncline and the model of the Atlantic margin of U.S.A. by Watts (1981). Jenkins and Gostin (1983) saw the Sturtian to Cambrian sedimentation within the Geosyncline in terms of a series of tectonic cycles.

A compilation of the entire geology of the Adelaide Geosyncline has recently been published by Preiss (1987), and the reader is referred to that volume for any of the details of the geology summarized below.

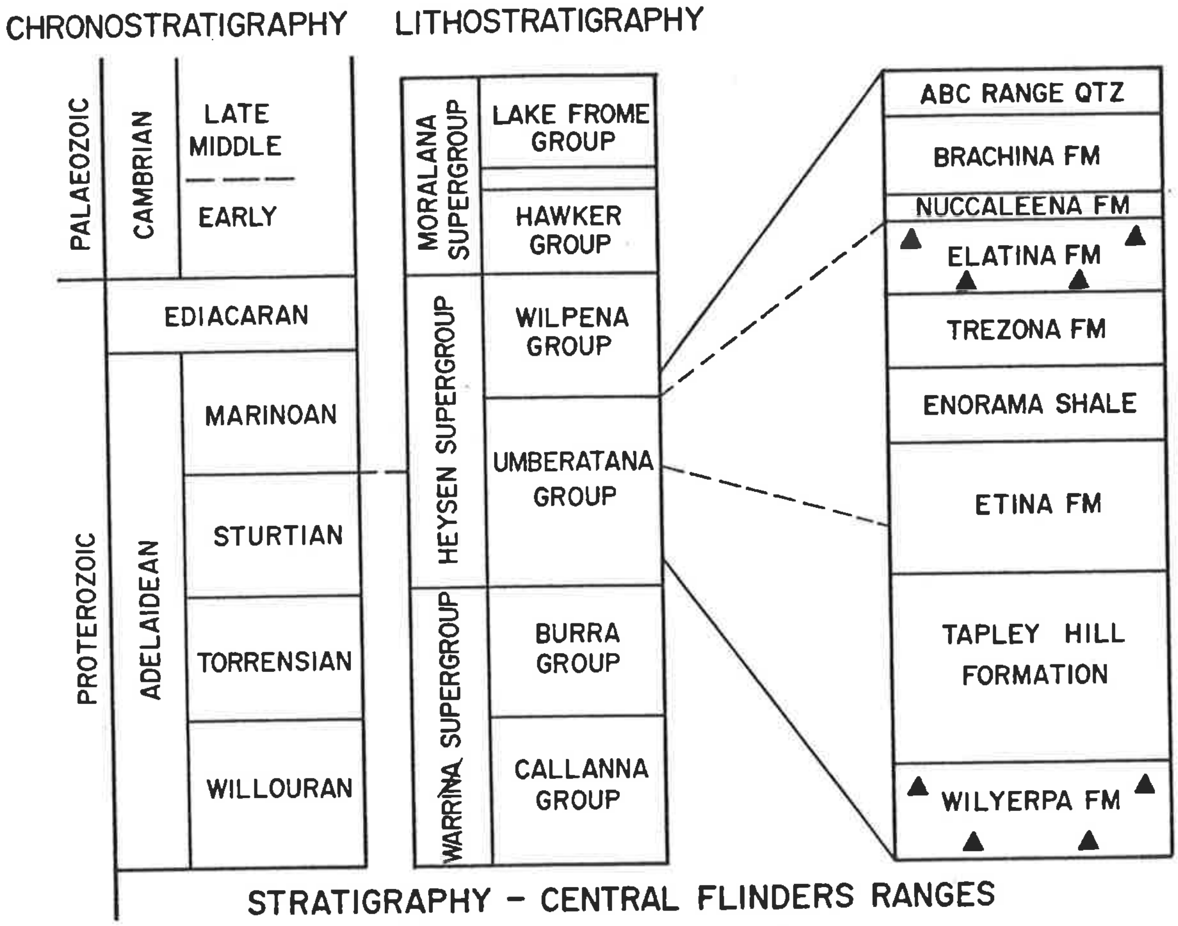


Figure 4. Summary of Adelaidean stratigraphy

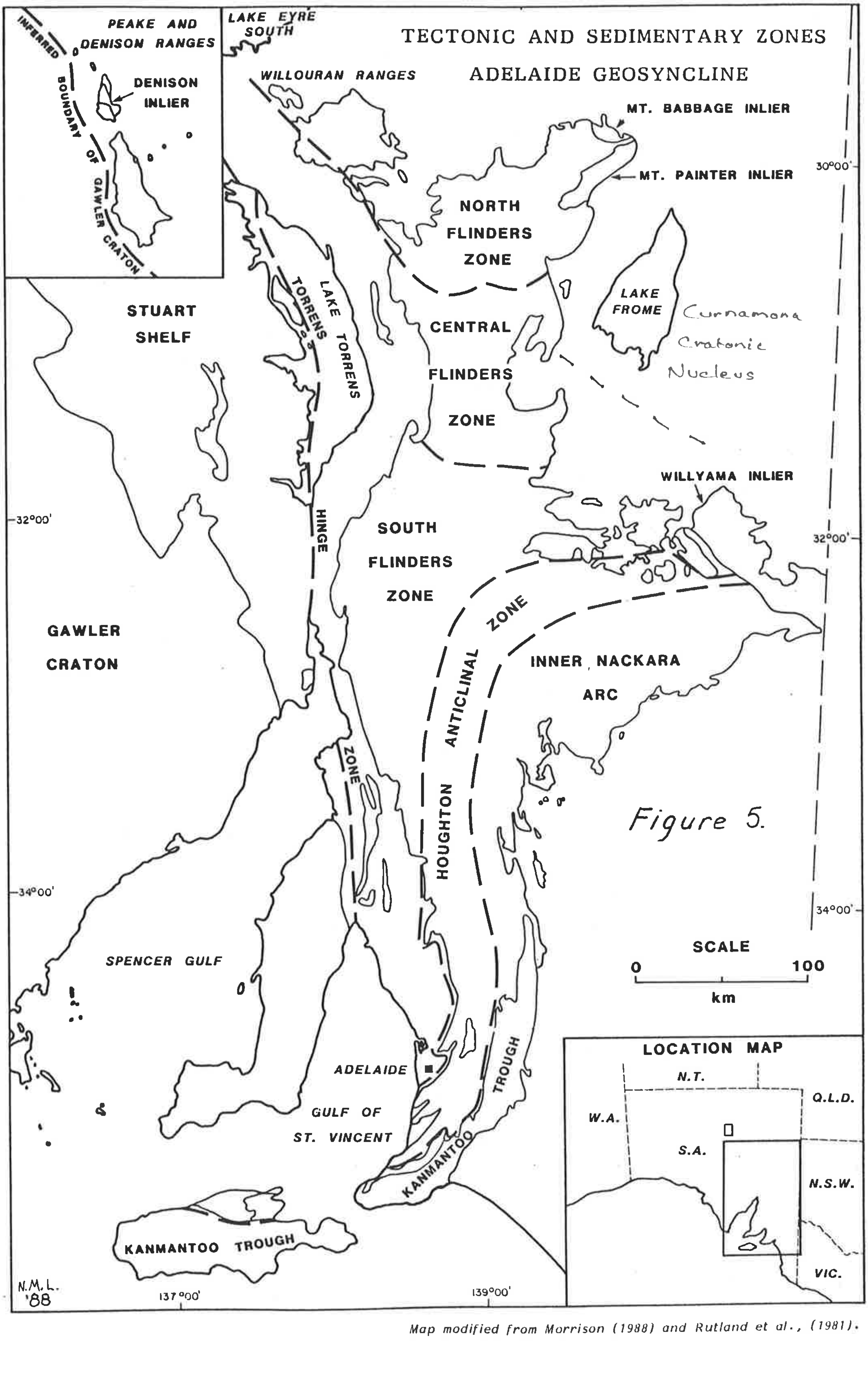
STRATIGRAPHY

The Adelaide Geosyncline is an area of thick accumulation of Late Proterozoic to Middle Cambrian sediments. The Adelaide Foldbelt covers the area of the thickest sedimentary sequence (see Fig.5) and is flanked to the west by the Stuart Shelf. The Torrens Hinge Zone separates the geosyncline from the shelf and is a zone of normal faulting and warping active during sedimentation, over which dramatic changes in thickness occurred. Sedimentation was originally restricted by this zone but gradually spread further across it to the west as the geosyncline developed.

Callanna Group

The basal units within the Adelaide Geosyncline are known as the Callanna Group and were recently fully defined by Forbes, Murrell and Preiss (1981). This group has been subdivided into a lower Arkaroola Subgroup and an upper Curdimurka Subgroup.

The Arkaroola Subgroup contains redbed quartzites, conglomerates and very shallow water sandstones, siltstones and mudstones. These show



Map modified from Morrison (1988) and Rutland et al., (1981).

ripple marks, mud cracks and occas-ional halite casts. There are some marbles and dolomites. This section also contains a basic volcanic sequence. The best outcrop of this is in the Wooltana area where amygdaloidal alkaline basalts are interbedded with sediments (Hilyard 1983). These volcanics are equated with other discrete outcrops of basic volcanics throughout the geosyncline and adjacent shelf and with basic rocks within the breccia bodies, (Preiss, 1987).

This sequence is overlain by the Curdimurka Subgroup of shallow water redbeds and carbonates. These contain heavy mineral banded sandstones and siltstones showing shallow water and desiccation features and abundant evaporite pseudomorphs. Rowlands et al. (1980), described halite, trona, shortite, gypsum and anhydrite psuedomorphs. They suggested a playa lake and associated sabkha environment for the clastics showing the evaporites and the interbedded stromatolitic dolomites and limestones.

A thick megabreccia is associated with this sequence in the Willouran Ranges but Forbes et al. do not include this as part of the sequence. Murrell (1977) referred to it as the Breadon Megabreccia and showed it to have some cross cutting relationships and to occur at several levels in the stratigraphy. Rowlands et al. (1980), referred to at least one of the major breccia units in the area as a graben foundering sequence.

The Callanna Group outcrop is best seen and described from around the margins of the present day foldbelt. Relatively undisturbed sections have been described from Arkaroola, Willouran Ranges, the Peake and Denison Ranges and minor outcrops at Depot Creek. Nearly all workers agree that the breccia bodies within the Adelaide Geosyncline consist almost entirely of fragments derived from the Callanna Group. Certain of the larger rafts within these brecciated areas show a measureable sedimentary sequence, parts of which have been equated with formations in the Callanna Group (Preiss, 1980, Mount, 1980.).

Burra Group

Callanna Group sedimentation was followed by the Burra Group. The nature of the contact is not well known since where it is seen around the margins of the geosyncline, it shows an unconformable transgression onto the older rocks. Preiss, (1983), suggests that elsewhere there may be a conformable transition from the evaporitic Callanna Group although mapping in the Mt. Painter area infers an unconformity, (Coats, 1973).

The Burra Group commences with a broad sand sheet interpreted as a series of coalescing deltaic bodies. This is followed by repetitions of black shales, fine sandy silts, feldspathic sandstones and dolomite with shallow water and evaporitic features and distinctive magnesite conglomerates. These are thought to represent a shallowing upward sequence from deeper water through prograding deltas to delta top sabkha-like lagoons.

Facies in the lower parts of the Burra Group are consistent throughout the Geosyncline but some variation develops between the northern and southern sections in the upper part. Megabreccias around the central areas suggest that some tectonic activity and uplift in the central parts may have divided the basin.

Sedimentation stopped for an unknown period after Burra Group deposition and there was some erosion. Minor tilting and faulting occurred during this break.

Umberatana Group

The Umberatana Group consists of the sediments deposited during and between the two major glacial periods. The lower Sturtian glacials and the upper Marinoan glacials are separated by a thick packet of "interglacial" sediments.

Sedimentation commenced with Yudnamutana Subgroup glacial sediments dropped into deep troughs adjacent to the Curnamona Nucleus. After minor tectonic movement and possibly a short break, glacial sediments were deposited throughout the geosyncline. This is known as the Sturtian glacial period. Coats, (1973), Coats and Forbes (1977) and others have outlined two glaciations in this period although Murrell, Link and Gostin (1977) and more recently Young (pers comm, 1986) suggest that the two periods of activity represent waxing and waning within an overall Sturtian glaciation.

The interglacial sequence is well exposed throughout the geosyncline and has been well studied. This sequence forms the basis of the fieldwork side of this thesis. A plethora of names has arisen to decribe this sequence which varies throughout the geosyncline in response to both subsidence rates and relative sea levels.

The interglacials

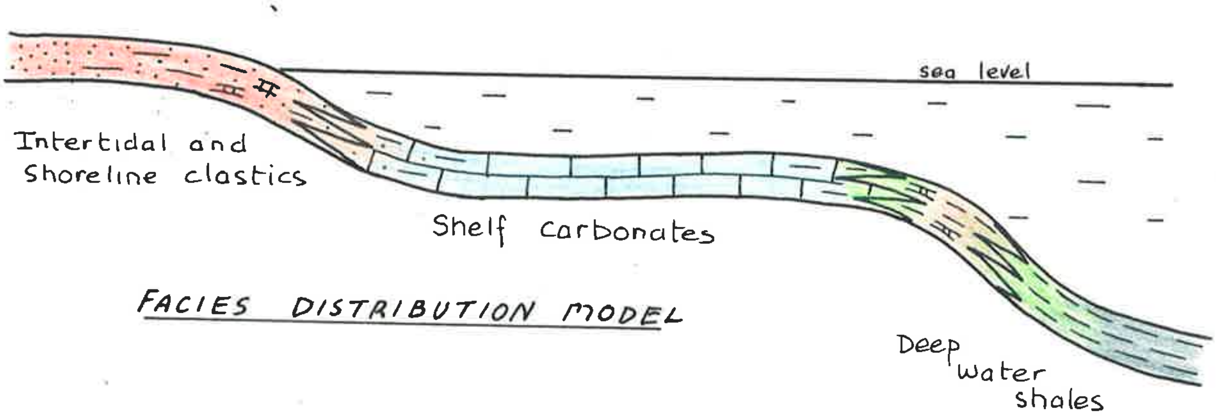
A number of names have arisen in the literature by the desire to separate deep water sediments, the Farina Sub-group, from shallow water sediments, the Willochra Sub-group. The tectono-sedimentary regimes of Rutland et al. (1981), (Fig.5), became quite apparent during the deposition of the Umberatana Group. The Central Flinders Zone was a shelf area between the deeper waters to the north and south. Shallow water sediments were deposited across the dividing shelf and along the eastern and western margins of the basin. This is shown in the paleogeographic reconstructions of Preiss (1987).

Understanding the interglacial sequence can be simplified if a simple depositional facies model is placed across the variations in depth throughout the basin and the facies moved toward and away from the shoreline in response to fluctuations in sea level. This facies model is shown in Fig.6. A shallow water carbonate platform separates near shore tidal clastics and shoreline clastics from calcareous siltstones grading off into deeper water green shales.

There was a major sea level rise in the basin immediately after the deposition of the Sturtian glacials, presumably in response to melting of the Sturtian ice sheet. The relatively deep water, dark grey Tapley Hill Formation shales are one of the most widespread units of the Adelaidean sequence and the first to transgress across the Stuart Shelf to the west. The start of the Tapley Hill Formation is marked by the Tindelpina Shale Member, a dark grey, often pyritic, shale with thin dolomite lenses common at the base. Dolomite increases in abundance toward the margin, eg. at Depot Creek. The exact position of the Woocalla Dolomite on the Stuart Shelf is unknown but it may represent the shallow shelf equivalents of the Tapley Hill Formation. Certainly Preiss (1987), considers it to be equivalent to at least the upper part of the Tapley Hill Formation. This fits in with the model proposed above.

Although the majority of the Tapley Hill Formation records quieter and/or deeper water sedimentation as a thick sequence of well laminated siltstones and shales, there is evidence of shallower conditions in the centre of the basin, localized around the Blinman, Enorama, Oraparinna and Upalinna Diapirs. The Tapley Hill Formation here is coarser grained than normal, being dominantly siltstone with a higher carbonate content throughout. Two members within the formation, the Mount Caernarvon Greywacke and the Wockerawirra Dolomite appear to be localized around the diapirs and both show distinct evidence of shallow water, if not in the immediate area of sedimentation, then at least nearby.

Sedimentation during an extensive regression, due either to sea level fall or merely progradation into the basin, is best described in terms of the three zones that developed in the basin at the time; the marginal areas, the Central Flinders shallow shelf zone and the deeper areas in the north and south of the basin.


sea level
Intertidal and
Shoreline clastics
Shelf carbonates
FACIES DISTRIBUTION MODEL
Deep
water
shales

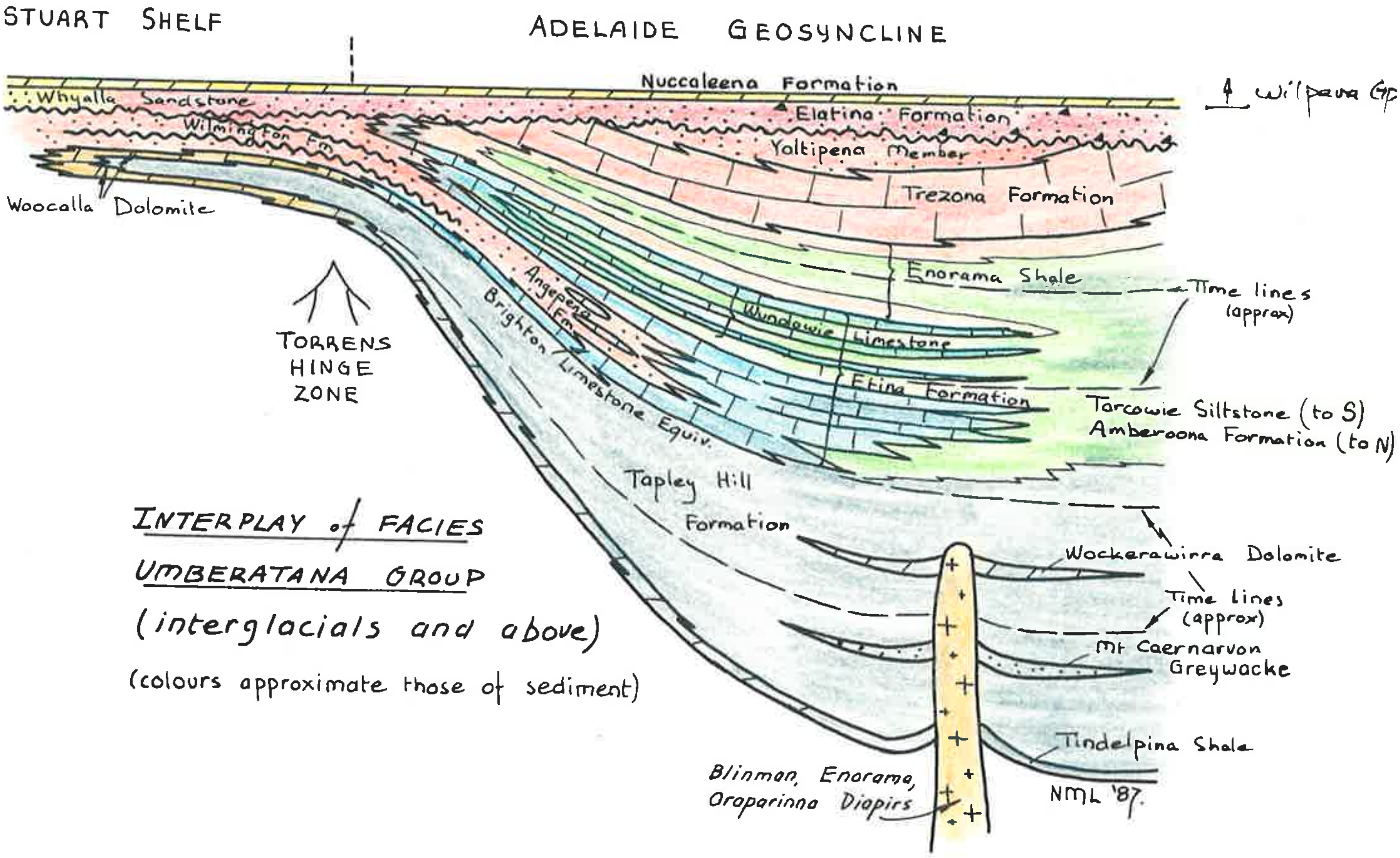

STUART SHELF
ADELAIDE GEOSYNCLINE
Nuccaleena Formation
Wilpena Gp
Whyalla Sandstone
Elatina Formation
Wilmington Fm
Yaltipena Member
Trezona Formation
Woocalla Dolomite
Enorama Shale
Time lines
(approx)
Angepena Fm
Brighton Limestone Equiv.
Wundowie Limestone
TORRENS
HINGE
ZONE
Etina Formation
Tarcowie Siltstone (to S)
Amberoona Formation (to N)
Tapley Hill
Formation
INTERPLAY of FACIES
UMBERATANA GROUP
(interglacials and above)
(colours approximate those of sediment)
Wockerawirra Dolomite
Time lines
(approx)
Mt Caernarvon
Greywacke
Tindelpina Shale
Blinman, Enorama,
Oraparinna Diapirs
NML '87.

Figure 6.

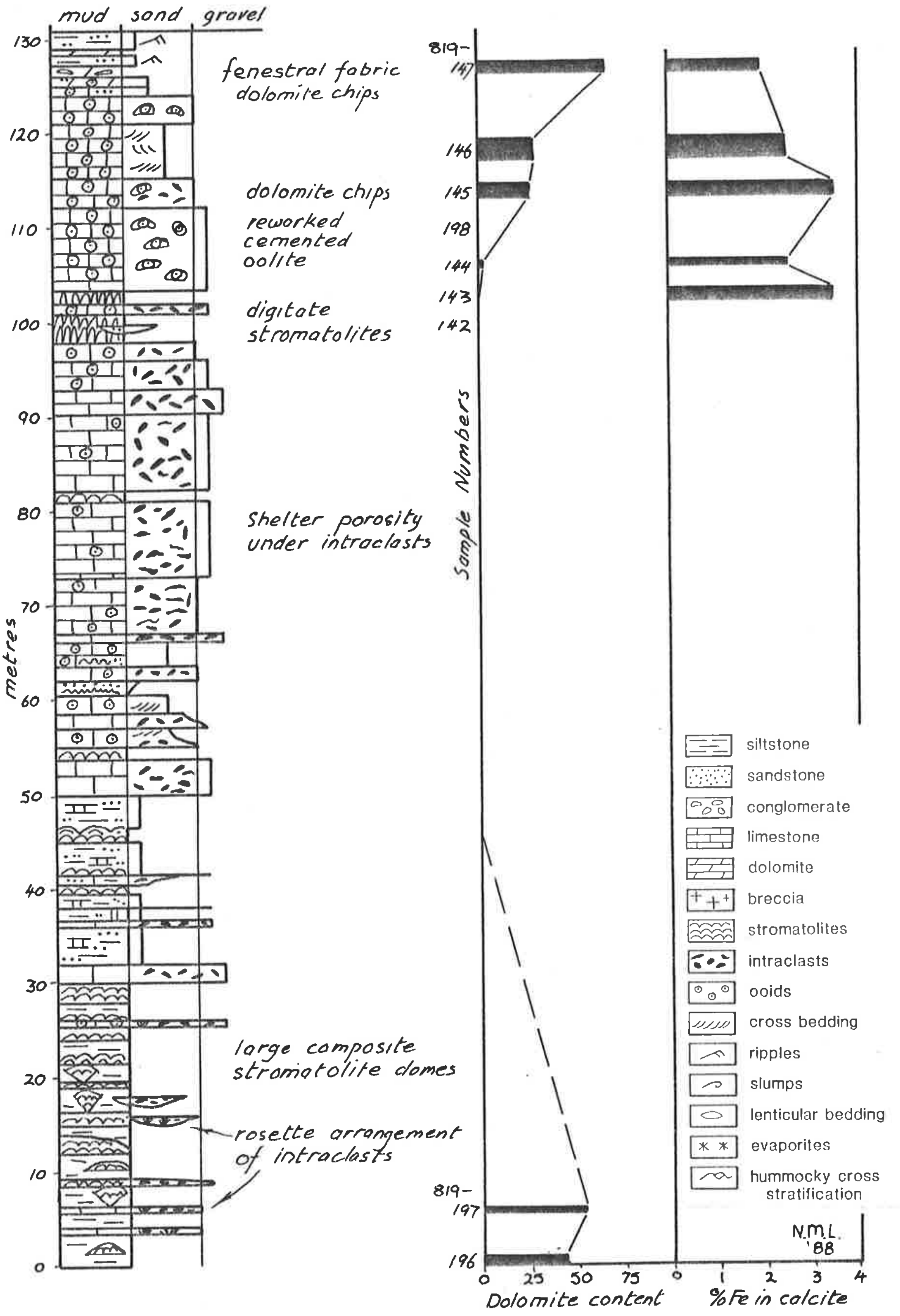
The marginal areas

The Tapley Hill Formation grades into the shallow water carbonates of the Brighton Limestone equivalents in the Depot Creek area, on the western margin of the basin. This limestone shows a change in facies from large stromatolites interbedded with grey calcareous siltstone, to a stromatolite dominated sequence, then a thick section of intraclastic limestones as higher energy conditions break up the stromatolites and algal mats. This then grades up into higher energy ooid shoals before being capped by supratidal, fenestral dolomites. Figure 7 shows this variation together with changes in dolomite content and iron content as measured by XRD scan.

The thickness of the Brighton Limestone equivalent at Depot Flat, around 130m, representing a continuous shallowing up package, suggests that the basin must have been gently subsiding at the time even though relative sea level was dropping.

The Brighton Limestone equivalent in the Quorn area is overlain by approximately 260m of redbed clastics, the Wilmington Formation of the Willochra Subgroup. Although sections 47 and 48 at Pichi Richi did not intersect the base of the sequence, outcrop of limestone nearby suggests that only about 20m of section was not measured at the base of the Wilmington Formation. This basin margin sequence is dominated by ripple cross laminated, red and brown sandstones with common grit bands. Green calcareous intervals and thin, poorly outcropping, algal limestones reflect the more marine conditions of the basin centre transgressing during periods of higher sea levels. The grit bands may represent prograding onshore deposits or hiatuses. The correlation diagram in Fig.6, together with the fact that the basal Elatina unconformity is downcutting to the west, suggests that the most marine influence in the Wilmington Formation is expected toward the top, equivalent to the Enorama Shale transgression.

A similar facies development to that at Depot Creek is recorded on the eastern side of the basin in the Balcanoona and Arkaroola areas. The Balcanoona Limestone is largely equivalent to the Brighton Limestone and its lower boundary with the Tapley Hill Formation is clearly diachronous, being much further down the section close to the shallow margins. The interbedded redbeds and carbonates of the Angepena Formation record the near shore influence as the sequence progrades during the Brighton-Etina transgression. The Weetootla Dolomite Member and the Wundowie Limestone Member, deposited to the west or basinward of the Balcanoona area, are equivalent to the Etina Formation. This relationship is not clear on the Copley 1:250,000 sheet but has since been clarified by Preiss (1987).



FACIES and CHEMICAL VARIATION through the BRIGHTON LIMESTONE equivalent, Section 46, Depot Flat.

Figure 7

The Central Flinders Zone

The Brighton Limestone is probably partly equivalent to the Tapley Hill Formation toward the centre of the basin. As the platform/shoreline sequences prograded, the shales of the Tapley Hill Formation became overlain by the shallow water limestones and interbedded slightly deeper water shales of the Etina Formation. In the central parts of the basin, The Tapley Hill Formation generally grades into the Etina in a different way to the gradation into the Brighton Limestone on the margin. Instead of stromatolites appearing within a slightly calcareous shale, the carbonate content rises up section to deposit a very calcareous siltstone and then a silty limestone. Ten-20m of silty limestone generally characterize the base of the Etina in the Central Flinders Zone before passing up into ooid shoals and then intraclastic and stromatolitic limestones. The base is clearly diachronous as the boundary moves down in the sequence toward the Blinman and Enorama Diapirs.

The bottom half of the Etina Formation is dominated by ooid, intraclast and stromatolitic limestones. There are three persistent green shale bands in this part of the formation, the middle one of which commonly becomes sandy before grading into the overlying limestone.

The top half of the Etina Formation is dominated by green shale and siltstone with three thin, but laterally persistent, limestone bands in the top third of the formation. These bands are so regular and persistent that they have been named the Wundowie Member of the Balcanoona Formation on the Copley 1:250,000 sheet. The Wundowie bands are traceable over much of the Parachilna sheet as well. The widespread nature of these three thin bands over at least two zones of differential subsidence suggests that sea level fluctuations dominated over basin subsidence during deposition of the upper half of the Etina Formation. Sea level probably extended to the lower half of the formation as the three shale bands mentioned above are equally mappable.

A peak of regression was reached midway through the Etina Formation where limestones dominate the sequence. A fluctuating transgression is recorded through the upper, shale dominated half of the formation until eventually limestone deposition ceased and the sequence passed up into the Enorama Shale. The basal third of the Enorama Shale near the type section, is a reddish, slightly calcareous/dolomitic silty shale. The middle third consists of non-calcareous, green, blocky weathering laminated shale. The upper third shows a return to reddish, calcareous shales and siltstones. These show an increase in the energy of the environment of deposition before passing into the first stromatolitic and intraclastic limestone band of the Trezona Formation.

The bottom half of the Trezona Formation is dominated by red shales and siltstones with thin beds of red intraclastic limestones. These are the distinctive "heiroglyphic limestones" of Mawson (1939). The top half of the formation consists of ooid and intraclastic limestones and very thick beds of red-grey stromatolitic limestones. These then grade into tidal flat mudstones and sandstones of the Yaltipena Member (new name).

There is an erosional dis/unconformity between the Trezona Formation and the overlying Elatina Formation. Erosion has removed a considerable amount of section, especially on the basin margins.

The shelf nature of the Central Flinders Zone during Umberatana Group sedimentation was inherited from the time of the Burra Group when there was probably no deposition in this area, (Preiss, 1987). Even though shallow water persisted in this area, sedimentation was considerable with a major depocentre in the east-central part of the zone. The Yaltipena Member is only preserved here and may not have been deposited over a very much larger area. The formation of major salt/shale domes may have helped to maintain shallow areas for carbonate precipitation and localize depocentres by evacuation of the source formations.

The north and south of the basin

In the deeper parts of the basin, drab grey and green shales and siltstones dominate the interglacial sequence. To the south of the Central Flinders Zone, the Tapley Hill Formation grades into the Tarcowie Siltstone with only minor development of the Etina facies around Carrieton. Distinctive members within the Tarcowie Siltstone, such as the Waukaringa Siltstone, are probably a reflection of distant shoreline offlap and onlap.

The Stuart Shelf

Much of the Umberatana Group is represented on the Stuart Shelf, if only with a much reduced thickness. Minor equivalents of the lower glacials, a very dolomitic equivalent of the lower Tapley Hill Formation, the Woocalla Dolomite, and silts of the upper Tapley Hill Formation have been drilled and mapped on the shelf. The coarse aeolian Whyalla Sandstone is the shelf equivalent of the Marinoan glacials, (Preiss, 1987 and Lemon and Gostin, in press).

The upper glacial units

The top of the Umberatana Group shows a return to glacial conditions with the deposition of the Elatina Formation fluvio-glacial sands and occasional diamictites along the western side of the geosyncline and thick diamictites and associated dropstone facies, the Yerelina Subgroup, deposited in the northeastern, eastern and southeastern parts of the basin. Details of this interval are covered in the paper by Lemon and Gostin (in press), which is included Appendix VI to this thesis.

Figure 8 shows the variation in the upper part of the Umberatana Group across the Central Flinders Zone. Sections 10, 13/30 and 50 are all influenced to some extent by the proximity to diapirs but section 10 was measured as close as possible to the Enorama Diapir and the closest interval, the Wundowie equivalent, shows the greatest thickening. Section 51 was measured as far east as present outcrop allows and this section begins to record the proximity of the eastern margin against the Curnamona Cratonic Nucleus. The basal Elatina unconformity is responsible for a large part of the thinning of the total section towards both margins. If the basin was subsiding at a regular rate through time, this unconformity would represent a considerable hiatus. Sections 46 and 47 are included on this diagram to show the equivalent facies development on the western margin of the basin. The redbeds of the Wilmington Formation are equivalent to the carbonate/shale Etina Formation and are considerably thinner. The position of the Brighton Limestone equivalents cannot be pinpointed but probably largely underlie the Etina Formation.

The colour of the rocks provides some indication as to the environment of deposition but is not always reliable. The deepest water sediments, those deposited in reducing conditions, are almost always green or grey. The nearshore oxidized sediments are red. The carbonate platform sediments are commonly green. This may not be due so much to redox conditions of the water but be more intimately associated with organic productivity and rates of sedimentation. In the Precambrian, with no shelly fauna to precipitate carbonate, seawaters were saturated with respect to calcium carbonate. Carbonate mud precipitated with an increase in temperature, agitation and a drop in the partial pressure of CO_2 due to the photosynthetic activity of abundant algae. All these conditions were likely to have been met on the platforms. Algal growth, as expressed by the sheer abundance of stromatolites in the limestones, was prolific. Associated micrite precipitation provided large volumes of sediment to the basin. Much of this was fixed on the platforms in the form of stromatolites and

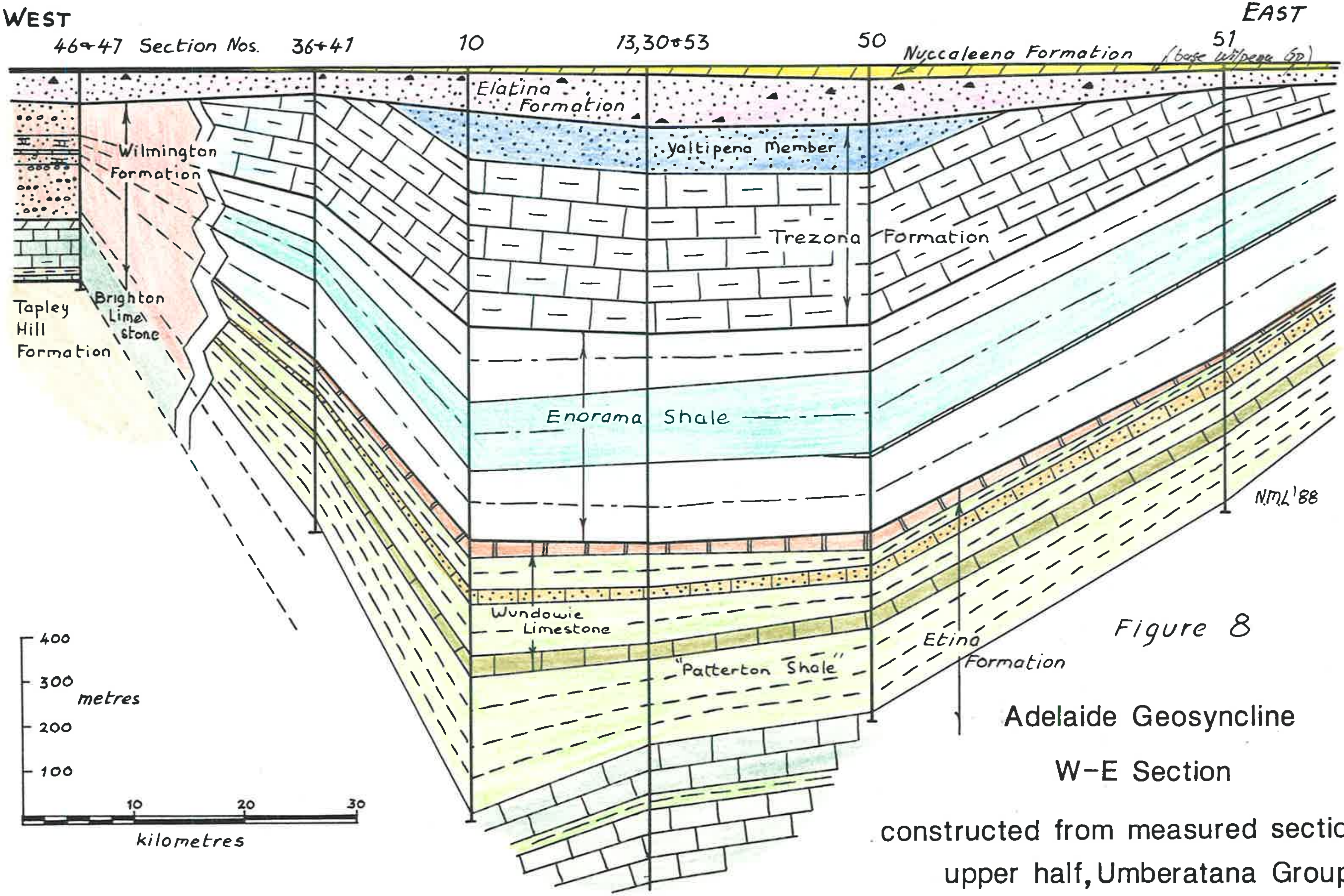


Figure 8

Adelaide Geosyncline

W-E Section

constructed from measured sections, upper half, Umberatana Group associated intraclast and ooid shoals formed from broken and perhaps desiccated partly cemented algal mats and stromatolites. Suspended micrite would also be swept seaward to be included in deeper water siltstones and shales.

The abundant organic productivity of the shelf areas may have provided sufficient carbon to the sediments to modify the oxidation of Fe++ to Fe+++ and give a relatively shallow water sediment a green aspect. Increased sedimentation rates may have also helped by rapidly burying sediments before they could be oxidized by the seawater. This appears to be the case with the Etina Formation and the upper and lower boundaries of the Enorama Shale. The Etina Formation limestone bands are clearly of shallow water origin with abundant stromatolites, ooids and intraclasts. These limestones and the interbedded shales are always green. The overlying Enorama Shale represents a major transgression most probably brought on by sea level rise and so the sediments should be seaward of the carbonate shelf. However, the basal third of the Enorama Shale near the type section is red. The middle third of the formation, that interval which shows no current activity at all, is green. The top third of the formation, approaching the shallow water carbonates of the Trezona Formation, is red.

Subdivision of units using colour as a major discriminating factor, as practised on the Copley 1:250,000 sheet, (Coats, 1973), has led to confusion. This is particularly evident on the boundary between the Copley and Parachilna sheets. The type section of the Enorama Shale, (Dalgarno and Johnson, 1964a), was measured through a secondary peripheral sink adjacent to the Enorama Diapir where local deeper conditions gave the whole section a green colour. Mapping around the Nuccaleena Dome by Leeson (1966) and Coats (1973), has the red units at the top and bottom of the interval between the Etina Fromation and the Trezona Formation marked as Angepena Formation, a unit originally defined as having been deposited in very shallow water, on the shore side of the carbonate platform. I have used the original nomenclature of Dalgarno and Johnson (1964a) for this interval for two reasons; the type section is in the middle of the thesis area, and the lack of subdivision on colour alone makes no assumptions about water depths or positions of the formation within the basin.

Wilpena Group

The thin but persistant dolomites of the Nuccaleena Formation which overlie the Marinoan glacials throughout the Geosyncline, mark the beginning of the Wilpena Group. Plummer (1978a), considered the lower half of the Wilpena Group to be a single depositional unit commencing with the shallow water dolomites of the Nuccaleena Formation, followed by the subtidal redbed sands and silts of the Brachina Formation and capped by the deltaic ABC Range Quartzites. All these units show a western source with a gradation across the basin to the east into the Ulupa Siltstone.

The deep water Bunyeroo Formation red shales commence the next cycle of sedimentation. This is followed by the Wonoka Formation of deep water turbidites topped by progressively shallower carbonates with a gradation into the deltaic redbed sandstones of the Bonney Sandtone, the lower unit of the Pound Subgroup. The top of the Pound Subgroup and of the Wilpena Group is represented by the Rawnsley Quartzite which contains the Ediacaran fauna. Only the lower half of the Wilpena Group is present right across the Stuart Shelf. The Bunyeroo Formation and those above progressively retreat east of Torrens Hinge Line, the boundary between the shelf and the geosyncline.

Cambrian Hawker, Lake Frome and Kanmantoo Groups

There was a basin wide hiatus at the end of the Wilpena Group prior to the commencement of Cambrian sedimentation. A marked change occurred in the areas of active sedimentation, with shallow water carbonates dominating both the southern area around Adelaide and the area north of Port Augusta, the Arrowie Basin. Middle Cambrian shallow water redbed clastics and minor carbonates overlie the carbonates in the Arrowie Basin (see Preiss, 1987). Deep water flysch like sediments of the Kanmantoo Group followed the carbonates in the southeastern parts of the geosyncline as tectonic activity rapidly deepened that part of the basin.

Delamerian Orogeny

Sedimentation in the basin ceased with the onset of the Cambro-Ordovician Delamerian Orogeny. There appears to have been at least two events within this orogeny with the main folding, oriented N-S, and metamorphism associated with the first. This dominated the southern 2/3 of the Adelaide Geosyncline... Intrusion of granitic magmas occurred during the waning stages of that first event. The second event was less pervasive but did reset the geochronological ages, so that all dates now measured for the orogeny are early Ordovician. Fold axes of the second event are oriented E-W and are particularly well developed in the North Flinders Zone, (Preiss, 1987). The effects of the orogeny are most intense in the southeast of the geosyncline east and south of Adelaide and in the northeast around Mt. Painter but generally the sediments only reached lower greenschist facies. The Central Flinders Zone was barely affected by the heating events and only mildly folded. Associated folding was widespread in the geosyncline but did not affect the sediments on the Stuart Shelf which are still relatively flat lying.

Geochronological Framework

The time frame for sedimentation within the Adelaide Geosyncline is rather imprecisely defined at present but all available data are summarized in Preiss (1987). Overprinting of the Delamerian Orogeny is widespread and appears to have disturbed the isotopic distribution of nearly all the rocks within the geosyncline. The few volcanic rocks dated so far have been altered to some degree and provide unreliable ages. To date, only K-Ar and Rb-Sr techniques have been used extensively and these are the most susceptible to isotopic redistribution. The most reliable dates so far have come from the underlying crystalline rocks, intrusions and metamorphic affects associated with the Delamerian Orogeny, Cambrian fossil correlations and shale dates from the relatively undisturbed sediments on the Stuart Shelf.

Several problems still remain. The crystalline rocks only give an estimate of the maximum age of the start of sedimentation. The Delamerian Orogeny is a multi-stage event and dates only reflect the last stage of folding and metamorphism. Cambrian fossils only occur in the very upper parts of the sequence and only a few of the Australian forms can be used in world-wide correlations. Some of the shale dates show large errors and there are problems with the exact correlation from the shelf into the geosyncline. Despite these factors, many of the dates are consistent with the stratigraphic sequence. Preiss (1977), used stromatolite stratigraphy to correlate the Adelaide System with the Late Riphean and Vendian of U.S.S.R. but many regard this technique as relatively imprecise. Jenkins (1984), has summarised much of the available data worldwide in an attempt to put a time frame around the Ediacaran Period and to determine the rates of sedimentation at that time. The upper limit of sedimentation within the Adelaide Geosyncline is framed by reliable dates from geochronology and fossil correlation at around 510 Ma. The lower limit is still very doubtful. The dates around 1000 Ma to 1150 Ma are either unreliable or not directly related to the geosyncline. The only reliable dates within the Adelaidean sequence are those above about 800 Ma, (Fanning et al., 1986), for a tuff in the Callanna Group. This is the closest date to the base of the Adelaidean sequence so that sedimentation may only date from near that date or possibly back as far as 850 Ma.

Tectonic Setting and Basin Development

The northern half of the geosyncline, at least, is thought to be intracratonic during the majority of the sedimentary history with sediment sources from the Gawler Craton to the west, the Mt. Painter area and the Curnamona Nucleus to the northeast, the Willyama Block to the east and possibly the Muloorina Ridge to the north during the earliest period of sedimentation in the basin. The southern half is less well defined with the eastern margin now obscured by the Tertiary sediments of the Murray Basin. Sediments in the south were derived mainly from the Gawler craton to the west and the Willyama Block to the northeast. During the latest Adelaidean, the basin also opened to the north with a shallower zone in the central Flinders between the Gawler Craton and the Curnamona Nucleus.

Although sedimentation continued in the geosyncline without interruption from a major orogeny until the Middle Cambrian, there were several minor orogenic disturbances which halted sedimentation temporarily and were followed by changes in the paleogeography and distribution of the sedimentary facies. There was a marked change in the Lower Cambrian when subsidence developed a shelf edge along the south eastern margin of the geosyncline and the deep water flysch-like Kanmantoo Group sediments were deposited. Up until this stage, the majority of the sediments in the geosyncline were relatively shallow water deposits.

Apart from major basin-wide influences on sedimentation, minor internal basin tectonics had local effects on facies distributions. These included syndepositional block faulting, some anticlinal warping, transverse faulting with possible associated flower structure faults and diapirism.

Sprigg (1952) suggested that the basin was more in the nature of a miogeosyncline deposited on a continental terrace with the "Stuart Stable Shelf" on the landward side and a continental margin to the southeast. Thomson (1969) considered that sedimentation was a result of basin downwarping with a transition across the Torrens Hinge Zone between the Stuart Shelf and the geosyncline. Forbes and Coats in Thomson et al. (1976) were unsure as to the accuracy of the term "geosyncline" and only used it as a convenient reference term for a belt of thick sediments. They envisaged the basin as being partially fault controlled but generally just a fractured and downwarped segment of basement that was more mobile than the adjacent Gawler Craton.

Von der Borch (1980) described the evolution of the Adelaide Geosyncline in terms of a rift model. He compared the Adelaidean and Cambrian sedimentation to that in post-Permian rifts and passive continental margins. The Precambrian-Cambrian unconformity was suggested as the break-up unconformity. This was based on the interpretation that marine conditions did not dominate until then with the Ediacara Fauna the first tangible evidence of marine conditions. Although regional downwarping commenced with the Tapley Hill Formation, this continued right through until the Cambrian. He suggested that the basin comprised of at least two three-arm rifts. The northern areas did not progress past the "failed arm" or aulacogen stage.

Forbes et al. (1981), recognized an early tensional regime existing from pre-Adelaidean times through to the Sturtian, exemplified by basic volcanism on the Stuart Shelf and by the Willouran deposition. Graben development characterized the sedimentation of the Burra and Callanna Groups. There were also large vertical fault movements in the early Sturtian but these diminished with time. The regional patterns of sedimentation became more widespread and uniform after the early Sturtian with transgression onto the Stuart Shelf. These authors suggest that subsequent transgressions became more widespread and that the post-Sturtian Adelaidean was relatively quiescent. The Lower Cambrian was deposited during a transgression though shallow water conditions generally prevailed. There was a Mid Cambrian regression in the northern areas coincident with the Kanmantoo trough sedimentation in the southeast of the basin.

Preiss (1983) subdivided the Adelaidean sediments into a lower Warrina Supergroup, the Callanna plus Burra Groups, and an upper Heysen Supergroup comprising the Umberatana and Wilpena Groups. He demonstrated a marked change in the depositional style and sedimentary distribution between the supergroups and related these to their position in the developing geosyncline. The Warrina Supergroup is similar in style and distribution to pre- and syn-rift sediments while the Heysen Supergroup parallels post rift sediments as defined by the generalized model of Watts (1981).

Jenkins and Gostin (1983) have subdivided the post-Sturtian to Middle Cambrian sediments of the geosyncline into five tectono-sedimentary cycles. Each commences with tectonic deepening of the basin and progresses with gradual infilling of the basin. They envisage the Callanna and Burra Groups as being deposited in a basin under a tensional stress regime with a change in the major stresses at the time of the Burra-Umberatana unconformity. The regime changed to one where strike-slip faulting and compression dominated. Activation of this regime lead to their five tectonic cycles. These cycles had climatic (glacial) and eustatic sealevel changes superimposed upon them.

The author broadly agrees with the ideas of von der Borch (1980) and Preiss (1983). There is also some evidence strike-slip faulting affecting deposition in the upper half of the Wilpena Group and the Cambrian so that the ideas of Jenkins and Gostin warrant inclusion in an overall model. However, the author feels that there are additional factors which need to be taken into account.

A recent paper by Bostrom (1984) investigated crustal extension under ice loading during major glaciations. The weight of a massive ice cap not only isostatically depresses the crust beneath it but also causes extension and thinning of that crust. Part of this strain is taken up by curvilinear faults as the crust is thought to behave as a quasi plastic solid. Consequently the strain is not fully recovered on deglaciation. These faults are concentrated along the coast lines at the margin of the ice cap and exert some control on the position and formation of fiords.

The extensive and intensive Sturtian glaciation may have initiated the Kaurna tectono-sedimentary cycle of Jenkins and Gostin (1983) by depressing the crust over a much wider area than was occupied by the initial rift sediments of the Warrina Supergroup. The earliest Sturtian glacials were locally deposited in deep, fault bounded fiords marginal to the Curnamona Nucleus. The retreating ice cap deposited glacial sediments in the wider basin created by the ice loading and the post-glacial sea rose to spread right across that basin. This, together with the now thinner crust beneath, allowed deposition of the most widespread and uniform unit in the Adelaidean sequence, the Tapley Hill Formation. Subsequent Umberatana Group sedimentation gradually became more restricted in distribution as the basin filled. The sequence in the Central Flinders Ranges shows a very restricted shallow water facies at the top of the Trezona Formation capped by an erosional surface prior to the deposition of Marinoan glacials. These restricted conditions are likely to be due to a sea level drop caused by the onset of glaciation.

All evidence suggests that the Marinoan glaciation was neither as extensive nor as intensive as the Sturtian event. The sequence immediately following each glaciation is very similar with a shallow water cap dolomite grading up into subtidal marine clastics. The Brachina Formation was deposited in shallower water conditions and is less extensive than the Tapley Hill Formation. However, this is to be expected if the reactivation of the basin is due to the degree of ice loading. The Brachina Formation gradually shallows upwards into the deltaic ABC Range Quartzite.

The overlying Bunyeroo Formation is a deeper water red shale sequence which marks the beginning of another tectono-sedimentary cycle as defined by Jenkins and Gostin. The author feels that, although this cycle contained a substantial tectonic element in that the effects of synsedimentary strike slip faulting are evident, sea level rise also played a major role. The Bunyeroo Formation is followed by the Wonoka Formation, which shallows up as the deltaic redbeds of the Bonney Sandstone prograde across the Wonoka carbonates.

Although the Brachina equivalents are almost as widespread as the Tapley Hill Formation on the Stuart Shelf, they always appear to be of shallower water origin. The Wilpena Group becomes more restricted with time with the base of the upper half only just spreading onto the shelf and the Pound Subgroup being restricted to east of the Torrens Hinge Line. As mentioned above, the earliest Cambrian sediments again transgressed across the shelf before the Middle Cambrian regression in the north of the basin.

CHAPTER 4

STRATIGRAPHY

In the description of the sequence that follows, I have tried to describe those parts of the sequence away from, and hopefully unaffected by, the influence of diapirs, as well as diapirically influenced areas. This state is impossible to achieve in the lower parts of the section as that interval only outcrops adjacent to the diapirs within the study area. The complete influence around several diapirs will be described in later chapters but the direct influence on the sediments will be detailed here and referred to in those later chapters.

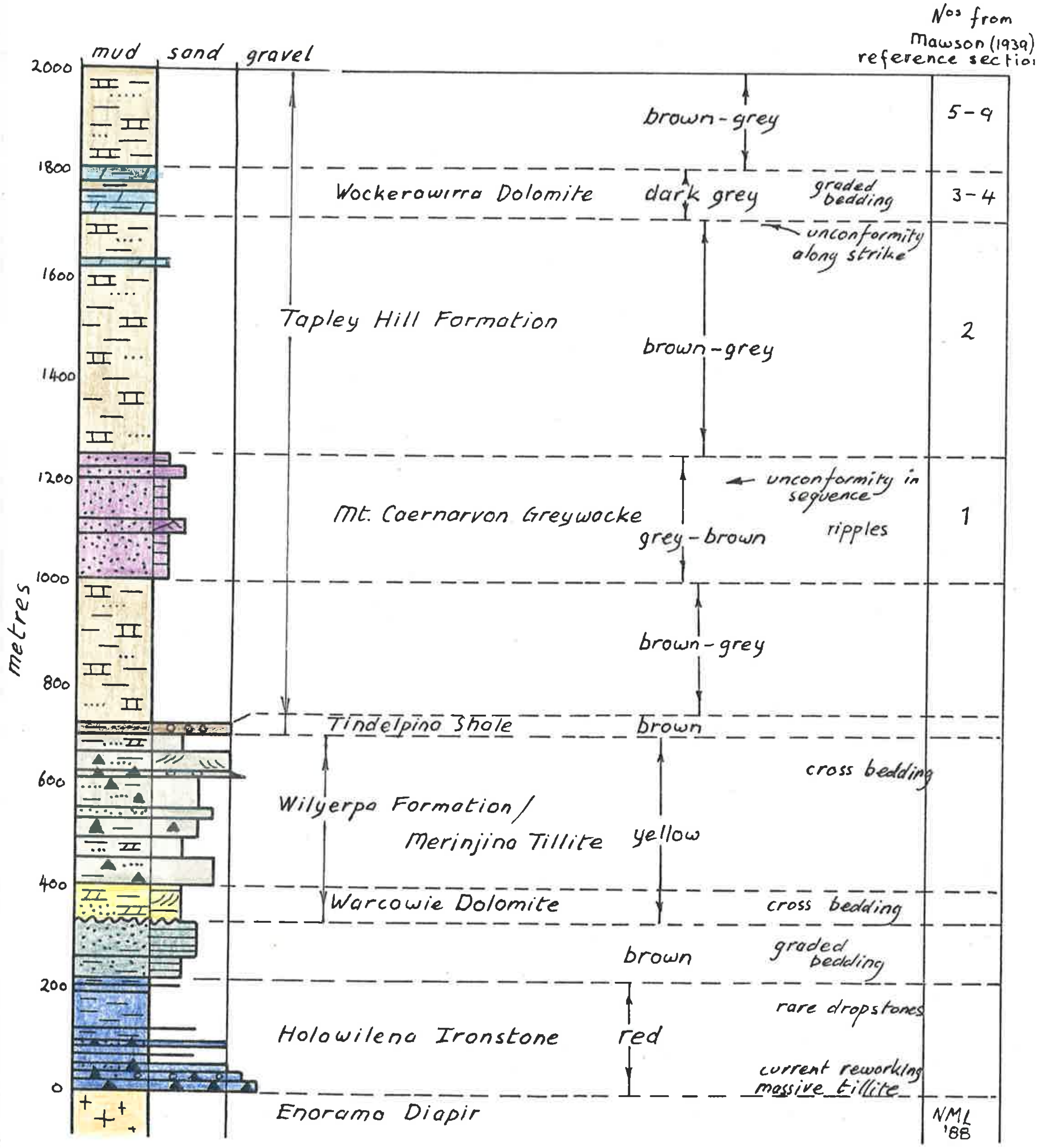
The most complete sequence of the lower half of the Umberatana Group in the area is that which outcrops to the east of the Oraparinna and Enorama Diapirs, along the Pantapinna Walking Trail. Sections 52 and 53 were constructed from several traverses in this area to cover the Umberatana Group up to the middle of the Etina Formation. Additional information on this interval comes from sections measured around the Blinman Diapir. Information on the remainder of the Etina Formation, the Enorama Shale, Trezona Formation, Elatina Formation and Nuccaleena Dolomite was gathered from throughout the study area. Section 1 was used as a "type" section of the Wundowie Limestone equivalent in the study area.

Umberatana Group

Yudnamutana Subgroup.

Outcrop of the Yudnamutana Subgroup (Preiss, 1987) and Wilyerpa Formation was measured along section 52 and shown in Fig.9. A dark red, iron rich facies equivalent to the Pualco Tillite and Braemar Ironstone can be seen in fault contact with the Enorama Diapir about 200m SE of the Oraparinna Asbestos Mine. This is the lowest part of the well bedded Upper Adelaide Series of Mawson seen in the area. The basal 20m is a red, hematitic boulder tillite, with all exotic clasts, equivalent to the tillitic section of the Braemar ironstone facies. Following the nomenclature used by Preiss (1985), both this and the overlying red shales are called the Holowilena Ironstone in the Central Flinders Ranges. Striated and facetted boulders attest to the glacial nature of the diamictite.

The sequence rapidly fines upwards through current reworked conglomerates and sandstones with dropstones into the dark red, finely laminated, iron rich shales more typical of the Holowilena Ironstone. Occas-ional dropstones and interbeds of diamictite suggest that this



SECTION 52 and part 53

Asbestos Mine, Pantapinna Walking Trail

Figure 9.

interval was also deposited under glacial conditions. Further up section, along the western flanks of the prominent Lizard Ridge, the red shales become interbedded with thin brown sandstones. These eventually dominate the section as the red shales are replaced by thin yellow-weathering siltstones. The crest of Lizard Ridge is composed of parallel banded, well sorted, feldspathic sandstone. The even bedding and 3-4 cm graded bedding seen at this level suggest deep water deposition, possibly from turbidity currents.

Wilyerpa Formation.

There is a marked change in the style of sediments overlying the boldly outcropping sandstone. Dolomitic siltstones, thin dolomites and interbedded yellow and brown lithic sandstones outcrop poorly along the eastern flank of Lizard Ridge. These may be equivalent to the Warcowie Dolomite Member,the basal unit of the Wilyerpa Formation. In the Worumba area, (Preiss 1985), this unit unconformably overlies the Holowilena Ironstone. Although the contact is obscured along section 52, pinchouts along strike suggest that there is an unconformity at the base of the Warcowie Dolomite in the Oraparinna area.

The dolomitic silts and sands are interbedded with, and overlain by, yellow weathering diamictites with an assortment of exotic pebble types, and lithic sandstones and conglomerates probably reworked from the diamictites. This is the main part of the Wilyerpa Formation, equivalent to the Appila Tillite and Merinjina Tillite, themselves equivalent to the Sturt Tillite in the Adelaide area.

The Wilyerpa Formation shows very rapid facies change along strike on the eastern flanks of Lizard Ridge. Within 600m, the bottom three quarters of the Wilyerpa Formation as described above, grades into a series of stacked channels of lithic and feldspathic sandstones. Granules and small pebbles of the underlying Holowilena Ironstone are reworked into the sands of the Wilyerpa Formation and the sequence is upturned against the Enorama Diapir. This upturning is clearly seen by mapping the unconformity at the base of the overlying unit. This is the first influence of activity in the Enorama and Oraparinna Diapirs seen on the surrounding sediments.

Tapley Hill Formation.

1300m of Tapley Hill Formation outcrops to the east of Lizard Ridge, along the Pantapinna Walking Trail, as measured on section 53, (see Fig.9). Three distinctive members occur within the sequence of dark brown and grey calcareous siltstones and shales.

Tindelpina Shale Member.

Away from the local influence of active diapirs, the Tindelpina Shale is usually seen as about 50m of dark grey to black shales with interbedded dolomites which become less prominent up section as this member grades into the typical Tapley Hill Formation. The base is usually a sharp contact on the underlying tillitic sequence. East of the Asbestos Mine, the Tindelpina Shale is in fact a conglomerate developed on an unconformity cut into the Wilyerpa Formation as it was turned up against the rising Enorama Diapir. This episode of diapiric activity was seen by Dalgarno (in Dalgarno 1983) along the southern margins of the Oraparinna Diapir where the Appealinna Fault intersects the diapir. Here, debris flow boulder beds up to 1m thick are interbedded with finely laminated black shales typical of the Tindelpina Shale Member over an interval of 100m.

Tapley Hill Formation.
(Sample numbers 819-181, 183 and 189.)

The Tindelpina Shale grades up section into more typical Tapley Hill Formation. Along the Pantapinna Walking Trail, this is a finely laminated calcareous shale with intervals of slightly coarser wavy laminated siltstone with a slightly higher carbonate content than the finer facies. There are occasional levels where the finely laminated nature of the sediment gives way to to massive beds about 50 cm thick. This is due to slumping in the basin, reworking the muds downslope. Away from the diapir contacts, these slump horizons contain rare small pebbles in the muds.

The very thinned section of Tapley Hill Formation that outcrops along the western margin of the Enorama Diapir, just south of the Asbestos Mine, is dominated by coarse sandy mudstone. The relationship between this subfacies, the diapir and the Tapley Hill Formation proper is best seen 1200m north of the Asbestos Mine, on the eastern margin of the Enorama Diapir. Along strike towards the diapir, several slumped intervals within the formation, interbedded with wavy laminated siltstones, grade first into sandy mudstone which becomes more dolomitic then eventually into a sandy pebbly dolomite upturned at the diapir contact.

Mount Caernarvon Greywacke Member
(Sample numbers 819-86, 126 and 182.)

300m above its base, the Tapley Hill Formation grades into the well sorted, very fine feldsarenite of the Mount Caernarvon Greywacke Member. This usually well laminated unit is boldly outcropping against the shales and siltstones, being cemented by quartz and dolomite. Weathering of the iron-rich dolomite gives a brown speckled appearance suggestive of a high lithic component. It may have been this that led the original workers in the area to call the unit a greywacke. Beds of fine grained, ripple cross laminated sands within this unit show that this sediment was deposited in shallower water conditions than the well laminated shales of the majority of the formation. Conditions were so shallow in parts of the basin that there were periods of non deposition and erosion, leaving paraconformities in the sequence. One such paraconformity shows near the top of this member just to the south of the walking trail. These breaks are most evident immediately adjacent to the diapir.

The top and bottom contacts of this member with the typical Tapley Hill facies are usually gradational, as this member is a very fine to fine sand sized facies of the Tapley Hill Formation with very similar mineralogy.

Wockerawirra Dolomite Member

(Sample numbers 819-14, 127, 128, 177, 185, 187 and 188.)

Dalgarno and Johnson (1965) and Dalgarno, Johnson and Coats (1964), mapped the Wockerawirra Dolomite on the Blinman and Oraparinna 1:63,360 scale sheets as the entire interval from the first appearance of the dolomite to the base of the Etina Formation, but subsequent maps eg. the Parachilna 1:250,000 scale sheet, show the Wockerawirra Dolomite to be a member of the Tapley Hill Formation, the currently accepted status of the unit. The Pantapinna Walking Trail outcrop was defined as the type section of the member.

In the type section, the Wockerawirra Dolomite is a well laminated, grey to dark grey, silty, micritic dolomite. A variation in silt content outlines graded bedding on a 1-2cm scale. Minor carbon content, probably originally organic, gives the unit its characteristic dark colour. The dolomite itself is commonly iron-rich, bordering on ankerite. This is shown both by XRD measurements and carbonate staining techniques. Some current activity at the time of deposition is evident as starved, isolated ripples 3mm high with a wavelength of about 25mm. The graded bedding and ripples show that the dolomite was detrital rather than a direct precipitate.

In situ cementation of a direct precipitate probably did occur where the sea floor was at or near exposure at the time of deposition. Examples of this are seen where the unit abuts a diapir at the waterfall along the eastern edge of the Enorama Diapir and in the White Cutting on the edge of the Blinman Diapir 800m south of Alpana H.S. (samples 819-187, 188).

As with the Mount Caernarvon Greywacke, the top and bottom contacts of this member with the Tapley Hill Formation proper are usually gradational over 1 to 2m. There is a paraconformable contact at the base on Section 54, the hiatus shown by an oolitic litharenite at the base. Section 56, east of Blinman, shows the return to the typical Tapley Hill facies is accompanied by slumping and the influx of conglomeratic diapiric detritus.

Top of the Tapley Hill Formation

The Tapley Hill Formation shows a gradational contact with the overlying Etina Formation. The carbonate content, usually calcite, increases toward the top of the formation along with a slight increase in grainsize. The very top of the formation is a very calcareous siltstone whereas the base of the Etina Formation is a silty limestone. This boundary is surprisingly easy to map as it has an associated change in soil colour from reddish to off white and the increase in cementation afforded by the higher lime content makes the base of the Etina Formation far more prominent topographically. This boundary is clearly diachronous in the vicinity of the Enorama and Blinman Diapirs and the onset of the Etina Formation is heralded along Section 57 by the early appearance of a sandy intraclast limestone, transported off the diapir into the Tapley shales.

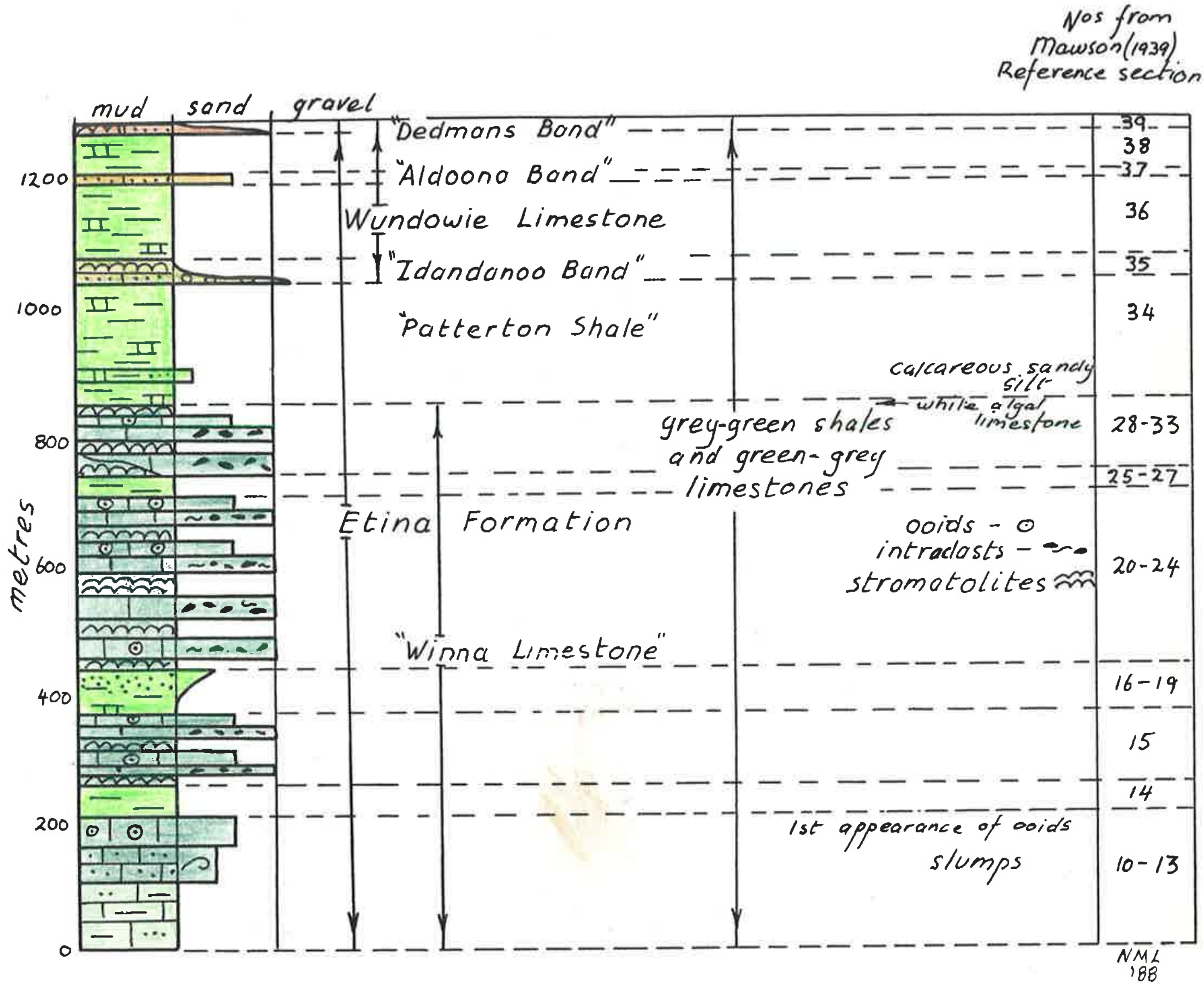
Etina Formation

The Etina Formation as measured along Sections 53 and 30 consists of about 1300m of interbedded shallow water limestones and slightly deeper water shales. A graphic summary of the complete Etina section is presented in Fig.10. To assist mapping in the local area, I informally subdivided this unit into three. The lower "Winna Limestone" consists of four shallow water, sandy, oolitic, intraclastic and stromatolitic limestones separated by three thin shale bands. The thick "Patterton Shale" separates the "Winna Limestone" from the Wundowie Limestone equivalent at the top of the formation. At least 40% of the new data in this thesis was collected from the Wundowie equivalent and, again to make mapping and reference to the section easier, I have assigned informal names to the three thin limestones which, together with the two relatively thicker interbedded shales, make up this part of the formation. The following informal nomenclature distinguishes between a limestone-dominated bottom half of the formation and a shale-dominated top half.

"Winna Limestone"

The base of the Etina Formation is a silty limestone that grades upward into a very fine to fine grained sandy limestone. Local slumping is

Figure 10



SECTION 39 and part 53

ETINA FORMATION – Pantapinna Walking Trail evident along section 53. The appearance of a sandy ooid limestone is the first definite indication of very shallow water conditions. The base of the formation, the silty limestone, moves down section along strike to the NNW, approaching the Enorama Diapir. As shallowing caused the change in style of deposition from the Tapley Hill Formation to the Etina Formation, it is evident that conditions were shallower in the immediate vicinity of the diapir. This feature is also prominent around the Blinman Diapir.

A thin band of green, calcareous shale above the ooid limestone marks a short term deepening of the basin. This shale marker is traceable over a large area, suggesting that the deeper conditions were a result of sea level rise, rather than basin subsidence which would restrict the shale to the centre of the basin. The shale does, however, pinch out locally due to shallowing against the Blinman Diapir.

A return to shallow conditions results in deposition of a thick limestone band, typical of the rest of the Etina Formation. Abundant grey-green stromatolitic limestones are interbedded with higher energy ooid and intraclast limestones. The ooids form widespread shoals which can be traced some distance locally. Intraclasts are commonly restricted to channels within the stromatolites but there are periods, probably related to shallowing upward cycles, when intraclasts become particularly widespread. The intraclasts within the inter-stromatolite channels are usually large flakes, derived from breakup and possible desiccation of stromatolites. The widespread intraclasts are usually more comminuted and better rounded than the flakes and have micritized envelopes, the result of algal boring. Broken flakes have become the cores of what are now technically ooids, with one or two thin oolitic rinds beneath the micrite envelope.

Two more thin shale bands divide the remainder of the "Winna Limestone". These shales are similar to the thin shale mentioned above and all the comments relating to that shale also apply to the succeeding two. The middle shale does have one distinctive feature, a coarsening upward sandy top.

The limestones of the Etina Formation are all the result of precipitation of lime in, or near to, the environment of deposition. The majority of the lime is precipitated as lime mud and directly fixed by algal fibres into stromatolites. These are then broken to form intraclasts. Ooids form only a small proportion of the entire formation and are usually associated with clastic sand, suggesting very shallow water and exposure of a clastic source. Much of the sand can be traced to a diapiric origin with chert and certain lithic types being particularly distinctive.

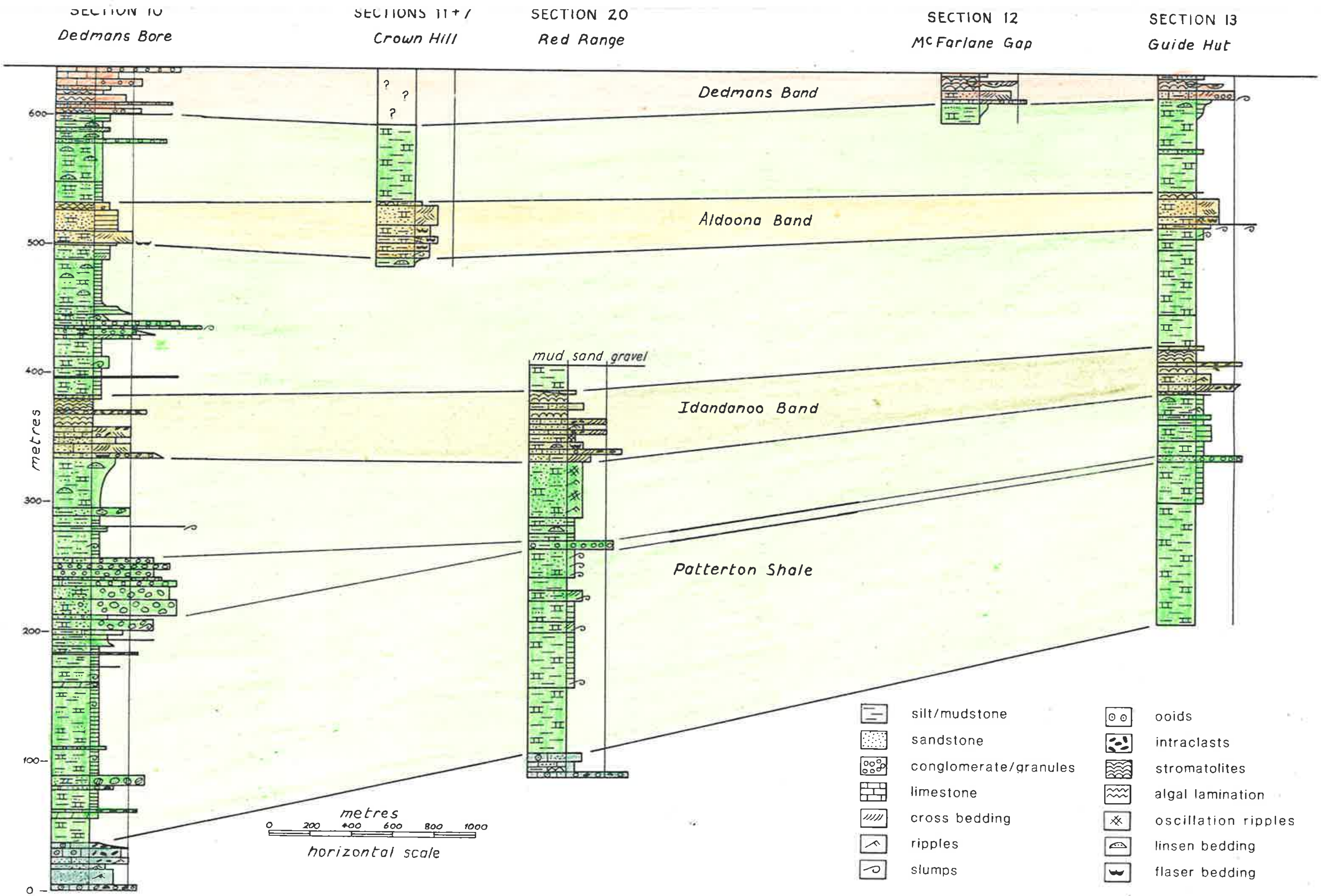
Debris swept into the basin from exposed diapirs is evident throughout the "Winna Limestone", particularly near the Enorama and Blinman Diapirs, especially at times when the water depths indicated by the sedimentary structures, are shallowest. The debris varies in size from pebbles and cobbles to fine sand and silt. The coarse fractions are most easily recognized as having come from the diapirs with present day outcrop providing identical samples. The most distinctive rock types include:- dolerite, basalt, amygdaloidal basalt, dolomitic sandstone and siltstone, dolomite with chert pseudomorphs after gypsum and halite casted, heavy mineral banded, very fine grained felsarenite. The finer fractions are harder to pick as having been diapir derived, although certain quartz, feldspar and chert varieties are somewhat distinctive. When assigning a diapiric origin to clastic detritus, a suite of clast indicators rather than a single indicator was used.

"Patterton Shale"

A thick shale sequence overlies the "Winna Limestone". This is traceable over the entire study area, including much of the Parachilna and Copley 1:250,000 sheet areas. I have informally named this unit the "Patterton Shale" after Patterton Waterhole and Creek, 2km west of a very good exposure of the complete unit on the northern flank of Mount Emily. This outcrop was measured as section 18. The "Patterton Shale" is dominantly a well laminated green, slightly calcareous siltstone/shale. The contact with the underlying limestone is quite sharp, with red, very calcareous mud drowning out distinctive white, laminar stromatolites at the top of the limestone. The red muds rapidly give way up section to green siltstones.

This shale unit has subdued topographic relief although there is commonly a small ridge about 50m above the base. This is due to an increase in carbonate content accompanied by a slight increase in grain size. A plot of carbonate content of the shales is shown in the chapter on geochemistry, (see Fig.45). The carbonate content and grainsize also increase at the top of the unit as conditions shallow toward the deposition of the overlying stromatolitic limestone. The slightly more calcareous silstone near the base of the unit was probably also deposited in slightly shallower conditions than the majority of the "Patterton Shale". This thin band within the unit becomes more prominent on the western side of the study area, particularly west of the Blinman Diapir and around Yanyanna Hut and section 42. In extreme cases, the bottom half of the unit becomes a silty limestone.

Although the "Patterton Shale" is usually well laminated, slumps in the upper part of the unit are common around the western flanks of the



FACIES VARIATIONS NEAR THE ENORAMA DIAPIR

UPPER ETINA FORMATION (Wundowie Limestone equivalent)

Figure 11.

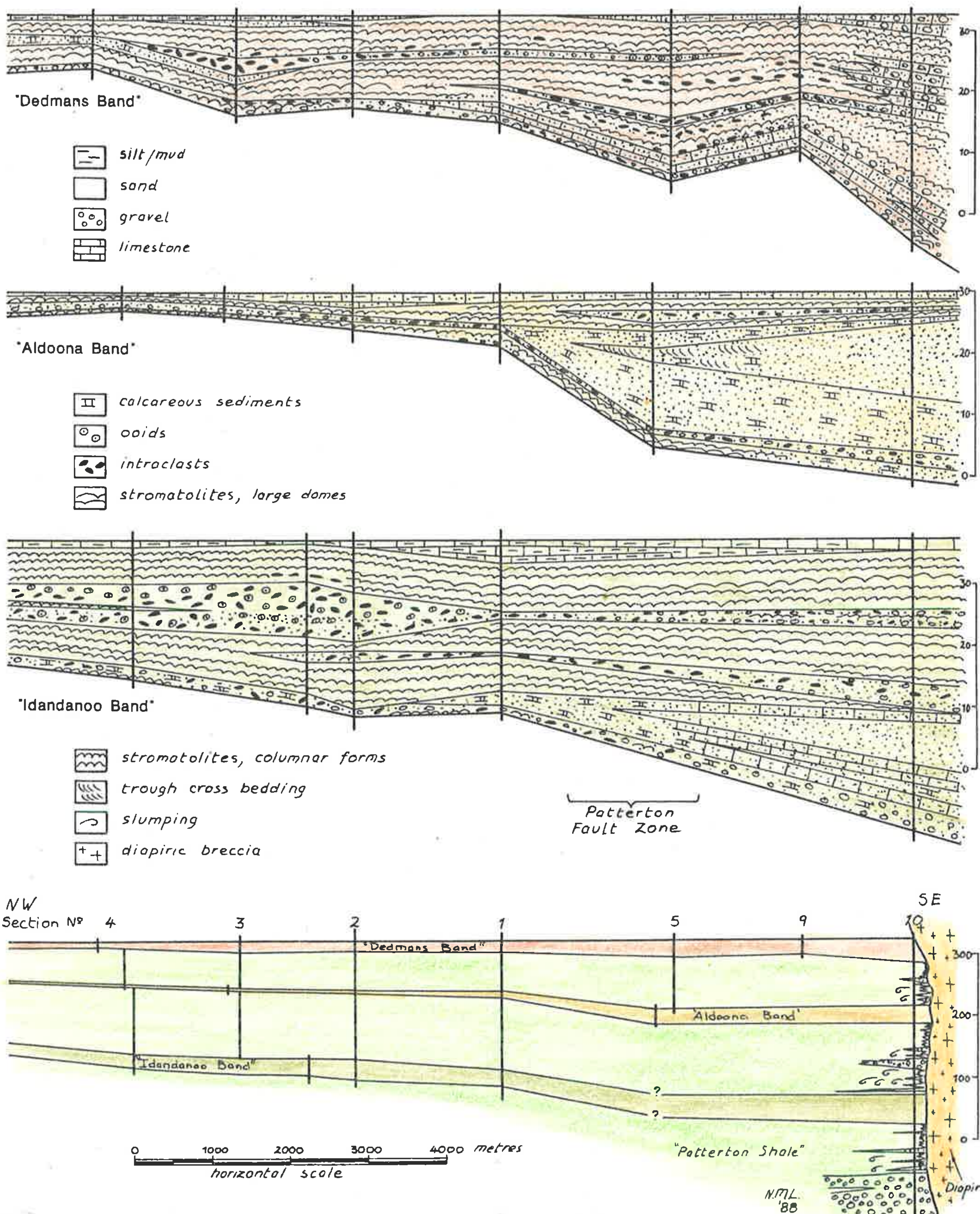
Blinman Diapir. These were clearly moving to the west, away from the diapir. Similar slumps are also common close to the Enorama Diapir. Many were measured along section 10 where they are associated with the influx of coarse diapiric detritus and a matrix of yellow dolomicrite (see Fig.11). In fact, the shale along section 10 is full of thin sand lenses so that the average grainsize close to the diapir is one to two phi sizes coarser than 2-3 km away. Section 10 also shows a 70m thick lens of conglomeratic diapir detritus swept into the basin from the adjacent Enorama Diapir. This lens rapidly thins and fines away from the diapir so that section 20 shows a 12m band of granule conglomerate but all evidence of the influx is lost by section 39, 4.5 km from the diapir contact. The "Patterton Shale" becomes conglomeratic against the western margin of the Enorama Diapir as well.

Wundowie Limestone equivalent

The Wundowie Limestone equivalent in the study area consists of three thin limestone bands separated by two shale units. For personal ease of reference, I have informally named each band after a spring or waterhole which occurs in that band. The bottom band has been named the "Idandanoo Band", the middle limestone, the "Aldoona Band" and the upper one, the "Dedmans Band". The intervening shales have not been named but merely referred to as the I-A shale and the A-D shale.

Section 1 was chosen as a reference section for the Wundowie Limestone in the study area but there is a distinct change in character of each band to the east of the major N-S fault that joins the Enorama Diapir in the vicinity of Dedmans Bore, to the Blinman Diapir just west of Alpana H.S., through Patterton Waterhole. Fig.12 shows the detail along section 1 where it crosses each band together with variation along strike within each band to the NW and the change in character across the Patterton Fault.

As the water became shallow enough to allow algal growth, micrite precipitated to form stromatolites. Continued shallowing changed the stromatolite form and eventually the sea floor became exposed. Erosion during exposure removed much of the previously deposited stromatolitic limestone and usually cut back down to the underlying shale. Exposure also allowed a wide dispersion of clastic material derived both from the margin of the basin to the west and from local diapiric islands. The bands are similar as each commences with a disconformity and associated conglomerate. The conglomerate consists of large clasts from local diapirs and reworked stromatolite heads. The conglomerate matrix consists of sand from the diapirs and possibly from a western source together with lime mud and intraclasts. Thus shallowing in the basin led to a change in deposition from



WUNDOWIE LIMESTONE

Thickness and facies variation near the Enorama Diapir

Figure 12.

shale to limestone.

Deposition above the conglomerate re-commenced with stromatolitic limestone. A high percentage of sand was incorporated immediately above the conglomerate but as the water deepened slightly, dispersion of clastics became far more restricted to their immediate source area. The sea floor remained shallow for a reasonable period, the shallowness probably maintained by rapid carbonate deposition. Stromatolite style shows regular cyclicity from algal mat to broad domes through distinct heads to more digitate and columnar forms.

Shifting tidal channels and local exposure eroded some of the stromatolites, creating a channel infill of flake intraclast limestone. Additional shallowing created large amounts of intraclasts, reworking them to form widespread layers of intraclastic limestone. These intraclasts are smaller and more rounded than the flake intraclasts and have a micritized envelope, as described above in the "Winna Limestone". These shallowing events also formed ooid shoals with occasional incorporation of locally derived diapiric detritus up to pebble and cobble size.

Eventually basin subsidence or sea level rise or both outweighed the effects of carbonate precipitation and algal growth stopped. This was due to either a decrease in sunlight necessary for photosynthesis or to being "drowned out " by mud accumulation or a combination of the two. Each band is capped by silty limestone, followed by a return to shale/siltstone deposition.

While the description above is a general model for the deposition of the three Wundowie Limestone bands, each band has its own characteristics.

The "Idandanoo Band" records a major shallowing with a disconformity cut down to the underlying shale. There is a second shallowing event halfway through the band creating sandy intraclast and ooid limestones. East of the Patterton Fault, sedimentation continued while the basal disconformity was cut. Sandy limestone and lithic sandstone was deposited as the material was eroded from the exposed platform west of the fault.

The "Aldoona Band" is the most distinctive of the three bands. Widespread slumping is evident just below the base of the band suggesting that the shallowing event that caused deposition of the band had superimposed local tectonic movement. Stromatolitic limestones are commonly preserved beneath a disconformity within the band and its associated

PLATE 2

VIEWS AND ROCKS OF THE ETINA FORMATION

Plate 2A

Basal conglomerate of the "Idandanoo Band" on section 33. Large clasts of recessively weathering reworked stromatolitic limestone and diapir derived dolomite with smaller clasts of diapiric dolerite, basalt and quartz arenite standing proud of a sandy intraclast limestone matrix. (Scale is 15 cm long).

Plate 2B

The "Aldoona Band" forms the prominent hill along section 50, shown in this photograph. The band consists of a lower stromatolitic, intraclast, sandy limestone and an upper, ooid, intraclast, stromatolitic dolomite; the two obvious dark bands. These are separated by cross bedded, ripple marked, poorly cemented sands. The ridge at the back of the hill is the "Dedmans Band" and the sawtooth range on the skyline is the Trezona Formation.

Plate 2C

Specimen 819-005, ooid and intraclast sandy limestone from the "Idandanoo Band", section 2. Brown and yellow intraclasts and sand are surrounded by a matrix of calcite spar, here stained deep purple. The scale to the right is difficult to read but shows the photograph to be just a little bigger than natural scale.

Plate 2D

Cross bedded sands and minor lime intraclasts of the "Aldoona Band", section 5. The prominent trough cross bedding displays the tidal bundles measured in Figure 13. (Jacobs staff has 10 cm segments).

Plate 2E

Photomicrograph of 819-005, the same sample as in Plate 2C. Ooids show authigenic overgrowths on the quartz and feldspar cores, intraclasts show micritized rims and the larger grains are dolomitic sandstone of diapiric origin. Some of these grains have one or two oolitic rinds. This specimen was collected from a large intraclast channel within a dominantly stromatolite sequence. (Plane light)

Plate 2F

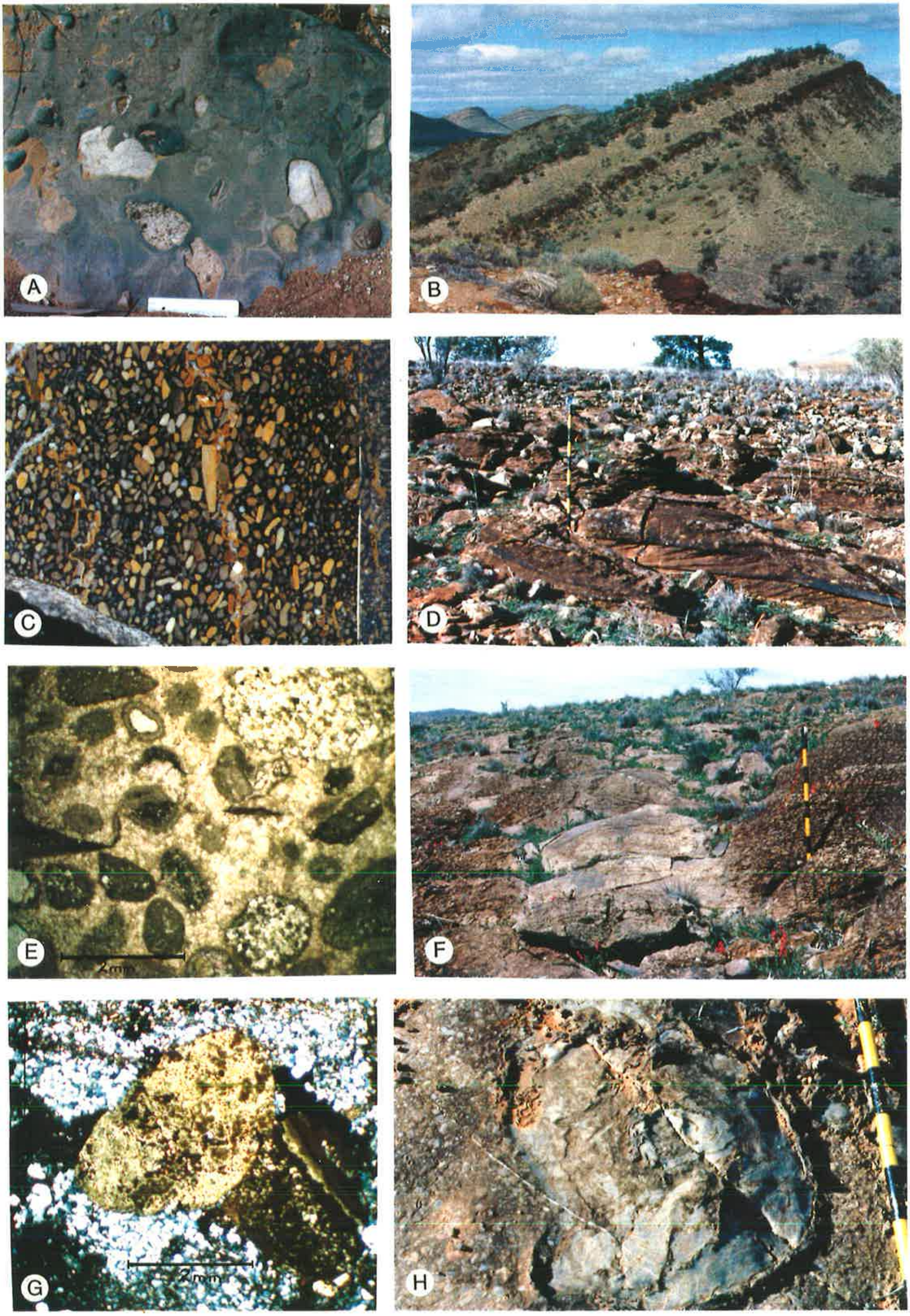
Channels of grey intraclastic limestone between mounds of stromatolitic limestone in the "Dedmans Band", section 12. The land surface in this locality is a dip slope so that these channels can be traced for up to 2km on a single bedding surface.

Plate 2G

Clasts of calcrete eroded from the Enorama Diapir into an Etina Formation sandstone. Sample 819-037 was collected along section 10, very close to the present day diapir margin. (X polars)

Plate 2H

A small stromatolite mound, composed of irregular tuberous columns, surrounded by large intraclasts of broken stromatolite fragments. This photograph was taken along section 1, in the "Dedmans Band".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conglomerate. The "Aldoona Band" is characteristically sandy with sandy stromatolites and ooids but only rare intraclasts. The tectonic activity at the start of the band may have had some influence on the supply of clastic material to the basin.

The Patterton Fault was activated during deposition of the "Aldoona Band" with marked thickening across it. Sand, reworked limestone and micrite were swept across the fault to be deposited as a thick sand interval equivalent to the hiatus west of the fault. Once across the fault, current directions swung around toward the syndepositional sink associated with the Enorama Diapir. A series of trough cross beds in this part of the sequence along section 5 show a record of tidal activity. Progressive advances of fine terrigenous and coarse lime sands as mega-ripples record the thick-thin diurnal variation and the sinusoidal spring tide-neap tide variation distinctive of purely tidal deposits. (Nio, 1983 and Visser, 1980). Fig.13 is a plot of the progressive advances recorded in several trough cross bed sets. The measured sets are shown in Plate 2.

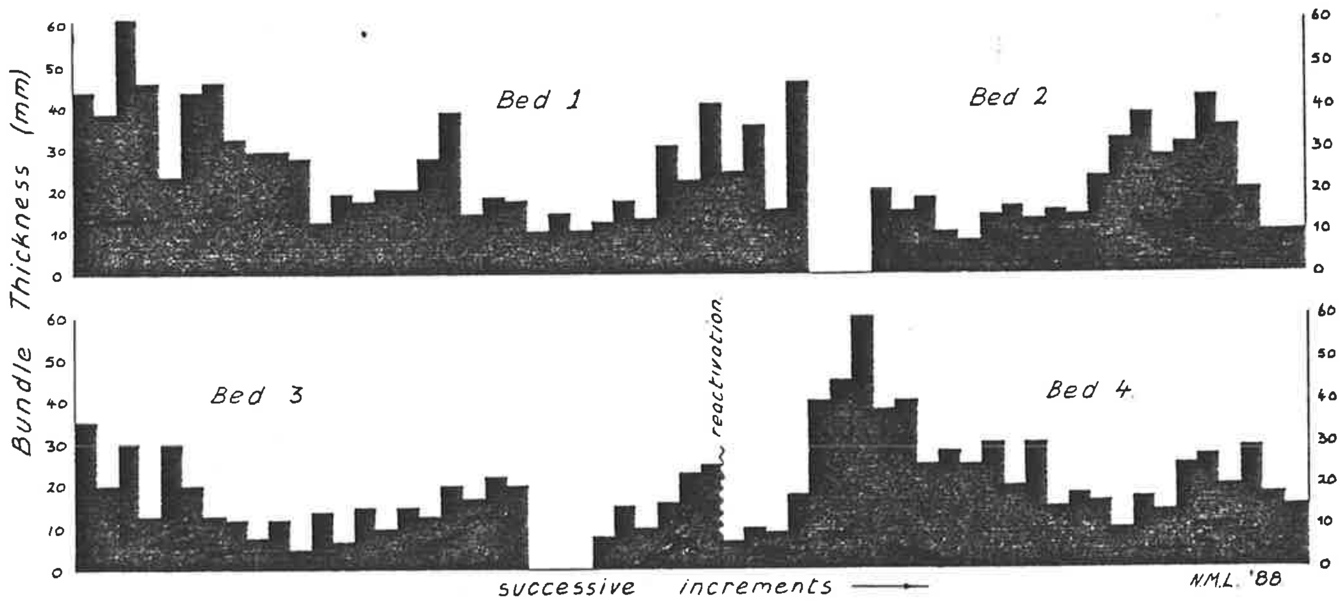


Figure 13. Tidal bundle thickness variation, "Aldoona Band"

The "Dedmans Band" is virtually a repeat of the "Idandanoo Band" with a major disconformity cut through to the base of the band. A second shallowing event is recorded halfway through the band as a level of widespread intraclasts, ooids and calcareous sands. Additional section of sandy limestone is preserved at the base of the band, east of the Patterton

Fault. On the east side of the study area, the very base of the band commonly shows a series of E-W channels cut into the underlying shale. These are filled with diamictite, slurried mud studded with blocks of diapiric debris and eroded stromatolitic limestone. The top of the "Dedmans Band" grades up through sandy then silty limestone, to red calcareous shales at the base of the Enorama Shale.

The shales between the limestones of the Wundowie Limestone are generally well laminated, slightly calcareous, green shales and siltstones. There is a considerable amount of included diapiric debris close to the Enorama Diapir but this will be discussed fully in the chapter on the effects of diapirism around the individual diapirs.

A major problem in measuring time interval thickness variations, necessary to prove a diapiric habit for the emplacement of the Flinders Ranges breccias, is the establishment of time lines in the non-fossiliferous Precambrian sequence. As mentioned in the chapter on regional geology, the limestone bands of the Wundowie Limestone are very regular and widespread and appear to be mainly related to eustatic sea level fluctuations. There is some tectonic overprint for the "Aldoona Band". The recommencement of sedimentation after the main disconformity within each band is the closest approximation to a series of time lines in the sequence. As these are at or near the base of each band, thickness measurements of the bands and intervening shales approximately equate to subsidence within an interval of time. There will still be some discrepancy near the diapirs where shallow conditions will onset earlier and persist for longer than away from the structures. This effect should be minor as the sealevel fluctuations appear to be quite rapid. It is on this premise that a series of isopach maps have been drawn for the "Patterton Shale", "Aldoona Band" and Wundowie Limestone to give an indication of subsidence rates in the study area. The thickening of units within the upper half of the Etina Formation is shown in both Figs. 11 and 12, drawn to the E and NW of the diapir, respectively.

The "Patterton Shale" isopach, Fig.14a, shows the thickest sedimentation in the vicinity of the Enorama Diapir with some extension southward along the eastern margin of the Oraparinna Diapir. There is a pronounced variation across the Patterton Fault with a thick lobe west of the fault in a graben south of the Blinman Diapir. Although data are not available directly over the Blinman area, there is a suggestion that the area was high with consequent thinning over it. The observation of slumping directed away from the area adds weight to this theory. The western margin of the Enorama Diapir was definitely exposed at the time with abundant debris shed from the diapir. The shale sequence thins along this contact. There is a well defined syndepositional sink to the north of the Enorama Diapir with less well defined sinks to the west and east. These clearly indicate that the Enorama structure was active as a diapir at the time. By contrast, the Blinman area shows no associated sink and may have been a stable high or an active pillow at the time.

The isopach map of the Wundowie Limestone (Fig.14b), shows a depocentre associated with the Enorama and Oraparinna Diapirs. In contrast to the "Patterton Shale", the main lobe of sedimentation is situated east of the Patterton Fault. A peripheral sink surrounds the Enorama Diapir with thinning onto the western margin. Activity of the Enorama Diapir is known from the inclusion of debris into the surrounding sediments throughout the deposition if the Wundowie Limestone and the isopach shows the distribution of the periheral sink above the area of evacuation. The Wundowie isopach includes both shallow and deeper water sediments and should be relatively free from the influence of shallowing around the diapir. As with the "Patterton Shale" isopach, the Blinman area during the Wundowie was a high, either as a static high or as a dome or pillow stage of salt/shale movement. ENE-WSW faults across the dome influence sedimentation during Wundowie deposition.

The "Aldoona Band" isopach, (Fig.14c), provides some variation to the pattern of the encompassing Wundowie Limestone. This is due to the tectonic activity at the time. The Patterton Fault was active as shown by marked thickness changes across it. Sediment transport directions were also affected by the relative uplift of the western side. The current directions show far less relationship with the thickness of the band. West of the Patterton Fault and away from the influence of the peripheral sink associated with the Enorama Diapir, the disconformity within the "Aldoona Band" has a marked influence on its thickness. Much of the band was eroded west of the fault and a rapid recovery of the sea level has restricted the overall thickness of the band in that area. This has a pronounced affect on the water depth index map displayed in Fig.14d.

The water depth index is the ratio of thicknesses; limestone plus sandstone over shale. It is the summation of the thickness of the three limestone bands of the Wundowie Limestone divided by the sum of the thicknesses of the intervening shales. As the limestones and sandstones are both shallow water deposits, the higher the ratio, the shallower the water was, on average, during the deposition of the Wundowie Limestone.

The Blinman, Enorama and Oraparinna Diapirs were all high during "Wundowie time". There is a marked syndepositional sink/depocentre around the Enorama Diapir with three distinct lobes; to the west, north and east of the present day outcrop. Averaged current directions for sediment flow in the three limestone bands all flow toward the deepest areas. There is a structural high or ridge associated with the ENE-WSW fault set across the Blinman Diapir suggesting either a deep extension of the shale/salt dome in that direction or tectonic uplift along the faults. Current directions support the water depth index as they feed off this high to the NE and SE. The apparent deep water west of the Patterton fault is a function of the very thin "Aldoona Band" rather than true water depth. Relative depths should be assessed separately on each side of the N-S line of diapirs without equating one side of the area to the other.

The Oratunga Diapir plays no part in altering the isopachs of the Wundowie Limestone as it did not become active until the time of deposition of the Trezona, Elatina, Nuccaleena, and Brachina Formations, (see Appendix II, Lemon, 1985.). Similarly, the Angorigina and Wirrealpa Diapirs were not active until the early Cambrian.

Enorama Shale

The Enorama Shale is a very widespread, recessively weathering unit that forms broad plains throughout the study area. The type section, as defined by Dalgarno and Johnson (1964a), is within the study area, stretching from the Brachina Turnoff on the Oraparinna to Blinman road, westward to Yuonconna Waterhole. This choice of type section was unfortunate as it traverses the peripheral sink of the Enorama Diapir leading to a locally thickened section with greater than normal water depths at the time of sedimentation. The most complete sections measured within the study area are numbers 4 and 10. Both these are shown on Fig.15. Section 4 in particular was measured through excellent outcrop along a small creek. The recessive weathering nature of the unit, particularly in areas of low dip, meant that continuous outcrop along which to measure sections was difficult to find. This is especially the case on the eastern side of the study area where the subdivisions of the formation in this area have not been shown on the maps.

Along section 4, the underlying limestone of the "Dedmans Band" at the top of the Etina Formation grades into the shales and siltstones of the Enorama Shale through a 10m interval of red calcareous siltstone with occassional very thin interbeds of red silty limestone. This interval is very well laminated, indicative of quiet water, even though the water depth must have been still quite shallow. The change from Etina Formation to Enorama Shale is brought about by an increase in water depth.

The red siltstone grades up into interbedded red-brown and khaki siltstones with some thin lenticular bedding indicating weak current activity. This interval is slightly calcareous. The calcite is concentrated in the lenticles within the bedding.

The middle third of the formation is a distinctive, green, laminated, mainly non-calcareous shale with a characteristic, blocky, conchoidal fracture of fresh and partly weathered specimens. The Enorama Shale is a deeper water sediment than the interbedded shales and limestones of the underlying Etina Formation and the overlying Trezona Formation. The green shales in the middle of the unit show no signs of current activity and were deposited in the deepest water at peak transgression.

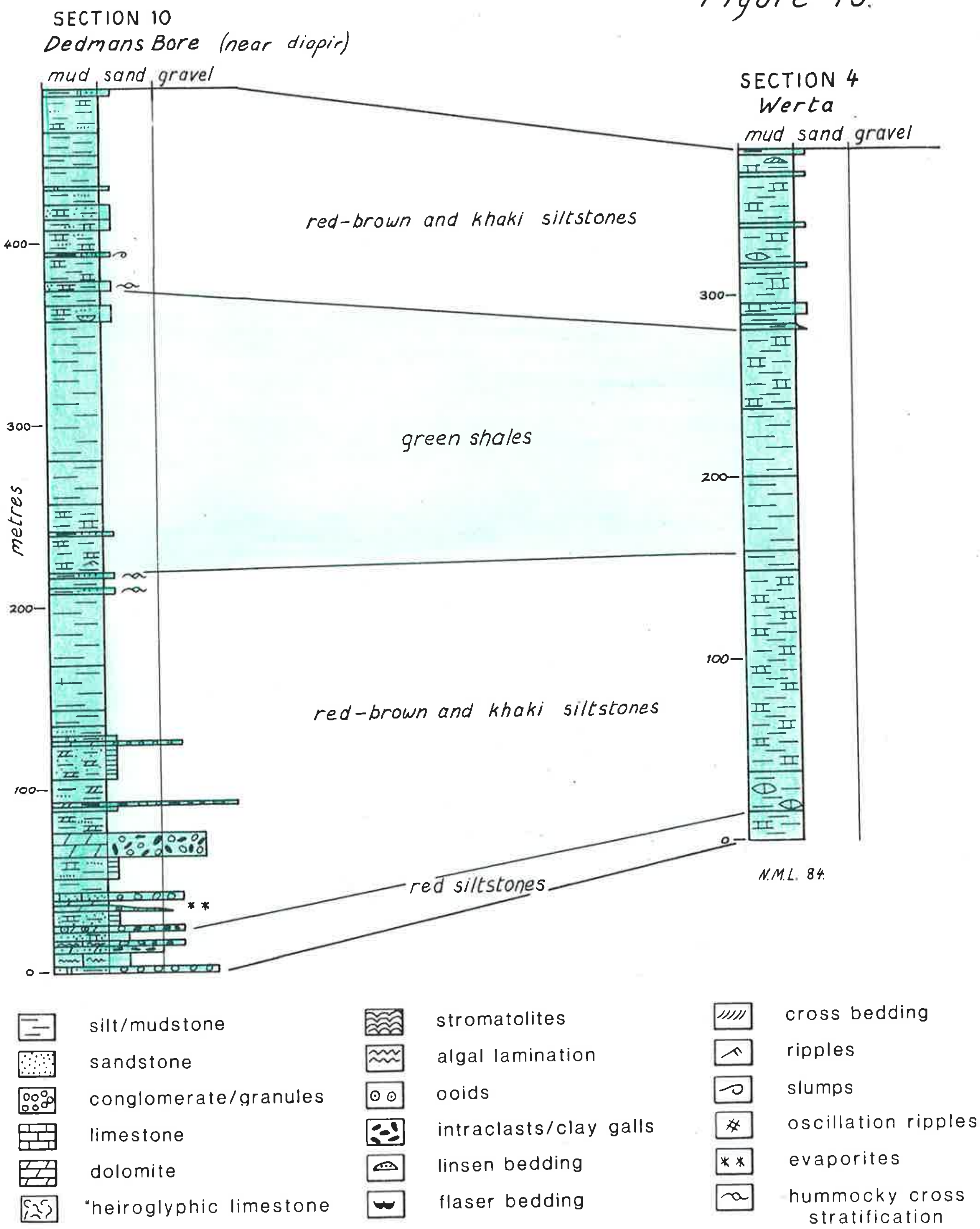
On section 10, near the Enorama Diapir, hummocky cross beds, (HCS), on the lower contact of the green interval, are the last indication of current activity in the formation until HCS returns with a colour change back to red-brown and khaki, two thirds of the way through the formation.

Sections 50 and 51, (Fig.8), on the eastern side of the study area and of the Adelaide Geosyncline, show a persistent, thin layer of buff to pink detrital dolomicrite between the lower red siltstones and the green shale.

The return to red-brown siltstones on section 4 is also marked by an increase in current activity. This is commonly expressed in the sediment as 10-30cm graded beds and sand layers with small scale hummocky upper surfaces. Some of these intervals are definitely turbidites, occasionally with ABCDE Bouma subdivisions, but more usually of the "BCE" style. More commonly the variation, in an otherwise evenly bedded/laminated siltstone sequence, is a series of thin beds of very fine sand showing little or no gradation but with a small scale hummocky upper surface. These appear to be tempestites, very fine sand worked into suspension and the fines winnowed away. Settling of the sand through continued but waning agitation produced a thin bed topped by HCS. The upper surface also resembles low amplitude lunate ripples and is probably formed by a combination of oscillation and current flow. In this situation, the turbidites are probably storm generated as well.

As the sequence shallows upward, toward the base of the Trezona Formation, there is a sandy influx near the Enorama Diapir. The frequency and thickness of the HCS-topped sandy beds increases and there is an

Figure 15.



FACIES VARIATIONS NEAR THE ENORAMA DIAPIR

ENORAMA SHALE

increase in the carbonate content generally.

The Enorama Diapir was particularly active during deposition of the lower part of the Enorama Shale. A deep peripheral sink has been mapped at the northern end of the diapir, around Dedmans Bore and the deep water shales shoal onto a shallow carbonate area along the western edge of the same diapir. Details of these features will be given in a following chapter.

Trezona Formation

The Trezona Formation was defined by Dalgarno and Johnson, (1964a), with the type section along Enorama Creek, starting at Yuonconna Waterhole and heading west through a gorge in the Trezona Range. The range is characteristically devoid of trees and composed of alternating bands of shale and strongly outcropping intraclastic and oolitic limestone.

The oblique aerial photo, Plate 3, shows all the major subdivisions of the regressive formation. These include two thin limestone bands on the flat below the range which mark the base of the formation, a thick interval of red mudstone then strongly outcropping bands of intraclastic limestone, interbedded with red muds. There is a distinct break halfway through the formation with a change from dark red sediments to those obviously lighter in colour. This corresponds to a change to sediments dominated by ooid and stromatolitic limestones. The uppermost interval is one of red tidal flat muds and sands of the "Yaltipena Member". The recessively weathering Elatina Formation outcrops behind the high ridge of the "Yaltipena Member". Section 30 was measured across the range on the left or northern side of the photo.

Sections 4, 10, 30, 50 and 51 were measured through the entire Trezona Formation but sections 4 and 10 provide both a complete picture of the formation together with the local influence of the Enorama Diapir, (see Fig.16).

The carbonate platform depositional models of Read (1985) provide a basis for the description of the Trezona Formation. The formation is regressive, prograding into the basin from the NW as parts of its shoreward regions become eroded.

The top third of the underlying Enorama Shale shows evidence of continual shallowing upward and the base of the Trezona Formation is marked by the first appearance of shallow water limestones. The base is characterized by two stromatolite/intraclast limestone bands separated by about 5m of red siltstone, uniformly distributed throughout the study area

PLATE 3

AERIAL VIEW OF THE TREZONA FORMATION

ON THE EAST SIDE OF THE STUDY AREA

The base of the Trezona Formation is marked by the lower of two thin stromatolitic/intraclastic limestone bands. The lower half of the formation is distinctly red in outcrop, largely due to interbedded red shales and siltstones. The upper part is mainly stromatolitic, ooid and intraclastic limestone and is much paler in outcrop. Thick bands of coarse sand to granule sized intraclasts form prominent bands, characteristic of Trezona outcrops. The red range in the top centre left of the scene is composed of the regressive tidal flat sediments of the "Yaltipena Member". Section 30 was measured across this interval from the trees in the bottom centre of the scene.

Photo courtesy SADME and W Preiss.
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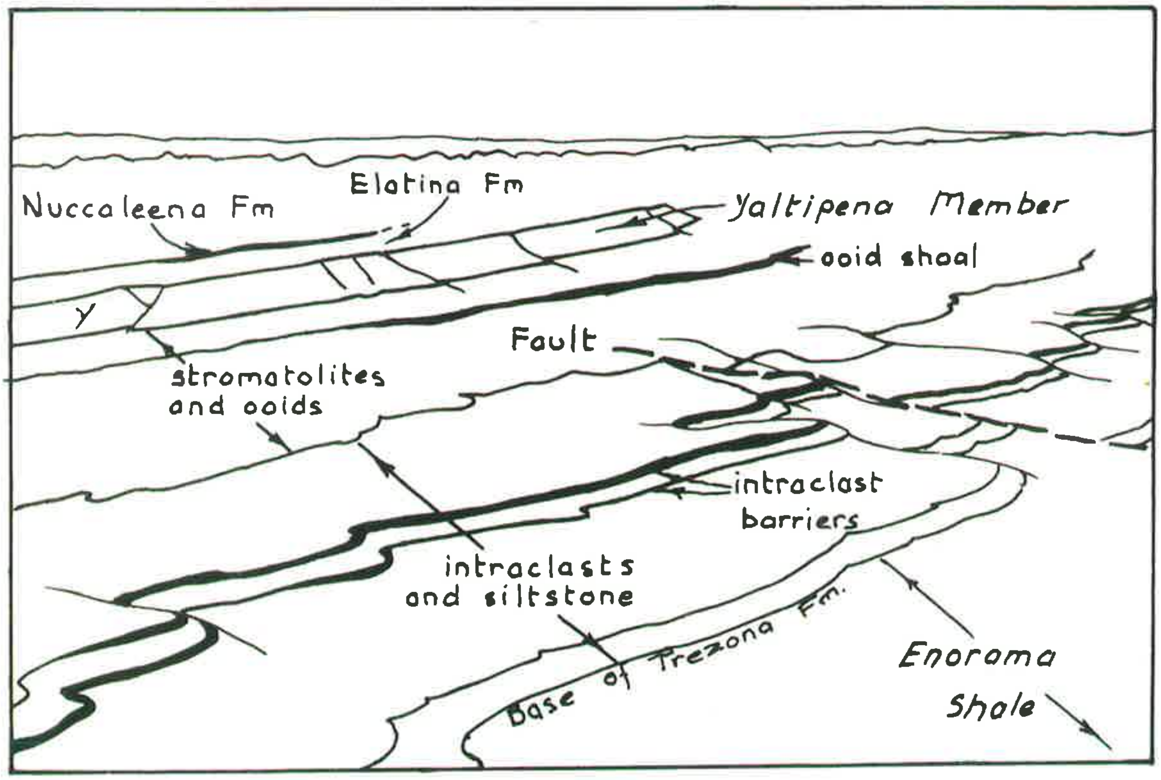
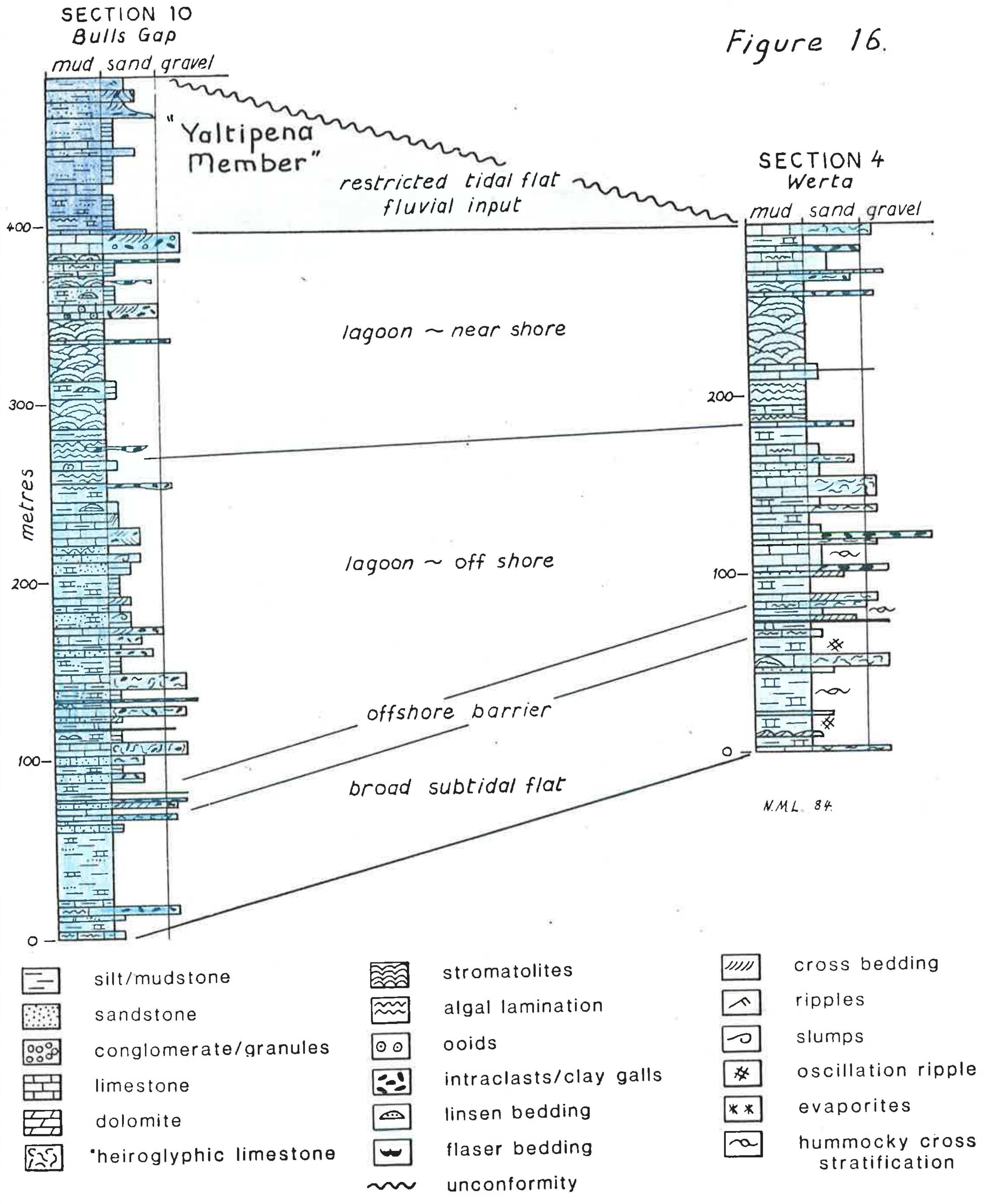


Overlay of the above plate

Figure 16.



FACIES VARIATIONS NEAR THE ENORAMA DIAPIR

TREZONA FORMATION

from Nuccaleena to Winnitinny Creek. The bands represent a widespread shallowing event, probably due to the combined influence of sea level fall and basin infilling. Large, 1m by up to 3m and 0.5m high, cumulate stromatolite domes, characteristic of much of this formation, appear for the first time in the overall stratigraphic sequence, in these two bands. Small tepee structures and reworking of algal flakes from the stromatolites show that the basin had shallowed to exposure or near exposure.

A slight sealevel rise returned the basin to dominantly red silt deposition but numerous thin algal mat limestones with subsequent reworking of these as large curled flakes into intraclastic limestones, (Plate 4), show the very shallow nature of the environment. The algal flake limestones are the distinctive "heiroglyphic limestones" used as a regional marker by Mawson (1939, 1942). Periodic reworking of the muds, probably under storm conditions, formed layers of lunate ripples, which, together with the thin limestones, provide a distinct bedding to the otherwise evenly laminated muds. Section 26, almost in contact with the Enorama Diapir, shows an increase in the proportion of intraclast bands and stromatolitic limestones. Section 10, only slightly further away from the diapir, has almost no intraclast beds and no stromatolite layers. This reflects the very shallow conditions adjacent to the diapir with slightly deeper conditions over the secondary peripheral sink.

All sections measured show the interval described above overlain by a dramatic deposit of intraclast granule conglomerate, often arranged as single foreset beds up to 5m high, (Plate 4). The intraclasts of this level are different from those below, being smaller and more rounded with a micritic envelope, suggesting they have undergone greater transport. The current directions on the large foresets are almost always toward 120°-150°, except around sections 10 and 24, where the currents diverge from this direction, with a few even in the opposite direction. The Enorama Diapir, while not exposed at this time, clearly still formed enough of a mound on the sea floor to modify current directions.

Preiss, (1987), shows how limited is the extent of Trezona deposition within the overall basin, but opening to the SE. This is in agreement with the observations on the intraclast complex which progrades into the basin from the NW. Section 4 shows the thinnest interval between the base of the formation and the intraclast complex as 66m. This interval increases to 77m around sections 10 and 26 and 100m around sections 30 and 50. Although part of this thickening can be explained by increased basin subsidence toward the basin depocentre at the time, the thickest full

Trezona section was measured at section 10. Excellent outcrop along the range south of section 30 shows the dominant intraclast bands move higher in the sequence to the south as the whole complex progrades into the basin.

The sediments above the intraclast complex are quite different from those below. Although, initially, red silts still provide the "background" sedimentation, there is a considerable influx of sand sized material, particularly in the form of intraclasts. For the first time since the initial two bands of the formation, stromatolites develop past the algal mat stage and are seen as columnar types as well as cumulate domes. Repeated influxes of intraclasts to the silty environment give the characteristic Trezona outcrop pattern of lenticular, hard limestone bands interbedded with recessively weathering siltstones. Channels, spillover lobes and flood tide deltas form the limestone lenses. These can be distinguished by the nature of their basal contact. The channels have a slightly scoured contact with occas-ional basal lags while the flood deltas show interfingering of progressive foresets with the underlying muds. The spillover lobes are usually quite thin. The flat bottom and convex top tidal deltas become indistinguishable from the flat top, concave bottom channels due to later compaction. Columnar stromatolites colonize the clean substrate of the intraclast lenses but die out as current activity switches to a new area and mud deposition returns.

The siltstones interbedded with the intraclast lenses are similar to those below the first intraclast complex but show a change in current directions as evidenced by the lunate ripples. Those below all point to 120° whereas those above are distinctly bimodal, to 120° and 180° opposed at 300° The latter set dominate. This is a reaction to the creation of a barrier with tides reworking sediments across it.

The muds with bimodally directed lunate ripples, the intraclast channels, tidal deltas and spillover lobes are all characteristic of a lagoonal environment created behind the developing barrier bank. Stromatolites "grew" in the protected lagoonal environment, provided that they had a clean substrate and were not silted over too quickly. The outer edge of the bank provided another clean environment for algal growth but the stromatolites there were largely eroded to supply the intraclasts building the bank.

Two extensive influxes of red silty sand to the lagoon provide useful marker horizons. These sands, swept in from the NW, are commonly slumped, suggesting rapid deposition. Sections not slumped show planar bedding with current lineations, also indicative of rapid transport.

About halfway through the Trezona Formation conditions change. The sediments are no longer dominantly red but become a series of brown, grey, green, khaki and reddish interbeds. Grey ooid limestone and green-grey laminar algal mat limestones are the first beds of this interval. The grey ooid shoals are particularly well developed on the eastern side of the study area. Section 30 has one ooid interval 20m thick with intercalations of laminar stromatolites. Section 50 has a similar 25m ooid band with laminar stromatolites.

Section 10 has only 5m of ooid limestone at this level but the ooids are rather unusual. Red and grey pisoids up to 1cm in diameter are cemented in a matrix of 1cm grey ooids. The pisoids are almost spherical with perfect concentric lamination, (sample 819-141). These "super ooids" fill in cavities along a karst surface etched into the underlying stromatolitic limestone. Extensive recrystallization plus iron and manganese enrichment are associated with the karst. Mapping of the alteration zone shows a relatively flat top with solution cavities filled with ooids and a very irregular base 2-20m below. Tracing this surface along strike shows it to extend 6km southward from section 10 to a point E of section 23. This parallels the margin of the Enorama Diapir and is the closest this stratigraphic interval outcrops to the diapir.

The ooid shoal interval is overlain by a thick sequence of reddish brown and khaki stromatolitic limestone. The stromatolites are the large, 1-2m cumulate domes (Plate 4), characteristic of the Trezona Formation, (Preiss, 1987). These domes often show a preferred elongation direction, generally in a NE-SW direction and parallel to that shown in Preiss (op.cit., p.383). Sections 4, 10, 30 and 50 have stromatolite intervals at this level of 50, 70, 80 and 120m respectively. Some thin intraclast and ooid limestones break up this interval and eventually light grey ooids and red intraclasts begin to dominate the sequence again.

Diapiric detritus is included in the Trezona Formation for the first time at this level. Section 4 shows a 1m band of intraclast conglomerate with 10% diapir-derived sand and granules standing proud of the weathered surface. Section 10 has a similar interval but the band thickens southward over the next 6km to be 6m thick with 40% diapiric detritus before thinning again further south. As with the karst surface, this is the area closest to the Enorama Diapir.

Above this level, stacked stromatolite mounds, 30-50cm in diameter are interbedded with intraclastic limestones green calcareous shales and intraformational conglomerates. The conglomerates are one of the last

PLATE 4

TREZONA FORMATION ROCKS AND SEQUENCES

Plate 4A

Enorama Shale along section 4. Thin, flat based, hummocky topped, fining upwards beds of very fine sandstone and coarse siltstone provide clear bedding features in an otherwise monotonous red-brown siltstone sequence in the upper third of the Enorama Shale. These are very similar to the tempestites described from the Wonoka Formation by Haines (1987).

Plates 4B and 4C

Irregular oscillation ripples and regular small linguiod ripples provide distinct bedding characteristics in the siltstones between the thin limestones bands near the base of the Trezona Formation.

Plate 4D

"Heiroglyphic" limestone, characteristic of the Trezona Formation. This particular example is unusually coarse with thin stromatolite flakes stacked perpendicular to the bedding. (Scale bar is 15cm long).

Plate 4E

Red shales and siltstones of the bottom third of the Trezona Formation. The regularly laminated sequence is broken by slightly thicker beds of sandstone and siltstone, the result of wave and storm reworking. The features within these beds are the ripples shown in B and C above.

Plate 4F

Large cumulate stromatolite domes, typical of the Trezona Formation. These are part of the 70m thick interval of continuous stromatolites exposed along section 10. Bedding surfaces near this outcrop show a strong linearity of the domes, supposedly due to current influences.

Plate 4G

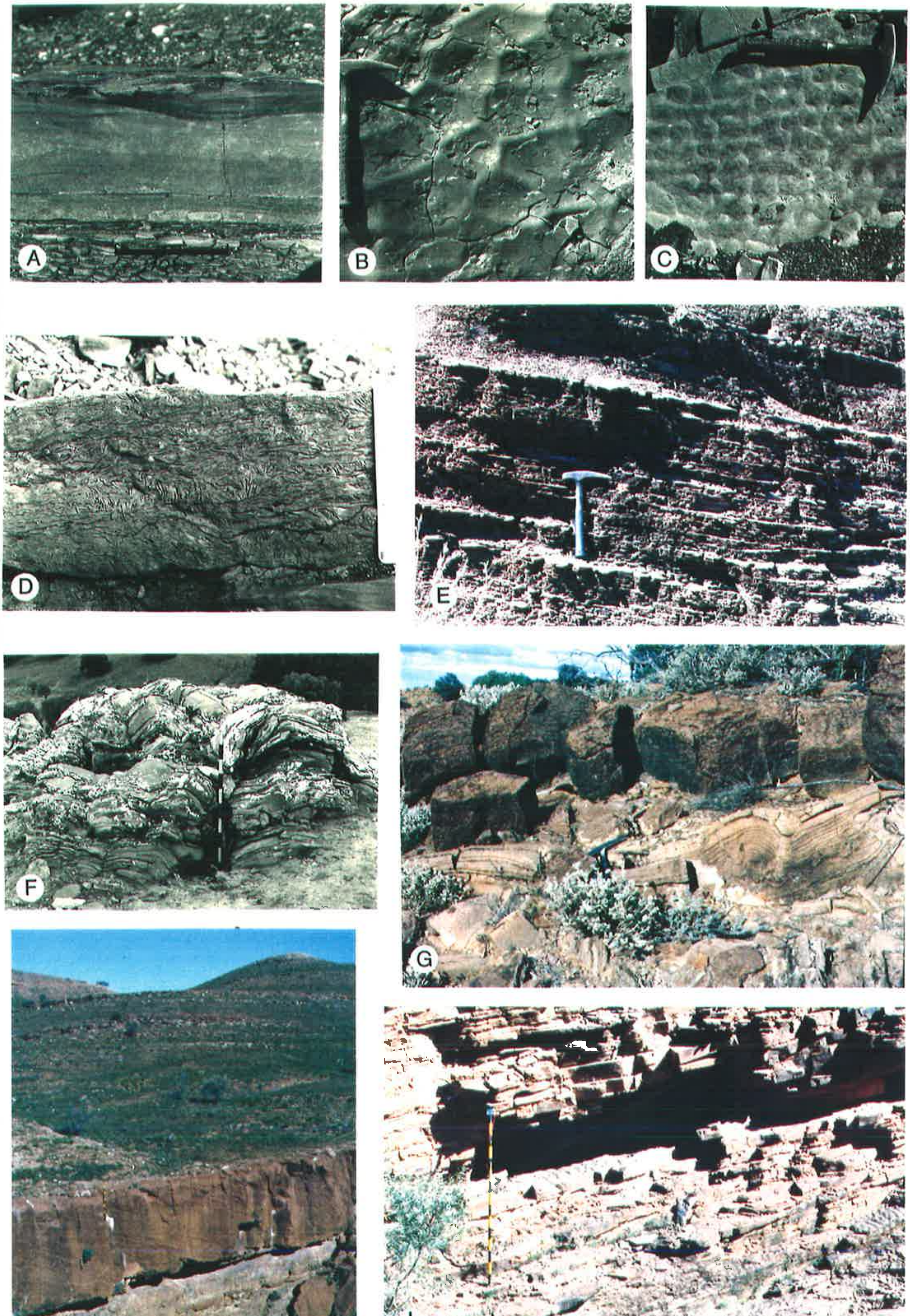
Red-brown cumulate stromatolite domes of the Trezona Formation along section 50. Occasional darker interbeds of intraclastic limestone, derived from the stromatolites, break up the very thick stromatolite sequence in this part of the basin.

Plate 4H

A thick bed of intraclastic limestone, 100m above the base of the Trezona Formation along section 30. This is the most prominent band in Plate 3. This band, together with one or two others, makes up what appears to be a barrier bar complex. This band is 4.2m thick and displays a single foreset bed the height of the band. Field relationships suggest that the band is a prograding ebb tide delta at this locality. The slope above the band consists of interbedded red siltstones with thin stromatolitic and intraclastic limestones.

Plate 4I

Lenticularly bedded, red and white, fine to medium sandstones of the "Yaltipena Member" at the top of the Trezona Formation along section 30. The channeled and current rippled sands are interbedded with mudcracked, dark red siltstones. Planed off ripples, ladder ripples, rain-drop impressions and dried and wrinkled algal mats are all indicative of the shallow to exposed tidal flat environment of deposition of this unit.


A
B
C
D
E
F
G
H
I

limestone beds in the formation and are quite distinctive. Well rounded flat cobbles and pebbles of green shale, ripped from below, are incorporated into red, very coarse sand sized, intraclastic limestone composed mainly of reworked flakes of stromatolites. These beds are shallow water storm deposits reworking lithified limestones and partially cemented shales.

Section 30 does not contain any diapiric detritus but does show a thick section of ooid and intraclast limestone above the main stromatolite interval as well as distinctive storm beds. The stromatolites continue to the top of the carbonate interval at section 50.

The top part of the Trezona Formation has been subdivided by the author as a separate member of the Trezona Formation, the Yaltipena Member. This is a coarsening upward, regressive sequence of redbed clastics deposited in a tidal flat environment, grading from mudstone to medium sandstone. Erosion of the Trezona Formation prior to the deposition of the Elatina Formation has removed the Yaltipena Member from the western and northern parts of the study area.

Sections 10 and 23 show well laminated red siltstone and mudstone overlying the intraformational conglomerate storm bed. There is only minor carbonate in the section above this level, being present as calcareous, algally laminated, green muds. Further up section, the average grain size increases to very fine sand and sedimentary features such as ripple cross lamination and oscillation ripples become abundant with minor cross bedding and channelling (Plate 4). A further size increase up section to muddy fine sand is accompanied by abundant mud cracks and mud rip-up clasts as well as the features mentioned above. Rain drop impressions were found at this level. Dalgarno and Johnson (1964b) also recorded raindrop impressions from the upper part of the Trezona Formation. Faint circular "wrinkles" associated with these impressions may be a body fossil record but may equally be interpreted as a pseudofossil formed by the wrinkling of a thin algal film on an exposed sediment surface.

As the grain size increases up section further to medium sand, the bedding becomes more lenticular as obvious channels filled with gritty sand and mud rip-up clasts cut across the flat bedded silty sands. Trough cross bedding, oscillation ripples, ripple cross lamination, mud cracks, ladder ripples, planed or truncated ripples, mud clasts, granule layers and current lineations characterize this part of the sequence. Current directions measured along section 30 vary from 080° to 180°.

An unconformity/disconformity on top of the sands marks the top of the Yaltipena Member of the Trezona Formation and the base of the Elatina Formation.

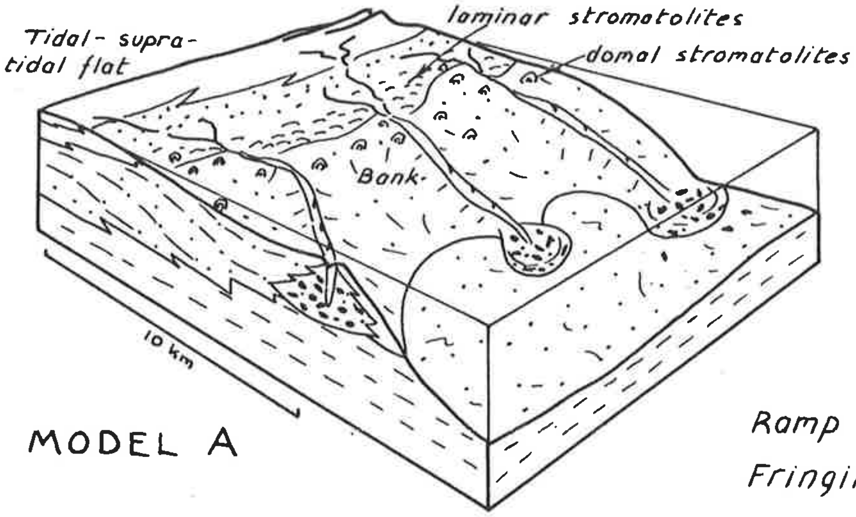
Models for deposition of the Trezona Formation

It appears that the model that best fits the start of deposition of the Trezona Formation is that of a simple homoclinal ramp, Model A of Read, (1985). The models have been modified to suite possible Precambrian conditions in Fig.17. Rapid cementation of lime muds fixed by algal growth and subsequent reworking in shallow conditions along the shoreline, provided sand sized particles that could be moved around to form a ramp - barrier bank type margin, Model B of Read, (op. cit.). The barrier bank system was mainly formed of intraclasts arranged as large scale foreset beds prograding into the basin from what is now the NW. As the barrier bank developed, it protected a lagoonal area shoreward of it. Siltstones, occasionally reworked by storm activity, were deposited in the lagoon. Stromatolites were able to "grow" in the cleaner parts of the lagoon but algae thrived on the higher areas of the barrier bank. Here, the stromatolites were broken up by storm activity to supply intraclasts to maintain the bank. Intraclasts were also carried over the bank to be deposited in the lagoon as flood tide deltas, spillover lobes and channel fill.

The distinct colour change halfway through the Trezona Formation is probably associated with a relative sea level rise. The barrier maintained its position and grew to be an offshore barrier, now dominated by ooid shoals in a higher energy regime, Model E of Read, (op. cit.). Wave energy now dissipated almost entirely against the barrier instead of progressively dissipating up and across the previous barrier bank.

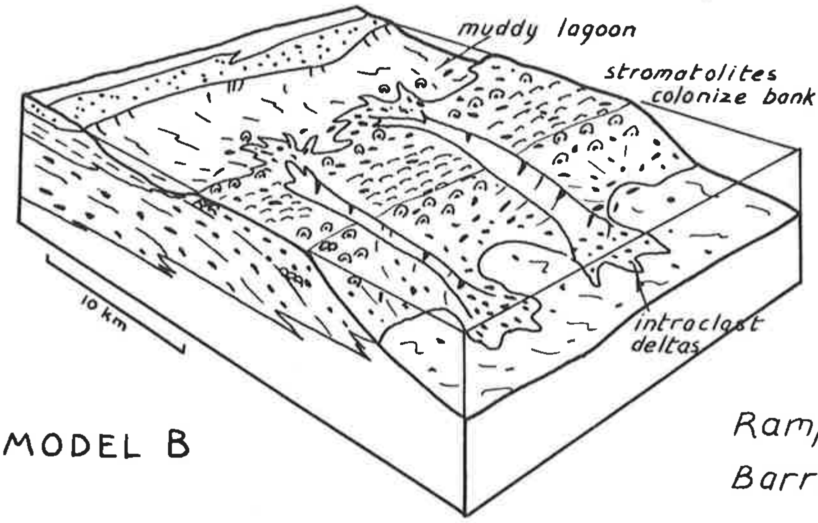
The lagoon behind the ooid barrier complex was now deeper. Algal growth thrived to form the thick sequence of stromatolites, possibly as the higher sea level pushed the muddy sequence further landward. Ooids swept off the barrier became intercalated with the stromatolites. Activity on the Enorama Diapir created an island within the lagoon which supplied some debris to the basin but locally halted deposition and allowed a karst to develop on the newly deposited limestones. As the sea levels dropped again, the lagoon filled over with with ooid and intraclast limestone and, eventually, a muddy tidal flat. This became increasingly exposed as sea levels dropped further and grainsizes coarsened upward. Erosion on the disconformity that followed was most prominent to the north and west. The retreat of the sea to the SE of the study area was probably brought about by the onset of the Marinoan glaciation, represented by the Elatina Formation.

Figure 17.



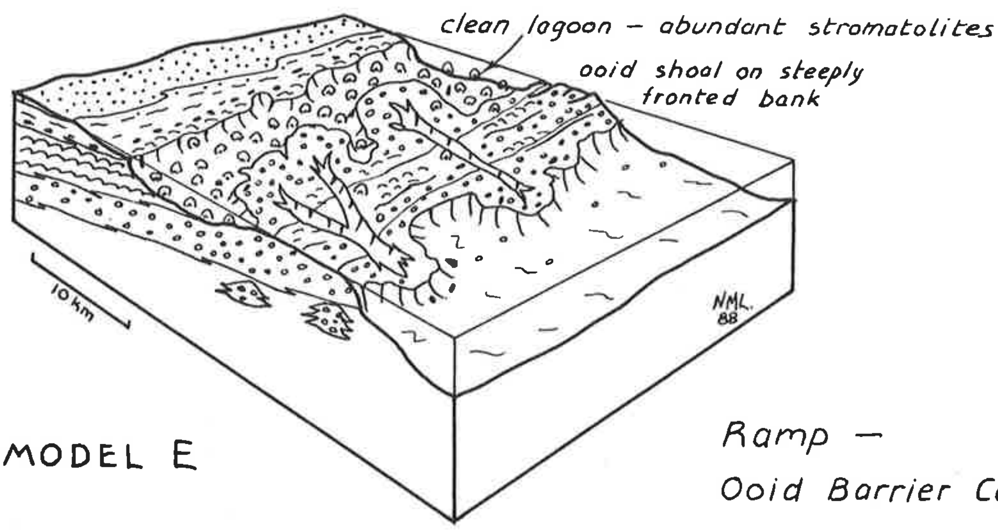
MODEL A

Ramp —
Fringing Bank Type



MODEL B

Ramp —
Barrier Bank Type



MODEL E

Ramp —
Ooid Barrier Complex

Trezona Fm. depositional models (after Read, 1985)

Nature of the unconformity above the Trezona Formation

Measurement of sections of the Trezona Formation shows that 120m of section has been removed by erosion on the unconformity between Sections 17 and 23. Sections 19 and 36, to the south of section 23 are similar to section 17, showing the removal of about 120m of section. Mapping in the Nuccaleena area, 45 km to the north, shows that the entire Trezona Formation, over 450m thick, has been removed, and the Elatina Formation is in contact with the Enorama Shale, the unit that underlies the Trezona Formation. Progressive truncations of beds within the Trezona Formation indicate that the unconformity is more developed to the north, west and south of section 23.

Locally, there is up to 2m relief on the unconformity surface with some possible solution karsting evident around section 19. The limestone surface often develops a small scale breccia up to 1m thick on the contact which may be related to frost shattering (samples 819-153, -154). Pebbles of eroded Trezona limestones are usually included in the basal conglomerate of the Elatina Formation where it is developed, (samples -108, -109).

Section 17 shows a weathered zone extending some 10m down from the unconformity into the limestones of the Trezona Formation. Distinct reddening, limonitization, manganese enrichment and some silicification are associated with this weathering. Elsewhere, minor dolomitization is evident. Immediately above this weathered zone, a massive mudstone with Trezona carbonate clasts probably represents a regolith. The Trezona Formation below section 28 in Parachilna Gorge has been weathered, altered and reddened to about 50m below the contact although this may be due to weathering along later faults.

Elatina Formation.

A complete account of the geology of the Elatina Formation is recorded in a paper by Lemon and Gostin entitled "Glacigenic sediments of the Late Proterozoic Elatina Formation and equivalents, Adelaide Geosyncline, South Australia". This paper is currently in press in the Brian Daily Memorial Volume to be published by the Geological Society of Australia. A preprint is included in this thesis as Appendix VI.

Thirteen sections were measured through the Elatina Formation in the study area. The longest and most complete sections are 10 and 23, (see Fig.18), in the secondary peripheral sink associated with the Enorama Diapir, and sections 30 and 50, on the eastern side of the study area, in the main local depocenter active at the time (Fig.8).

In summary, the Elatina Formation can be subdivided into three parts over much of the western side of the geosyncline. The lower part of slumped sands, a middle interval of dropstone diamictites and an upper interval of current reworked diamictites. These divisions can be explained in terms of water level in the basin. The slumped sands were deposited as sea level deepened after deposition of the basal ice contact tillite and fluvial channel sands. As water depth increased, finer sediments were deposited and icebergs were able to raft gravel into the basin. Sea level then fell or the basin began to fill without subsidence and the diamictites were reworked by current activity. Water levels began to deepen again at the close of the glacial period and the Nuccaleena Formation dolomites were deposited, grading up into red shales with continued transgression.

Pockets of additional section are preserved at the base of the formation in the local basin depocentre and in secondary peripheral sinks adjacent to active diapirs. This additional interval consists of a lodgement till near sections 23 and 30, followed by a polymict conglomerate of exotic clasts reworked from the till, a high percentage of Trezona Formation limestones and rare diapiric clasts. This is overlain by dropstone diamictites and current reworked, sandy mudstones with channelized fluvial sands and dramatic slumped silts and sands. This apparently lacustrine sequence is then overlain by the more widespread slumped sand interval.

A tillite on the basal contact and a dropstone diamictite in contact with the overlying Nuccaleena Formation attest to the fact that the whole of the Elatina Formation was deposited under glacially influenced conditions.

The upper contact of the Elatina Formation varies from sharp to gradational over 20 cm into massive dolomites of the Nuccaleena Formation. Such cap dolomites to the glacial sequences of this age are known worldwide (Williams 1979, Hambrey and Harland, 1981).

Thus it appears that the Elatina Formation was deposited following the peak of the Marinoan glaciation. Onset of the glaciation resulted in a drop of baselevel. That led to the creation of a major disconformity at the base of the Elatina Formation in the shallower parts of the basin. In deeper parts, a minor local ice contact tillite was preserved with the remainder of the formation deposited under subaqueous conditions. Water levels increased for a short time after deposition of the lodgement till to allow the reworking of that till and deposition of the local lacustrine sequence. The basin was shallow during deposition of the widespread slumped sand interval, deepened during the middle diamictite unit, shallowed during the deposition

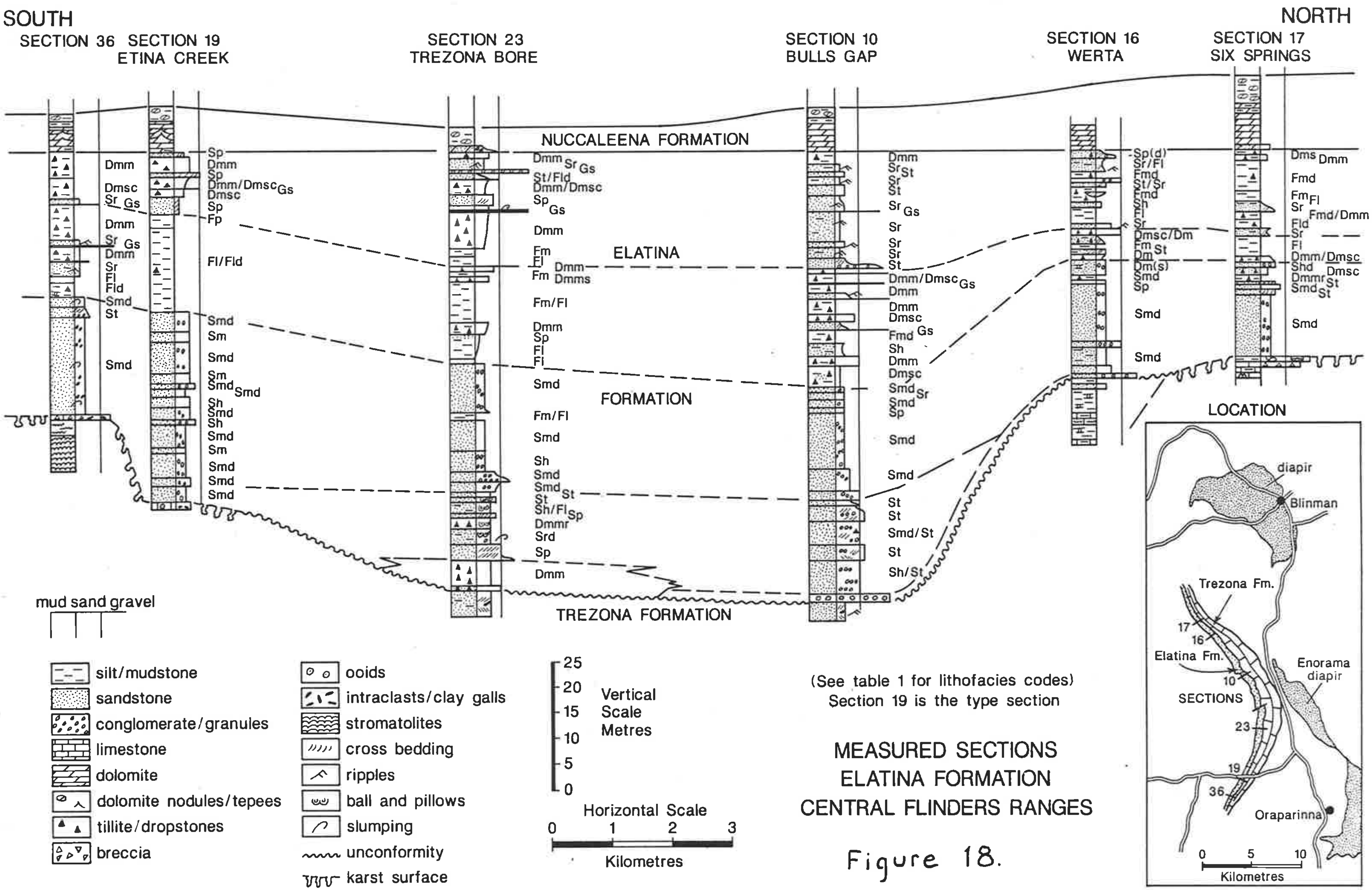

SOUTH
NORTH
SECTION 36
SECTION 19
ETINA CREEK
SECTION 23
TREZONA BORE
SECTION 10
BULLS GAP
SECTION 16
WERTA
SECTION 17
SIX SPRINGS
NUCCALEENA FORMATION
ELATINA
FORMATION
TREZONA FORMATION
mud sand gravel
silt/mudstone
sandstone
conglomerate/granules
limestone
dolomite
dolomite nodules/tepees
tillite/dropstones
breccia
ooids
intraclasts/clay galls
stromatolites
cross bedding
ripples
ball and pillows
slumping
unconformity
karst surface
25
20
15
10
5
0
Vertical
Scale
Metres
Horizontal Scale
0 1 2 3
Kilometres
(See table 1 for lithofacies codes)
Section 19 is the type section
MEASURED SECTIONS
ELATINA FORMATION
CENTRAL FLINDERS RANGES
LOCATION
diapir
Blinman
Trezona Fm.
17
16
Elatina Fm.
10
SECTIONS
23
19
36
Enorama
diapir
Oraparinna
0 5 10
Kilometres

Figure 18.

of the upper unit, then deepened again at the close of the glacial period with deposition of the Nuccaleena Formation and the rest of the Wilpena Group.

Apart from deposition and preservation of sediments in the secondary peripheral sink of the Enorama Diapir, sections measured close to the diapir show its influence. The boulders and pebbles found as isolated dropstones and as lags at the base of current reworked beds in the middle diamictite unit are dominated by diapir clasts. Dolerites and vesicular basalts are very common and virtually identical to rocks presently outcropping in the Enorama Diapir, 2-5 km east. The remainder of the coarse suite consists of dolomites and heavy mineral banded sandstones which are also found within the diapir. Many clasts are marked by facets and striations, attesting to their glacial character.

There is a further diamictite at the top of the formation which again shows local derivation from an exposed nearby diapir. Between sections 19 and 23, several channels of polymict, small pebble to cobble conglomerate occur within the current reworked interval. These contain clasts derived directly from the diapir together with diapiric clasts reworked from the diamictites plus clasts of ooid and algal limestones from the Trezona Formation. This shows that the diapir must have been actively rising to both supply clasts from itself and to drag to the surface, Trezona sediments previously deposited around its margin.

WILPENA GROUP

Nuccaleena Formation

The basal contact of the Nuccaleena Formation is usually quite sharp, showing a change from the siltstones and sandstones of the upper part of the Elatina Formation to dolomite of the Nuccaleena Formation over 10-15 cm. This is the case along Enorama Creek although further north, on section 23, there is evidence of erosion with a thin granule conglomerate separating the Elatina Formation from the overlying Brachina Formation. The contact becomes more gradational around section 17 where 1.5m of pink silty dolomite outcrops beneath the massive dolomite more typical of the base of the Nuccaleena Formation. Usually the base of the formation is obscured as scree from the dolomite cascades over the more recessively weathering Elatina Formation or, as is often the case, the dolomite has undergone dissolution during weathering.

The Nuccaleena Formation was defined by Coats (in Thompson et.al., 1964) from outcrop in the northeastern corner of the Copley 1:250,000 sheet. The type section is dominated by 130m of red shale overlying about 10m of cream coloured, well bedded dolomite. Dalgarno and Johnson, (1964a), correlate the dolomitic part of the type section to 3m of calcitic dolomite in Enorama Creek, along the line of the type section they chose for the Parachilna 1:250,000 sheet, including the red shales in the Brachina Formation.

The Nuccaleena Formation in the study area characteristically has a massive, cream weathering, pink, micritic dolomite at its base. grading up into pink silty dolomite, interbedded, flaggy, red silt and dolomite then a red shale with lenticular dolomite beds becoming nodular to the top of the formation. I have used the last appearance of dolomite as the top of the formation which is then usually 10-15m thick in the study area. The nodular dolomite is clearly diagenetic in character with fine shale-like laminations penetrating the nodules (sample 819-74).

Plummer (1978b), divided the Nuccaleena into four facies which varied in their environment of deposition from supratidal and intertidal to shallow water marine. Much of his interpretation was based on the recognition of common tepee-like structures as true peritidal tepees with immature, mature and senile forms as described by Assereto and Kendall, (1977). The shapes may be similar but there are no associated intraformational conglomerates or breccias, as pointed out by P. Holmwood, (pers. comm, 1986). A close look at many of the outcrops in the study area shows no evidence of associated breccias, which Assereto and Kendall, (op.cit), and more recently, Kendall and Warren, (1987), suggest are almost universally present with peritidal tepees.

Assereto and Kendall (1977), mention the occurrence of pseudo-anticlines that form in submarine conditions. The tepoid structures in the Nuccaleena Formation resemble the psuedo-anticlines of these authors. The Nuccaleena tepoids, as seen in the vicinity of sections 19, 32 and 36, are up to 1m high in section and 2-5m by 10-20m in plan (Plate 4). The large polygons look like boat keels as the direction of elongation within each outcrop area is constant. Divergence of the orientation of the crests as shown by the current rose is due to measurements of the shorter sides of the polygons (see Fig.19).

The tepoids form in that part of the formation where dolomite was clearly deposited as detrital grains. Cross bedding, while often difficult to observe, is common, and Plummer (op.cit), describes graded beds, scoured

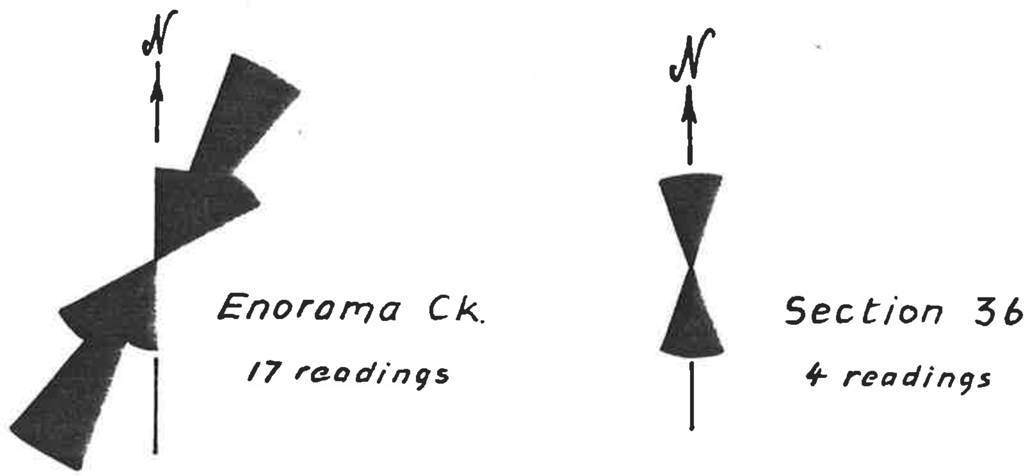


Figure 19. Directions of tepoid crests, Nuccaleena Formation.

surfaces and current crescents. Cryptalgal lamination is common and Plummer found rare stromatolites. The tepoids clearly formed during deposition. The culminations die out upward as successive beds thin or pinch out over the feature. The thinned beds lower down the flanks are upturned slightly, suggesting progressive growth. The beds in the core of some "anticlines" are overthrust but there is still no evidence of intraformational conglomerates or breccias.

Tepees may grow as a reaction to a variety of forces in the three environments in which they are known to occur but Assereto and Kendall, (op.cit), were of the opinion that only the force of expansion resulting from crystallization was common to each environment and likely to be the cause of formation. Sample 819-173 was collected to investigate the hypothesis of crystallization as the driving force. Transmitted light microscopy and scanning electron microscopy both showed a fairly even grain size of 4-10 microns with only rare larger rhombs. There was no preferred orientation of the dolomite rhombs although the fact that all grains are now rhombs even though transported detritally shows some growth after transport. The detailed microscopy results are inconclusive.

Assereto and Kendall (op.cit), found few examples of submarine pseudo-anticlines in the literature, but cite that of the Ordovician in Sweden (Lindstrom, 1963). The tepoids of that example are also in micrite. There is evidence that they stood on the sea floor for a long time while covered by a slow rain of micrite. Lindstrom suggested that gravity sliding may have influenced their formation but this was discounted by Asserto and Kendall.

Gravity sliding may be a factor in the formation of the Nuccaleena tepoids as there is evidence of buckling and rumpling of a leathery, cohesive, dolomicrite "carpet" along section 10, (see Plate 6). This outcrop is close to the Enorama Diapir and the buckles form parallel to the diapir margin. Similarly, at sections 19 and 36, the direction of elongation of the polygons is subparallel to the margin of the Enorama-Oraparinna Diapirs. Section 32 shows tepoid crests parallel to the margin of the Blinman Diapir. This is not conclusive evidence as the margin in each case is near north-south. Further searches for tepoids in the Nuccaleena Formation near diapir margins in other orientations need to be made to prove the theory.

While it is quite possible that the Nuccaleena dolomites were exposed near one or more active diapirs in the Central Flinders Ranges, there is no evidence for exposure if the peritidal origin of the tepoids (Plummer, op.cit), is discounted. I would argue for a slightly deeper environment of deposition than that favoured by Plummer. The Nuccaleena Formation, however, does show deepening up section. The thickness of the dolomitic section varies regularly across the study area but if the top of the formation as defined by Coats, (in Thompson, 1964), is used, the thickness varies wildly. As suggested by Dalgarno and Johnson, (1964a), the red shales above the dolomitic interval lie within the base of the Brachina Formation and should not be included in the Nuccaleena Formation.

Detailed sections were not measured in the sequence above the Nuccaleena Formation and the reader is referred to the previous chapter on regional geology or to Preiss (1987).

CHAPTER 5

ENORAMA DIAPIR

This chapter deals with all the influences mapped in the sediments surrounding the Enorama Diapir. These are summarized in Fig.20, a pictorial representation of approximately 4000m of sediment as they appear on the accompanying map sheet, the geology of the Oraparinna Area, which is included in the map pocket at the back of the thesis as Enclosure 2. Fig.20, however, is not drawn to scale but merely shows the various relationships. Each distinctive feature is numbered and this chapter is organized to explain each of these features in turn.

Features 14-21 and 25-37 are included in a field guide written for both the Eighth Australian Geological Convention and the Twelfth International Geological Congress. This has been included in this thesis as Appendix V.

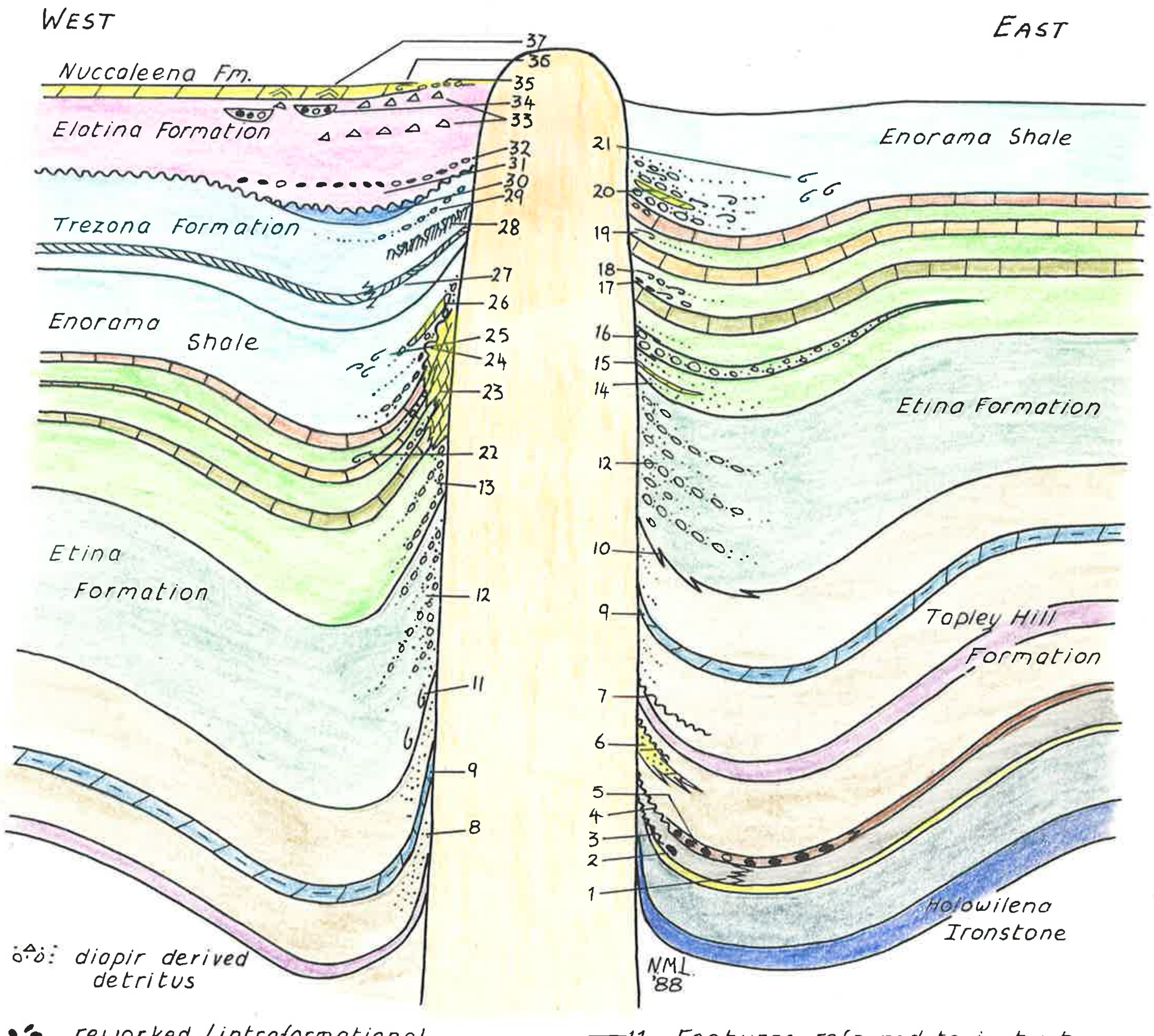
Apart from the numbered features described below, the Enorama Diapir shows several gross characteristics which are also depicted in Fig.20. Several unconformities are seen in the lower parts of the stratigraphy adjacent to the diapir. These, together with several paraconformities, enhance the overall thinning of the section toward the diapir from the Holowilena Ironstone to the base of the Etina Formation. From this level upward, the sequence thickens toward the diapir as the feature intruded as a true diapir and developed a secondary peripheral sink. The whole sequence on the eastern side of the diapir is topographically higher than on the west as later thrusting, partially controlled by the diapir, pushed the eastern side over the diapir.

1/. There is a sharp facies change within the Wilyerpa Formation between dolomitic sandstones, lithic sandstones and conglomerates deposited in the basin generally and the clean lithic sandstones against the diapir margin, (see Chapter 4, Wilyerpa Formation).

2/. The sandstone, 1/. above, contains dark red granules and small pebbles of the distinctive Holowilena Ironstone. This unit was uplifted in the region of the diapir to be reworked into the overlying formation (see Chapter 4, Wilyerpa Formation).

3/. The unconformity at the base of the Warcowie Dolomite Member can be seen well developed locally where the Holowilena Ironstone was tilted up against the diapiric intrusion to be eroded and included in later sediments (see 2/. above and Chapter 4, Wilyerpa Formation).

Figure 20



4000m of sediment depicted in diagram

(not to scale)

ENORAMA DIAPIR A summary of the influence on surrounding sediments

4/. The Wilyerpa Formation itself, becomes upturned as the diapir rises and an unconformity was developed locally on the diapir margin.

5/. Clasts from the Wilyerpa Formation are incorporated in a basal conglomerate of the Tapley Hill Formation. This is laterally equivalent to the Tindelpina Shale Member of the Tapley Hill Formation (see Chapter 4, Tindelpina Shale Member).

6/. Dolomitic sandstones and conglomerate developed as a lens within the Tapley Hill Formation, adjacent to the diapir, north of the Asbestos Mine. Details of this outcrop are shown in Fig.21. Slumping occurs within the Tapley Hill Formation, basinward of this outcrop (see Chapter 4, Tapley Hill Formation). This is the first noted occurrence of major inclusions of diapiric detritus in sediments around the Enorama Diapir. The uplift associated with this influx also produced a local unconformity towards the top of this lens.

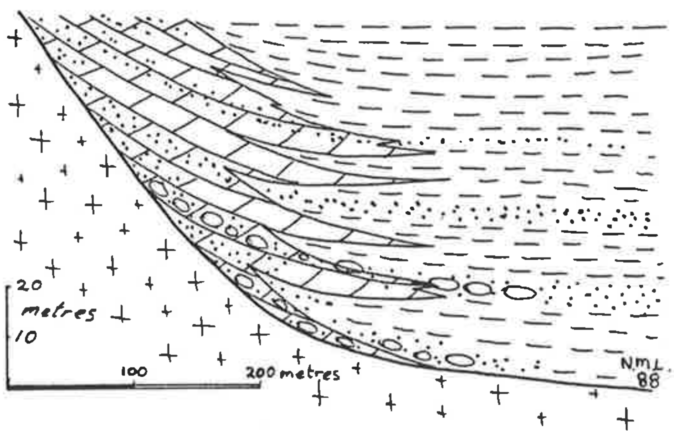


Figure 21. Detail of the contact between the lower Tapley Hill Formation and the E side of the Enorama Diapir, N of the Asbestos Mine.

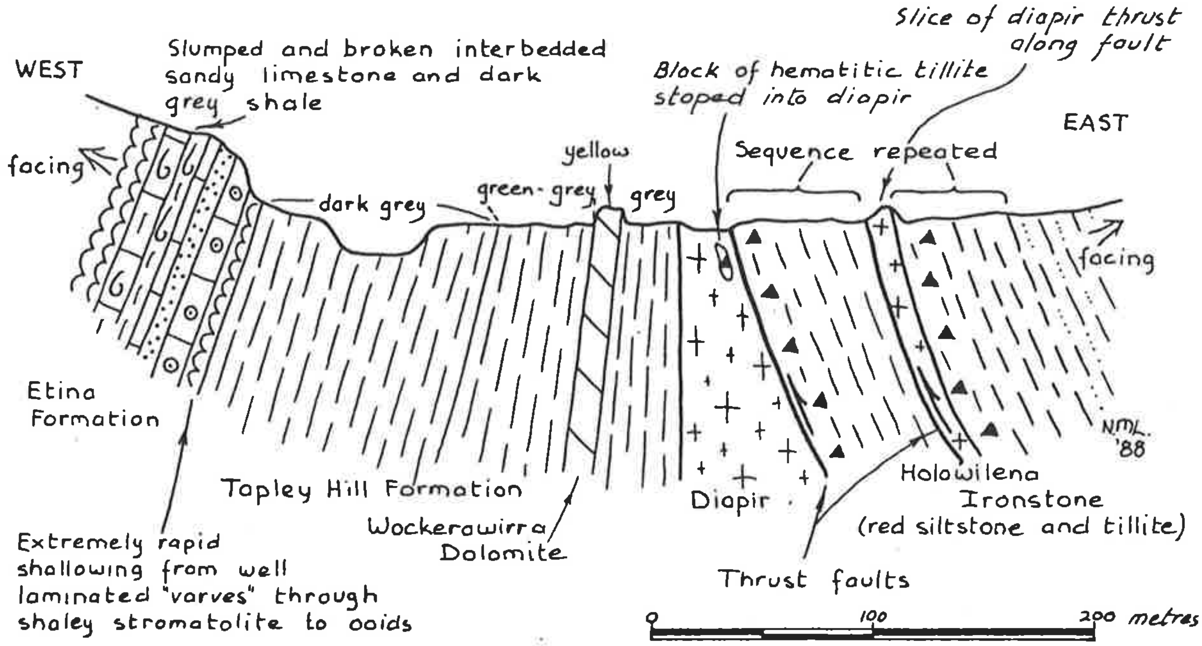
7/. The Mount Caernarvon Greywacke thins toward the diapir. Mapping shows paraconformities within this unit near the contact as being the reason for the overall thinning (see Chapter 4, Mount Caernarvon Greywacke).

8/. The Tapley Hill Formation shows a considerably thinned sequence on the western margin of the diapir at the same stratigraphic level as 7/. above. The thinned sequence has a high percentage of sand within it, compared with the normal shale and siltstone deposition of this unit. The sand could be due to a higher energy depositional environment in shallow waters around the diapir or influx of sediment from the diapir.

9/. There is a distinct facies change within the Wockerawirra Dolomite on the diapir margin. This formation is usually represented as a silty, clearly detrital, dolomicrite with fine laminations and graded bedding. Against the diapir, the dolomite changes to a well cemented, clean, massive dolomite, (sample 819-187). Early cementation is indicated by the numerous stages of brecciation. The cementation may have been due to exposure during or soon after deposition. A similar facies variant against the Blinman Diapir shows a relict fenestral texture indicating exposure. The clean dolomite is exposed on both sides of the Enorama Diapir.

10/. The change from the Tapley Hill Formation to the Etina Formation is primarily due to shallowing within the basin (see Chapter 4, Top of the Tapley Hill Formation). Mapping along the eastern margin of the diapir shows the base of the Etina Formation is stratigraphically lower adjacent to the diapir.

11/. Significant slumping is seen near the base of the Etina Formation near the western side of the diapir. Well cemented ooid and intraclast limestones, interbedded with laminated micrite are fractured and slumped by movement on the diapir, (see Plate 5, and Fig.22). This is the first sign of increased movement on the diapir which heralds feature 12/. below.



Sketch section across Enorama – Oraparinna Diapirs near Section 52.

Figure 22.

12/. The shallow water ooid, intraclast and stromatolitic limestones of the "Winna Limestone", Etina Formation, (see Chapter 4), contain an apron of conglomeratic debris within 500m of the diapir margin on both the eastern and western sides of the diapir. The conglomerates are particularly well developed on the eastern margin. Samples 819-092 and -093 are granule and small pebble conglomerates collected from the western side of the diapir, near the Asbestos Mine. All the detritus in these samples can be traced to clasts and rafts within the diapir. Deeper water shale and siltstone interbeds of the "Winna Limestone" pinch out toward the diapir margin where shallower water conditions persisted.

13/. Coarse conglomerates are incorporated in the "Patterton Shale" at the base of sections 38 and 39. These conglomerates dominate the sequence within 300m of the margin but are not observed in section 35, 2km away.

14-19/. Features 14-19 are all exposed within the upper half of the Etina Formation as measured along section 10. Fig.23 shows the disposition of many of the features described near the northern end of the Enorama Diapir around Dedmans Bore and the position of section 10. Fig.24 is a summary of the measured section.

14/. The boundary along section 10 between the "Winna Limestone" and the "Patterton Shale" is quite sharp and occurs at the base of the ridge at the eastern end of the traverse. Ooid, intraclast and sandy limestones grade quickly into calcareous siltstone with small layers and lenses of medium to very coarse sand. The "Patterton Shale" near the diapir is 1-2 phi units coarser on average than it is 2-3 km away. All the sand appears to have been derived from the diapir. Intervals of the siltstone are highly contorted by slumping, apparently directed down the slope, away from the diapir, which presently outcrops about 400m to the south.

15/. Many of the slumps stand out in the weathered outcrop, both by being a yellow orange colour as distinct from the background yellow-green and by being less susceptible to erosion. Both these characteristics are imparted on the sediment by a higher percentage of dolomicrite than the rest of the siltstone. The dolomicrite is derived from the vicinity of the diapir as it decreases away from the contact (see Chapter 14, Geochemical signature). There are some thin interbeds, 30-100 cm thick, of orange dolomicrite. These are invaribly associated with slumps and commonly carry a suite of coarse, sand to cobble sized

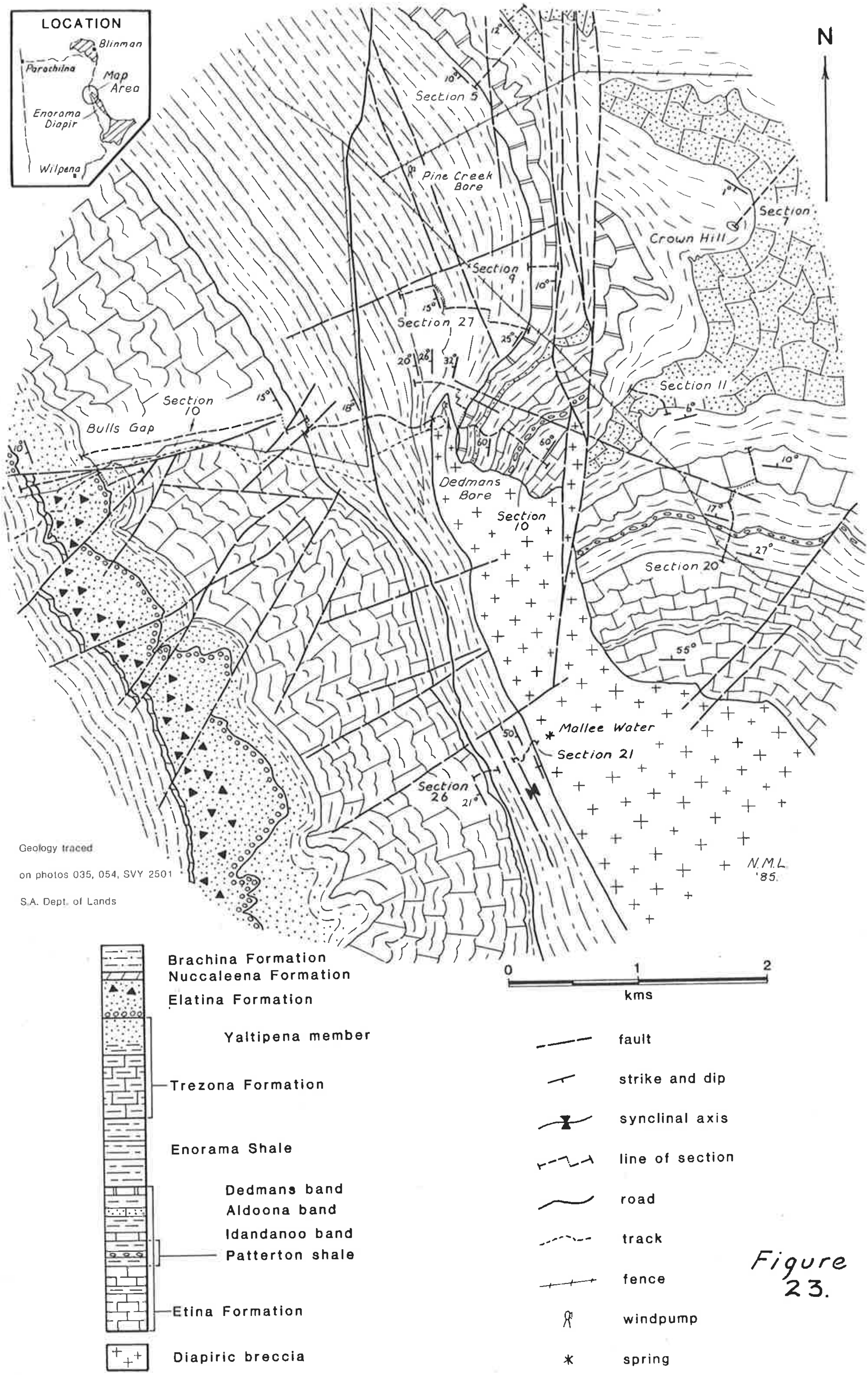


Figure 23.

GEOLOGY AROUND DEDMANS BORE - NORTHERN ENORAMA DIAPIR diapiric detritus. This material has been swept off the flanks of the diapir into the surrounding basin which, at the time, was depositing calcareous shale and siltstone. Pulses of coarse sediment record pulses of movement on the diapir.

16/. From 200-270m along section 10, pebbles and cobbles derived from the diapir dominate the sequence. Clasts of halite-casted sandstone, dolerite, amygdaloidal basalt, cherty dolomite with gypsum rosettes and dolomitic siltstones and sandstones, some with blue asbestiform magnesio-riebeckite layers can all be found within both the conglomerate and the nearby diapir. The coarse material is heralded along section 10 by an increasing frequency of slumps and slump diamictites. The coarsest sediments occur midway through the conglomerate band which then fines up to a slump diamictite, a distorted pebbly mudstone, (specimen 819-039). This wedge of coarse sediment can be traced 4km to the east, through sections 20 and 13 but the grainsize drops to granules then coarse sand and the width of the band from 70m to 12m at section 20 (see Fig.11).

The "Patterton Shale" shallows up to the "Idandanoo Band" as it does elsewhere in the basin but the grainsize of the sediment near the diapir remains 1-2 phi sizes coarser. Locally derived sands dominate the "Idandanoo Band" and distort stromatolite "growth". Algal mats studded with sand grains occur at the same level as columnar forms composed entirely of silt and micrite, 2km away.

17/. As the sea level rose again and the limestone deposition of the "Idandanoo Band" returned to shale deposition, slumping within the sequence again became very common. Two metres above the limestone-shale contact, blocks of cemented limestone from the "Idandanoo Band", eroded by uplift near the diapir, are carried out into the shale basin. Through the next 40m of sediment, disturbed bedding shows evidence of slumping throughout. Some intervals show inclusions of small clasts of limestone from the "Idandanoo Band" as well as detritus from the diapir mixed with basin muds as a slump diamictite.

18/. Cobble and boulder conglomerates are included in the section 50m above the "Idandanoo Band". These reflect a pulse of movement of the diapir. The progression of sediments through this packet gives some idea of the paleogeography at the time. Slump diamictites herald the pulse, (specimen 819-042). This is overlain by a well sorted, well rounded, lithic, granule conglomerate, (819-041). The maturity characteristics of the granules suggest reworking of diapir detritus

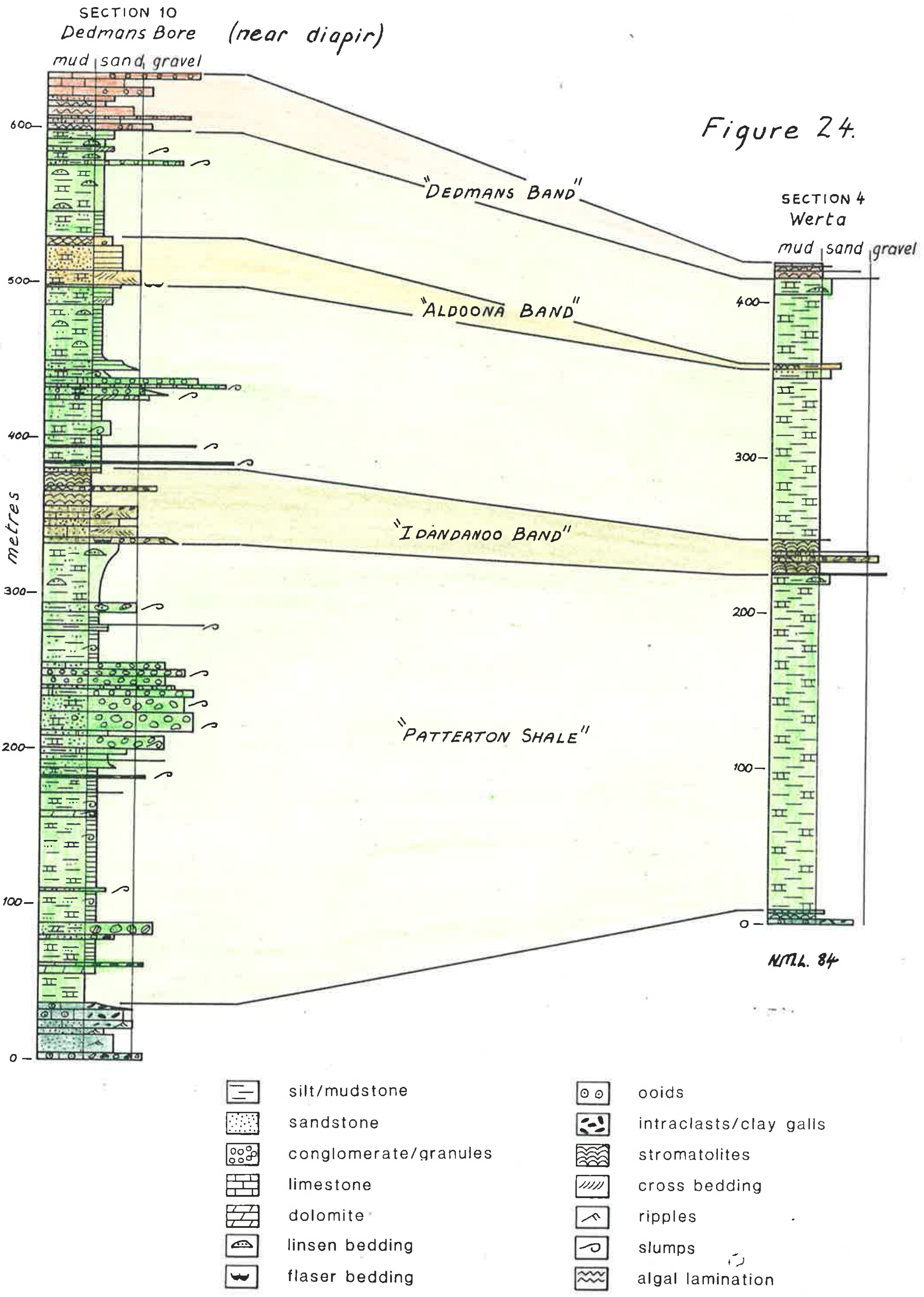


Figure 24.

FACIES VARIATIONS NEAR THE ENORAMA DIAPIR

UPPER ETINA FORMATION (Wundowie Limestone equivalent) under wave action on a beach around the diapir. As the pulse of diapir movement progressed, the beach deposits were swept into the basin. These are followed by very coarse, angular clasts derived directly from the diapir. This material is accompanied by a slurry of yellow dolomicrite, probably derived from behind a barrier around the diapir margin. As the pulse of movement waned, the associated sediments grade back through slump diamictites (819-195) to well bedded silts and muddy sands.

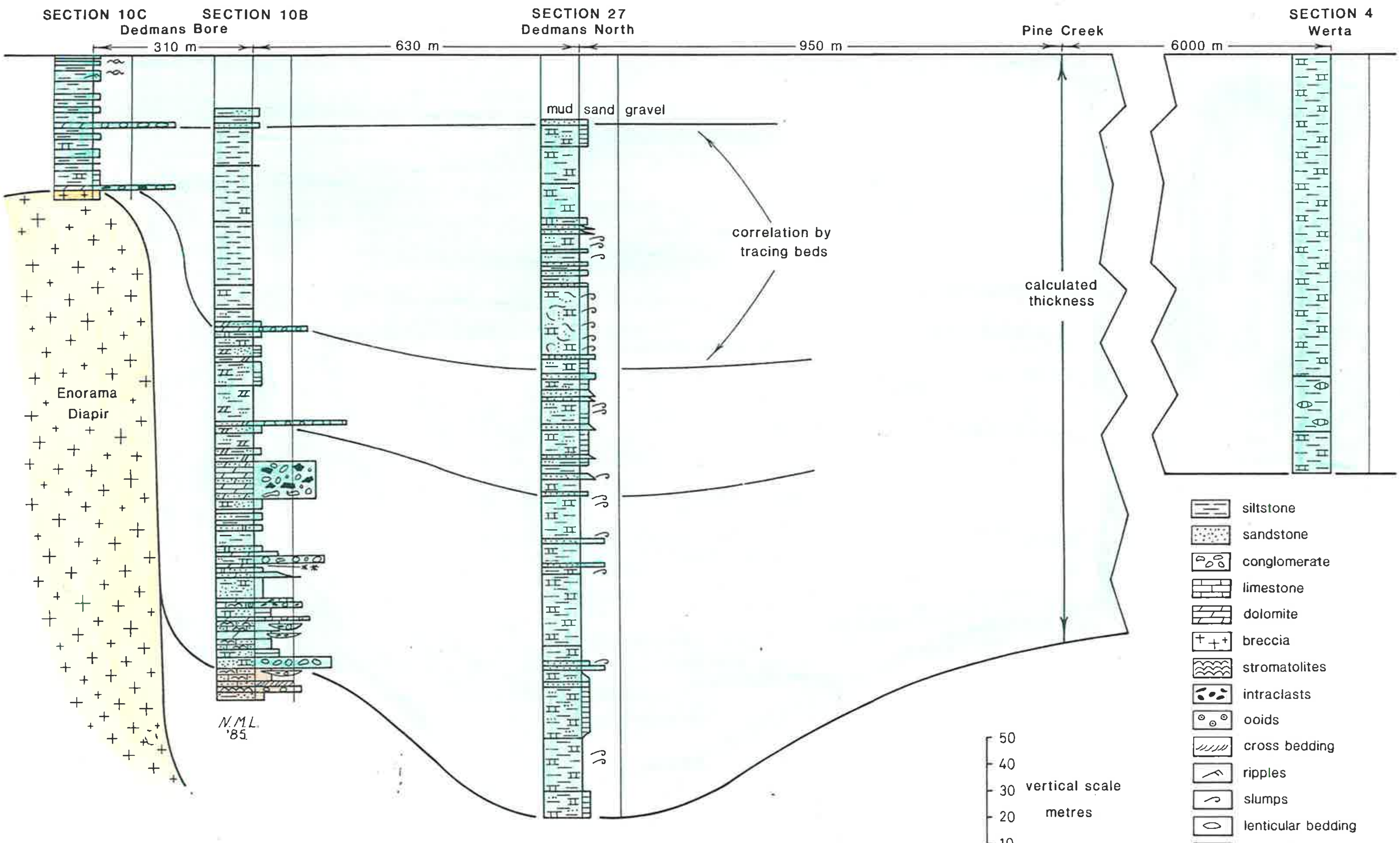
Shallowing in the basin brought about deposition of the "Aldoona Band". Flaser bedded sands mark its base. These are overlain by channel fill calcareous sands then flat bedded, sub-lithic, quartz arenites deposited in a beach environment. These are laterally equivalent to a flaser bedded, oscillation/wave ripple dominated, sub-tidal sandstone exposed in section 11 and 7. Stromatolites mark the top of the band as they do elsewhere in the basin.

19/. Calcareous, fine silty sands and sandy silts were deposited near the diapir between the "Aldoona" and "Dedmans Band". Slumps carried diapiric detritus into the basin at this level. These grade laterally into turbidites.

Lowered sealevels brought on the deposition of the "Dedmans Band" as explained in Chapter 4. Locally derived conglomerates occur throughout this band near the diapir. As with the "Idandanoo Band", stromatolite "growth" is subdued by clastic input. Sandy algal mats (819-040) predominated along section 10 with no columnar forms.

20/. A major pulse of diapiric activity is recorded as the basin underwent substantial deepening and transgression associated with the deposition of the Enorama Shale. A secondary peripheral sink to the north of the diapir at Dedmans Bore is outlined by the measured sections 10B, 10C and 27, displayed as Fig.25. Section 10B is dominated by thick lenses of pebble to boulder conglomerate composed entirely of diapiric detritus. Stromatolite "growth" can be seen in some of the finer intervals, suggesting that the basin remained shallow near the diapir. Some sand was swept into the basin in a dolomicrite slurry (819-103). Yellow dolomicrite also forms to matrix to most of the coarser clastics.

Two beds in this interval show deposition of evaporites in sequence with the Enorama Shale. The level marked on section 10B, Fig.25, is a 2m thick lens of yellow carbonate, dolomite and calcite,



FACIES VARIATION NEAR THE ENORAMA DIAPIR

LOWER PART OF THE ENORAMA SHALE

Figure 25.

at least 20m long. It is clearly part of the sequence, underlain by muddy sandstone and overlain by conglomerate. Specimen 819-104 from this layer shows numerous randomly oriented dolomite crystals replacing gypsum in a background of small dolomite crystals with a peculiar "flywire" texture (see Plate 5). The micrite was deposited as a slurry which flowed into position quickly enough to prevent dissolution of the incorporated gypsum.

Sample 819-105 was collected about 15m up section from 819-104. This specimen shows the distinctive "chicken wire" texture of anhydrite, now replaced by calcite and chert (see Plate 5). The sample was collected from very near the diapir contact and it was uncertain whether it belonged to the diapir or Enorama Shale. A further three samples were collected after the recognition of the anhydrite texture. All three, 819-134, -135 and -136, show unusual textures which destroy the bedding but all have a number of things in common. All contain dolomite and quartz after gypsum and anhydrite in a hematitic calcite matrix. Distinctive poikilitic quartz aggregates mirror original gypsum crystals. These shrank after sedimentation as they were altered to anhydrite which still remains as small inclusions in the poikilitic quartz (see Plate 5). The visual variability of these samples implies that they have been derived as lithified clasts from the diapir but the calcite matrix mitigates against this. It is difficult to pick a boundary in this area between diapiric breccia and talus derived from that breccia but the weak banding in the outcrop is parallel to Enorama bedding and I have yet to find calcite within the breccias of the Enorama Diapir. It appears that the gypsum formed at the time of deposition of the Enorama Shale and was swept into the basin as a density current slurry.

Bed tracing established correlation to section 10C in contact with the diapir. Coarse, angular conglomerates (eg. 819-106) rapidly grade into sands and granule conglomerates away from the contact.

21/. Section 27 was measured 630m north of 10B and conglomerates are totally absent. The thicker section suggests that this point is close to the centre of the secondary peripheral sink, about 1 km away from the diapir margin. The conglomerates along 10B can be traced laterally to a series of slumps and turbidites. Specimen 819-133 is a full Bouma turbidite with all ABCDE subdivisions present. The A subdivision is a coarse sand sized litharenite with all the clasts of diapiric origin, (819-132). Many of the turbidite packages contain no sand fraction and

PLATE 5

FEATURES AROUND THE ENORAMA DIAPIR, 1

Plate 5A

Well bedded ooid and intraclast limestone at the base of the Etina Formation is broken by synsedimentary slumping near the contact with the Enorama Diapir, just to the south of the Asbestos Mine.

Plate 5B

Coarse grained chert nodules in a matrix of dolomite crystals, sample 819-104, (crossed polars). The chert is after anhydrite and the dolomite after gypsum. The smaller dolomite crystals are arranged in a perpendicular grid pattern and all have the shape of "seed" gypsum. The large dolomite crystal has replaced a twinned gypsum crystal. This sample was collected from within the Enorama Shale along section 10, close to the Enorama Diapir at Dedmans Bore. (x polars)

Plate 5C

Sample 819-105, calcite after nodular anhydrite. The typical "chicken wire" texture is outlined by anastomosing stylolites. The centre of some nodules shows minor radiating chert after anhydrite. This sample, like that in Plate 5b, was collected from within the Enorama Shale nears Dedmans Bore. (x polars)

Plate 5D

Sample 819-134, small nodules of granular quartz in a calcite cement. As the quartz contains small inclusions of anhydrite, the nodules were probably originally that mineral. (sample collected adjacent to 105). (x polars)

Plate 5E

Sample 819-135, also from the Enorama Shale near 104 and 105, shows granular quartz replacing gypsum. Although the quartz grains are much smaller than the original gypsum, the twinning can still be seen. Cracks filled with matrix calcite along the length of the crystal show shrinkage, suggesting the gypsum altered to anhydrite before replacement. (x polars)

Plate 5F

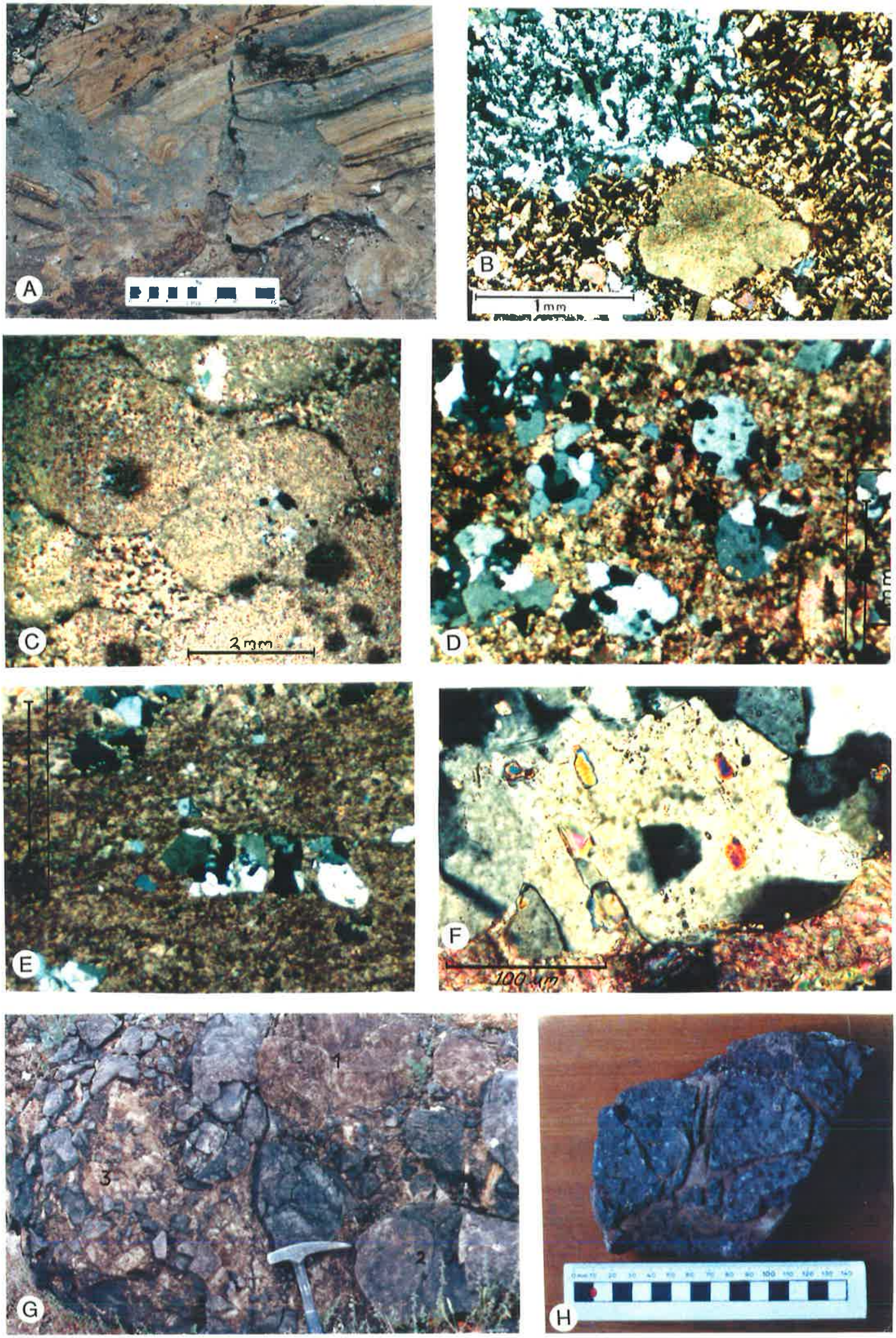
Detail of quartz subgrains in 189-135, Plate 5E. Inclusions of anhydrite are common in the granular quartz. The distinctive features are the birefringence and the square stepped terminations. The quartz has replaced anhydrite after gypsum. (x polars)

Plate 5G

Conglomerate from the Enorama Shale - diapir contact shown in Fig.27b. The boulders labelled 1, 2 and 3 are reworked conglomerates, each 40cm in diameter. 1 is a boulder of gravelly dolomite and 2 contains two cobbles of basalt in a matrix of basalt derived sand cemented by dolomite. 3 is a boulder of basalt pebbles in sandy dolomite. Repeated uplift of the diapir has exposed previously deposited conglomerates and reworked them.

Plate 5H

Large rafts of amygdaloidal basalt outcrop within the Enorama Diapir, along its western edge. Where the rafts are at the contact, dolomicrite, infiltrating from the adjacent sediments, has cemented the fractured basalt. The basalt blocks in this sample, 819-164, would fit together as a jigsaw if the dolomicrite were removed.


A
B
1mm
C
3mm
D
E
F
100 μm
G
1
2
3
H

may have been deposited into the secondary peripheral sink from the side away from the diapir. There is a single slumped interval 30m thick, 270m above the base of the section where the visible bedding is twisted and contorted in all orientations. Flat bedded silty sandstones above and below show the slump to be in sequence. A turbidite at the top of section 27 was traced 1 km to the south to tie in with a similar turbidite on section 10B and a dolomite conglomerate on section 10C.

22/. Evidence of tectonic activity is common at the base of the "Aldoona Band". This usually takes the form of slumping, as seen at the base of section 11. A gravity slide can be seen on the western side of the diapir at this stratigraphic level. A partially cemented silty limestone band has slid down into the secondary peripheral sink away from the diapir. The toe of the slide is exposed in a tributary of the Enorama Creek, downstream from section 38. Fig.26 is a sketch of the feature. A limestone band outlines the structure as it pushed down a gently inclined detachment surface. Overturned folds at the rear of the slide push over sediments upturned against an upward imbricate thrust fan complex. A gentle anticline has formed at the "foreland" end of the slide. The slide mirrors many of the features described from full scale foreland fold and thrust belts, (Lowell, 1985).

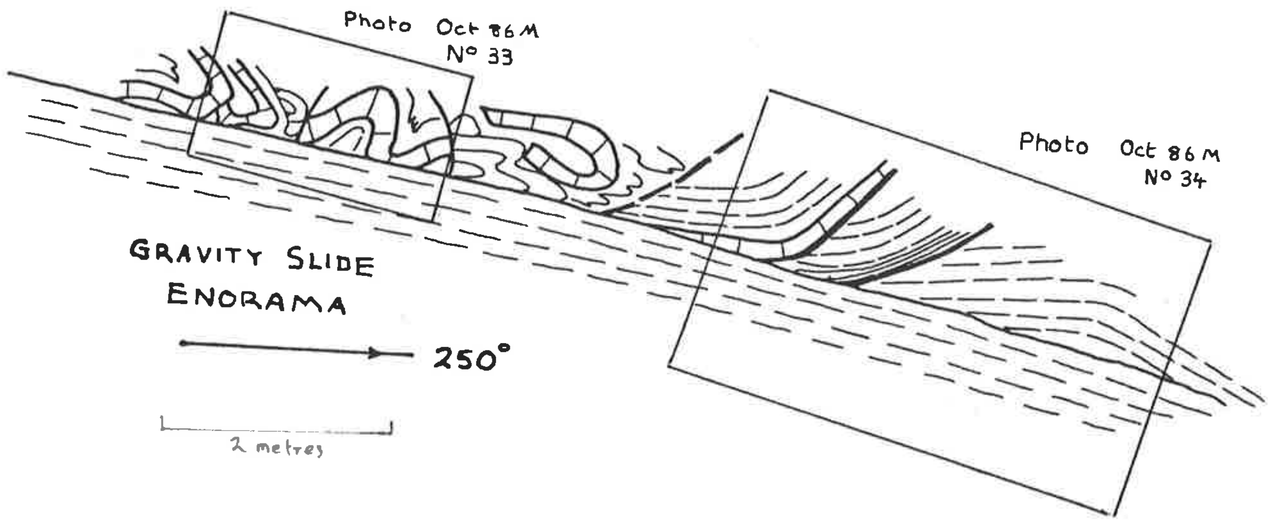


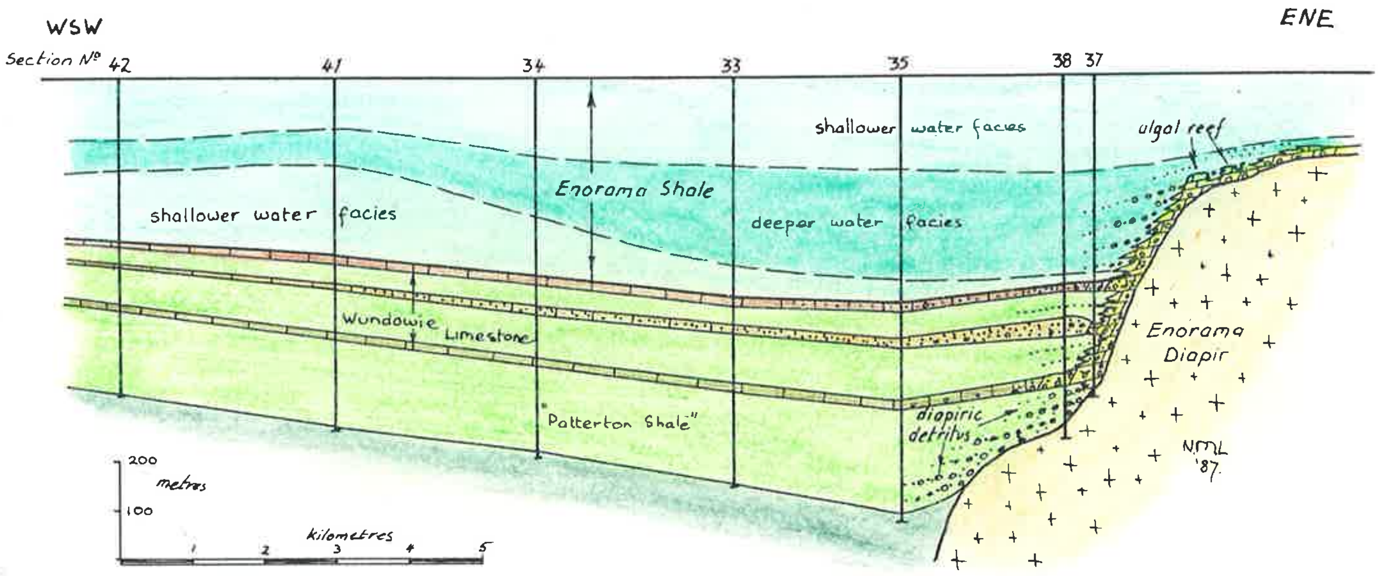
Figure 26. Gravity slide near the base of the "Aldoona Band", W of the Enorama Diapir, directed away from the diapir.

23/. The Wundowie Limestone equivalent and the lower half of the Enorama Shale abut the western side of the diapir as an original sedimentary contact. Movement of the diapir after deposition has turned the contact, and the sediments immediately above it, to a vertical orientation. The present day plan view of the area near the diapir is therefore a true section of the sedimentary pile. Fig.27a shows a number of measured sections leading up to the contact from the west. The sequence gradually thickens into the secondary peripheral sink from the basin then rapidly thins onto the diapir. Detritus is shed from the diapir almost continuously over this interval. This detritus was deposited close to the diapir at times of deeper water sedimentation and became more widespread during the shallow water periods. Recognizable diapir clasts and sands are still present in the Wundowie Limestone bands at section 42, 15 km away from the diapir.

There is a very distinct facies change against the diapir during the deposition of the Wundowie Limestone equivalent and the lower Enorama Shale. The limestones grade into dolomites within 400-500m of the contact and these dolomites persist against the diapir during periods of deeper water sedimentation out in the basin. Tongues of sand and granules push past the dolomite and interfinger with the basin shales. Many of the dolomites are conglomeratic with coarse, angular to very well rounded pebbles to cobbles and boulders of diapiric rock types included in a yellow dolomicrite matrix. There is evidence of reworking with boulders of previously deposited dolomite conglomerate eroded, rounded and recemented with dolomicrite. Three and possibly four generations of conglomerates can be recognized, testimony to continuous movement on the diapir, (see Plate 5).

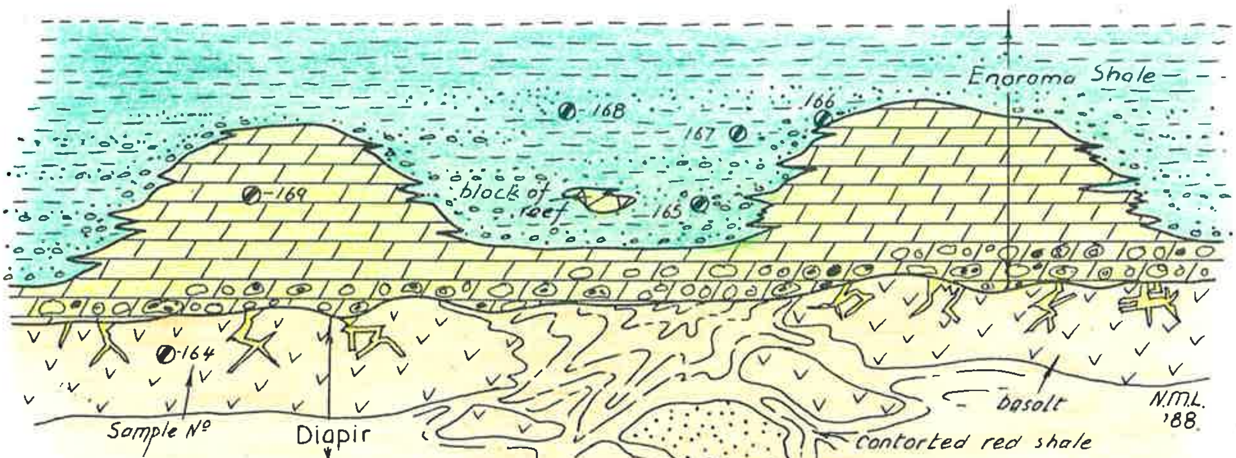
Dolomicrite infills fractures and weathered joints of some of the more resistant rafts within the diapir that were exposed at the time, (sample 819-164 and Plate 5). This is particularly common with the dark green basalts which form a high percentage of the rafts along the western side of the diapir.

24/. R.Dalgarno, (pers comm, 1985), pointed out an irregular contact against the basinal shales on the western side of the diapir. Detailed mapping of the feature showed it to be a reef like structure, within the Enorama Shale, on the diapir contact. Fig.27b shows some of the details of what appears to be a Precambrian algal reef. Massive, fenestral, stromatolitic and intraformational breccia dolomites have cemented into a solid structure which maintained some positive relief



Upper Etina Formation and Enorama Shale
True Thickness and facies variation along the western side of Enorama Diapir
(base Trezona Fm. as datum)

Figure 27a.



Detail of algal reef - W margin, Enorama Diapir

Figure 27b.

during deposition of the surrounding shales and sandstones. Interfingering of dolomites with clastic sediments shows that the structure grew with sedimentation rather than later erosion having scoured channels to produce the relief. The total height of the reefs is about 50m above their base and 40m above the channel between adjacent reefs. Plate 6 shows a photo of the northern mound from the southern one. Shales and sandstones fill the intervening gutter and strike directly into the mounds.

Each mound is surrounded by a halo of detritus, mainly derived from the diapir but with some derived from the reef. A large block of reef dolomite, 3m across, has rolled down into the channel. Samples 819-165, -167 and -168 show the composition of the sands.

Samples 819-166 and -169 were collected from the reefs shown in Fig.27b Both these samples are dolomicite to microsparry dolomite with a distinctive "clotted" texture (see Plate 6), reminiscent of the calcareous alga, Renalcis, which first appears in the geologic record in the Cambrian, where it encrusts and binds reefs, (James, 1983). A fenestral fabric is common in parts of both samples, indicating some periods of exposure of algally bound sediments. There was substantial porosity within the reef but this has since been nearly filled with authigenic quartz, microcline (adularia) and dolomite. The reefs may have originally been calcite or aragonite as dolomitization appears to have been later, producing significant microporosity, now partially filled with limonite, especially in the zones now microspar dolomite.

Samples -161 and -162 were collected from section 38, still on the contact with the diapir but stratigraphically equivalent to the "Idandanoo Band" in the Etina Formation. These show the fenestral fabric and clotted texture of the reef dolomites as well. 819-162 is a conglomerate/breccia of reef dolomite cemented by early isopachous cement and later carbonate, now microsparry dolomite (see Plate 6).

25/. Section 21, measured west from the diapir contact at Mallee Water, shows sediments of the Enorama Shale upturned against the diapir. Bedding at the western end of the traverse flattens out into a small syncline, possibly the secondary peripheral sink, although it is too close to the contact when compared with the position of the sink to the north of Dedmans Bore. The normally well laminated shales of the Enorama Shale become beds of massive siltstone up to 1m thick, at the western end of the traverse (see Plate 6). These are turbidites deposited from sediment with a limited grainsize range. The beds are sharp based with gradational tops, being particularly massive at the base and grading upward into finer silt sizes with weak but increasing evidence of bedding then lamination. The turbiditic nature of the beds is shown by the occurrence of flute marks on the base. The direction of movement indicated by the flutes is particularly interesting. All currents flow parallel to the diapir margin but a group of 2-3 beds show flow to the north, 000°, with an overlying group of 3-4 beds showing flow to the south, 180°. Beds still higher show the flow back to the north again.

This reversal of flow can be explained by see-saw pulses of movement on the diapir. If uplift occurred at the northern end of the diapir, debris would spill from the diapir into the sink and the resultant turbidity current would move into the bottom of the sink then along it. Should the southern end of the diapir move and generate a turbidity current, then it would move along the trough of the secondary peripheral sink to the north. Bertagne (1984), describes how salt diapirs around the Campeche Knolls, in the Gulf of Mexico, modify the bathymetry to change the direction of, and channel turbidite flows, that they themselves initiate.

26/. Section 21 also crosses the diapir contact at Mallee Water. Conglomerates interbedded with shales have been pulled up to vertical by diapir movement, (Plate 6). Right on the contact, the conglomerates consist of subrounded dolerite, basalt and quartz arenite clasts in a matrix of lithic arenite. Above an interval of vertical to overturned green shales, is an outcrop of dolomite conglomerate. The clasts consist of angular to well rounded cherty dolomites with evaporite pseudomorphs together with granules of basalt, siltstone and sandstone, (Plate 6, sample 819-117). The matrix to this conglomerate is the yellow dolomicrite seen in many other places interbedded with shales near the diapir. Two thin beds of this dolomicrite are interbedded with red and green shales above the dolomite conglomerate.

27/. The Trezona Formation west of Mallee Water has also been influenced by the proximity of the diapir. Current directions in the first main intraclast band switch around from the usual progradation into the basin from the northwest, (see Chapter 4, Trezona Formation). There is also an increase in the number of thin intraclast bands seen at this level near the diapir, a result of increased algal growth and more reworking in the shallower conditions.

PLATE 6

FEATURES AROUND THE ENORAMA DIAPIR, 2

Plate 6A

The northern half of the reef system shown in Fig.27b, viewed from the southern mound. The diapir contact on the right of the picture, with the smooth land surface over the recessively weathering diapir. The dip of the adjacent sediments is vertical, facing to the W or left of the picture. The area between the reef mounds contains shales, sandstones and conglomerates, striking into, and interfingering with, the reef rock.

Plate 6B

Sample 819-169, the reef rock comprising the mounds in Plate 6A. A globular texture, still visible through the complete dolomitization, is reminiscent of the calcareous alga, "Renalcis". Dolomitization has produced an intercrystalline porosity and enhanced the fenestral and vuggy porosity inherent in the rock. (Plane light)

Plate 6C

Sample 819-162, clasts of sandy dolomicrite, with the clotted texture of Plate 6B, have been reworked off the reef into a forereef breccia. Isopachous cement rimmed the clasts prior to later dolomite, quartz and microcline (adularia) cement. This reef developed on the W margin of the Enorama Diapir at the level of the "Idandanoo Band", (section 37). (× polars)

Plate 6D

A thick bed of conglomeratic dolomite, interbedded with green and red siltstones of the Enorama Shale at Mallee Water, section 21. The sequence has been pulled up to vertical against the Enorama Diapir. The contact is 10m to the left of the picture. The thin dolomicrite bands on the right of the picture show how quickly the dip has dropped back to 48°.

Plate 6E

Sample 819-117, detail of the conglomeratic dolomite in Plate 6D. Clasts of diapir derived cherty dolomite, dolerite, basalt and quartz arenite in a matrix of very fine grained, beige dolomicrite.

Plate 6F

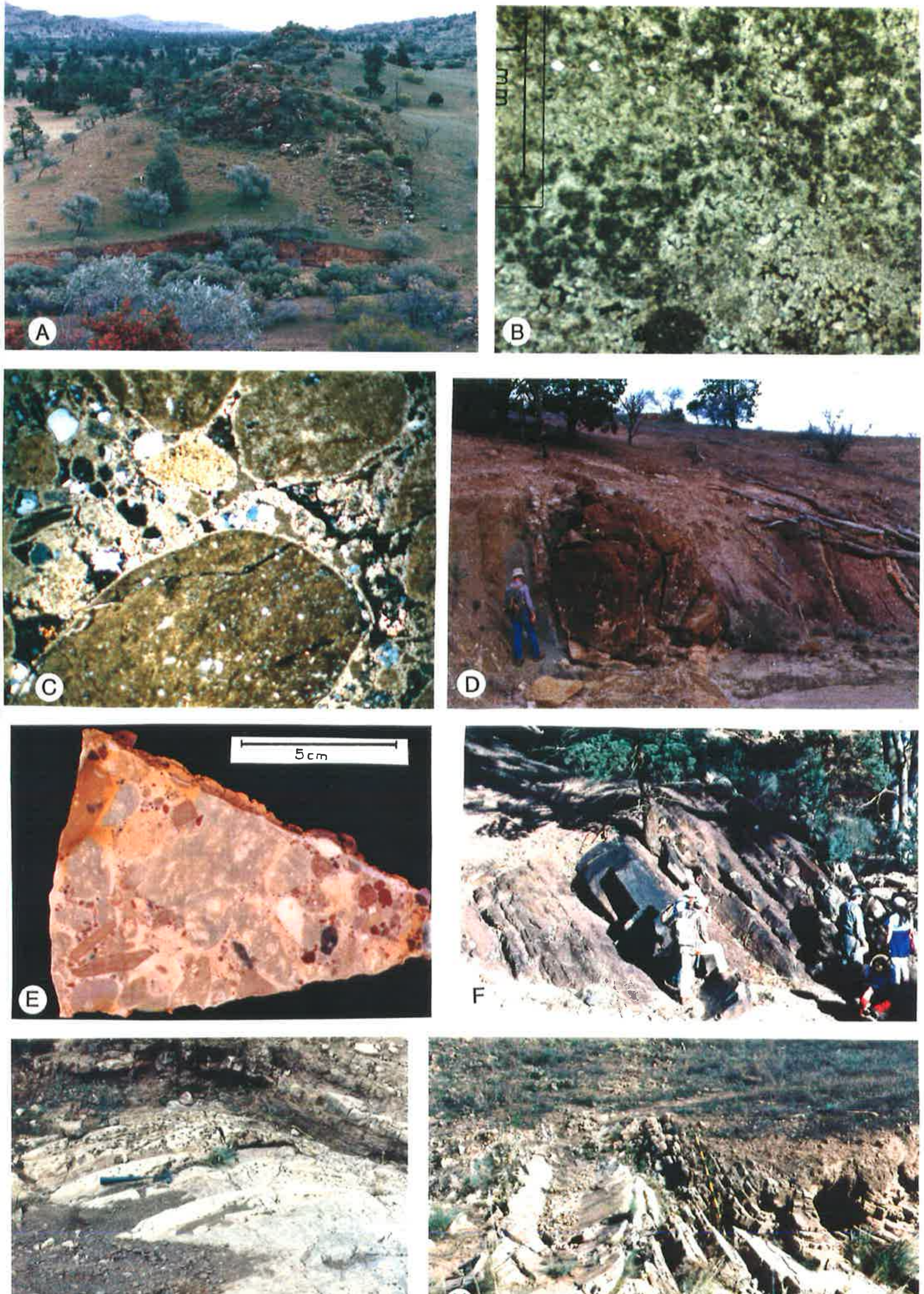
100m W of Plate 6D, the Enorama Shale dips at 40° to the west. Massive beds outcrop within the normally well laminated sequence. These sharp based, graded topped turbidites have basal flute marks which indicate currents to 000° on some beds and 180° on others. Turbidity currents, generated by diapir activity, were channelled along the rim syncline adjacent to the diapir. These flowed in opposite directions, depending at which end of the trough they were generated.

Plate 6G

50cm amplitude wrinkles (transverse in this photograph) disturb the bedding of the Nuccaleena Formation dolomite along section 10. Downslope movement, possibly generated by uplift on the nearby Enorama Diapir, appears to have caused a semi-cohesive dolomicrite mat to move.

Plate 6H

Large tepoid structures in the dolomites of the Nuccaleena Formation at section 36. The elongate polygons resemble boat keels where large bedding planes have been exposed. The direction of elongation is parallel to the nearby diapir margin and may be controlled by movement similar to that suggested in 6G.


A
B
1 mm
C
D
E
5cm
F
G
H

28/. Uplift of the diapir has also exposed the Trezona Formation at one level. This lead to the formation of a karst surface as described in Chapter 4, Trezona Formation.

29/. Continued uplift of the diapir eventually led to exposure of the diapiric breccia toward the top of the Trezona Formation. Detritus shed into the basin forms a halo around the diapir, (see Chapter 4, Trezona Formation).

30/. On the western side of the study area, the Yaltipena Member of the Trezona Formation is only preserved in the secondary peripheral sink of the diapir. Away from the diapir, the unconformity at the base of the Elatina Formation has removed the Yaltipena Member and cut down into the limestones of the Trezona Formation (see Chapter 4, Trezona and Elatina Formations).

31/. Additional section (an ice contact tillite) is also preserved at the base of the Elatina Formation in the vicinity of the diapir, (see Chapter 4, Elatina Formation).

32/. The conglomerate that forms the base of the Elatina Formation, as preserved in the secondary peripheral sink, contains a bimodal clast suite. 40% of the clasts are exotic, derived from reworking of the underlying tillite. The remaining 60% of the clasts were derived from the Trezona Formation, (see Chapter 4, Elatina Formation). Mapping of the unconformity at the base of the Elatina Formation shows the Trezona Formation was exposed over a wide area and the clasts could have been derived from anywhere. However, the limestones are unlikely to have been transported any great distance and the present outcrop of this conglomerate is restricted to the vicinity of the diapir. Occasional distinctive diapir clasts mixed with the conglomerate suggest some erosion off a high associated with the diapir.

33/. Glacial diamictites in the middle and near the top of the Elatina Formation near the diapir contain a high percentage of basalt, dolerite and amygdaloidal basalt clasts. These rocks are virtually identical to rafts presently exposed within the diapir. Dalgarno and Johnson, (1964b), also commented on this similarity. Obviously, the diapir must have been exposed at the time. Many of the clasts show facetted and striated surfaces, indicating ice erosion and transport, clearly a subaerial or near shore phenomenon.

34/. Several channels of conglomerate were deposited near the top of the Elatina Formation between section 19 and Enorama Creek, (see

Chapter 4, Elatina Formation). The conglomerate within these channels consists of up to 50% pebbles of Trezona Formation, distinctive red, algal micrites, grey oolite and red, intraclast, (heiroglyphic), limestones. The remaining 50% of the rock consists of pebbles and sandy matrix of diapir detritus, (samples 819-150 and -172, Plate 6). The channels indicate flow away from the diapir. Trezona Formation underlies the Elatina Formation and must have been uplifted and exposed around an active Enorama Diapir.

35/. The Nuccaleena Formation shows several subtle influences of activity on the diapir. Local shallowing around section 23 either caused erosion of the Nuccaleena dolomites or the higher energy of the shallow conditions resulted in the deposition of a conglomerate in place of the dolomite, (see Chapter 4, Nuccaleena Formation). Sample 819-118 shows that 95% of the detritus in this conglomerate is of diapiric origin. This could have been derived directly from the diapir or reworked from the diamictites.

36/. Buckling of a partially lithified dolomite layer on section 10 could be due to gravity sliding away from the nearby diapir, (see Chapter 4, Nuccaleena Formation, Plate 6).

37/. The preferred orientation of elongate polygonal tepoids could also have a similar origin (see Chapter 4, Nuccaleena Formation).

Although preliminary aerial photo-interpretation shows facies variations within the Brachina Formation where it most closely outcrops to the diapir, no work was done above the Nuccaleena Formation around the Enorama Diapir.

Measured section 10 shows a number of pulses of diapiric activity recorded by major influxes of diapiric detritus to the adjacent basin. These are closely associated with increased slumping of the sediments already deposited. There is a good correlation between the evidence of diapiric activity and the position in the stratigraphy. Each pulse is recorded in a shale unit immediately following a limestone band. As the limestones represent shallow water deposition and the shales deeper water, the diapir shows pulses of activity as the sea level rises. Loading of a low density layer with sediments of higher density causes the initial instability and sustains diapir movement. Loading in a basin is dominated by sediments but a rapid increase in loading can be achieved by raising the sea level. The rapidity of this is seen by the lack of sedimentation recorded during transgression compared with a thick prograding wedge during regression or standstill.

Diapir activity associated with transgression is recorded in the bottom half of the "Patterton Shale", "Idandanoo"-"Aldoona" shale and Enorama Shale. The "A-D" shale does not record a pulse as it was only a minor transgression. Relative stability returned to the diapir as the sea level stabilized or shallowed in the upper half of the shale units mentioned above.

CHAPTER 6

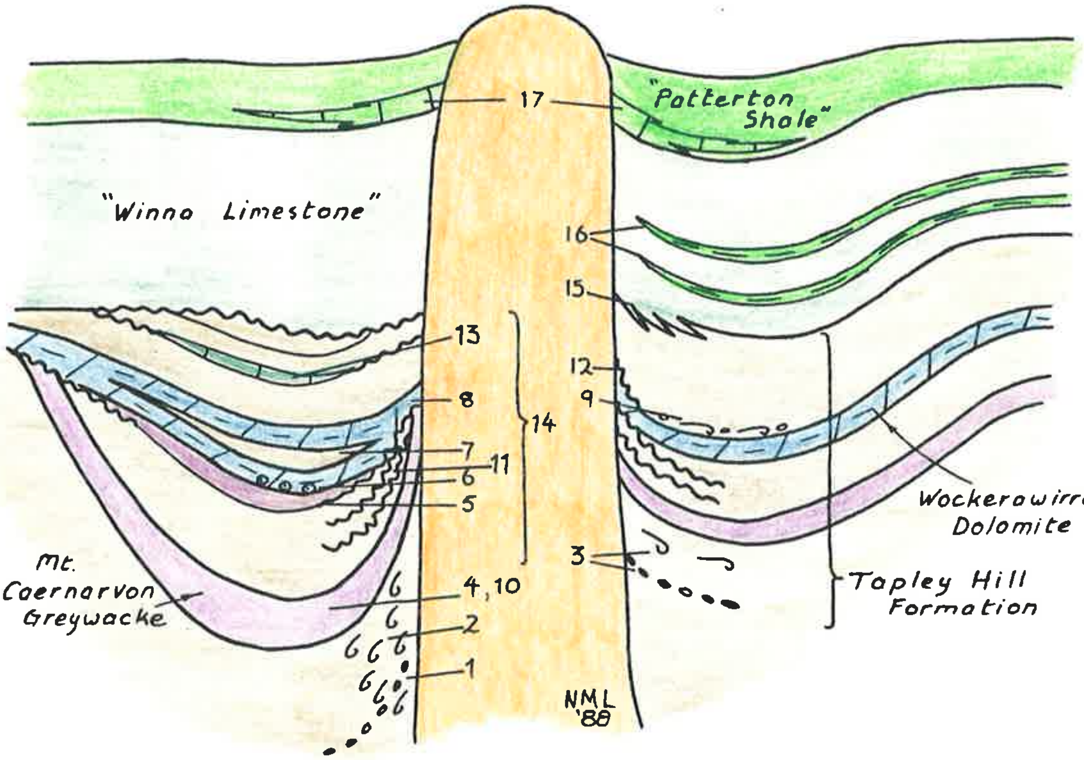
BLINMAN DIAPIR

The Blinman Diapir presents a different perspective to the Enorama Diapir. The Blinman feature is roughly circular, about 12 km in diameter, outcropping at the center of a dome with all sediments dipping away from the structure which is seen essentially in plan view. The geological map of the Blinman area, (Enclosure 1), shows the outcrop pattern. Fig.28 is a summary of the influence the diapir had on the surrounding sediments. It is difficult to project this influence too far up the stratigraphic column as the outcrop pattern prohibits this. The isopachs of the Wundowie Limestone equivalent, (Chapter 4, Fig.14), show almost no influence. This may be due to the fact that the diapir had stopped moving at that stage or that the sections measured were too far from the contact to record the influence.

Five sections were measured around the diapir as shown in Fig.29. The influence of the diapir is profound at the base of each section in the Tapley Hill Formation as this is in near contact with the diapir. A complicating factor is introduced by the secondary peripheral sink which is not equally distributed around the diapir, (Fig.29). The southern area of the sink, traversed by section 54, is now fault bounded but these faults largely developed after thickening of sediments into the sink. The northern area, around section 57, has only minor synsedimentary fault control. Seni and Jackson, (1983a), showed that secondary peripheral sinks in the East Texas Basin varied in plan from equidimensional to elongate with the axial trace of the sink intercepting the associated dome. The secondary peripheral sink of the Blinman Diapir is elongate and its north-south axial trace intersects the diapir.

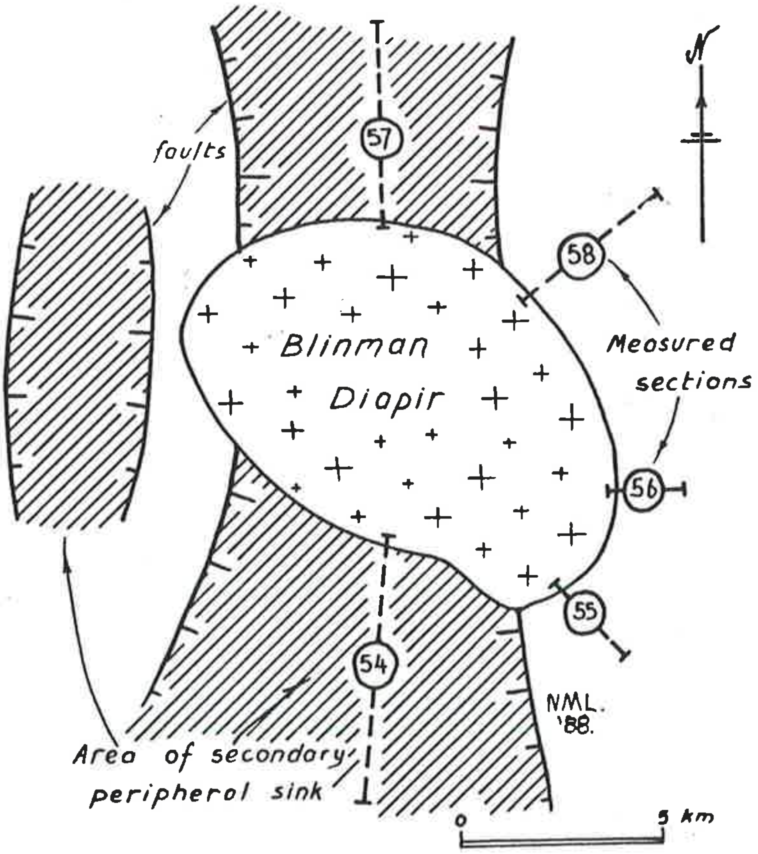
The position of the secondary peripheral sink is directly related to the withdrawal of salt from the underlying pillow. This in turn can be controlled by either basement faults or faults within the sedimentary sequence. Intra-sequence faults are introduced early in the history of pillow movement. Doming over the pillow will result in the formation of a crestal graben, (Currie, 1956), and this can persist through to the diapir stage where it controls the position of the secondary peripheral sink.

Features 1 - 9 on the summary diagram are shown on Fig.30, a cross section along the southern margin of the diapir from the deepest part of the secondary peripheral sink to a shelf developed along the eastern side of the diapir.



BLINMAN DIAPIR — summary of influence on sediments

Figure 28.



Structure controlling deposition of the lower Umberatana Gp.

Figure 29.

1/. Granules and small pebbles are included in the Tapley Hill Formation in association with slump deposits. Sample 819-181 shows that some of the granules were possibly derived from the diapir.

2/. Over 150m of Tapley Hill Formation along section 54, from near the position of 819-181 (Fig.32), to the base of the Mt. Caernarvon Greywacke, shows continuous tectonic disturbance in the form of intraformational slumping.

3/. Slumps and conglomerates are also present at the same stratigraphic level on the eastern side of the diapir along section 56 and further north on the Blinman golf course, just south of the township.

4/. The Mt. Caernarvon Greywacke shows considerable thickening into the graben south of the diapir when compared to the preservation of the unit east of the diapir around sections 55 and 56. The thinning is probably achieved by intraformational paraconformities as it is around the Enorama Diapir, (Chapter 5, 7/.).

5/. The southern extension of the secondary peripheral sink has over 250% greater thickness of Tapley Hill Formation preserved within it compared to the eastern shelf area. Overall thinning is achieved by thinning of individual units and by the development of paraconformities and unconformities during hiatuses. The unconformity at the base of the Wockerawirra Dolomite erodes a sandy unit within the Tapley Hill Formation, itself an indication of shallowing prior to the erosion.

6/. The change from dominantly shale and silt deposition to dolomite within the Tapley Hill Formation is due to local shallowing. This is not obvious in the normal silty Wockerawirra Dolomite with thin, micritic, turbiditic, fining upwards packages preserved within the sink. However, sample 819-185 is an oolitic limestone. High energy, shallow water conditions must have existed nearby even if the final environment of deposition appears to have been deep water. Those shallow conditions either existed over the rising diapir or outside the sink to the east. Current directions suggest the ooids were derived from the shelf to the east.

7/. Marked thinning and facies changes are observed within the Wockerawirra Dolomite between sections 54 and 55. A lens of possibly deeper water shale between two bands of silty dolomite suggests conditions were considerably deeper within the secondary peripheral sink.

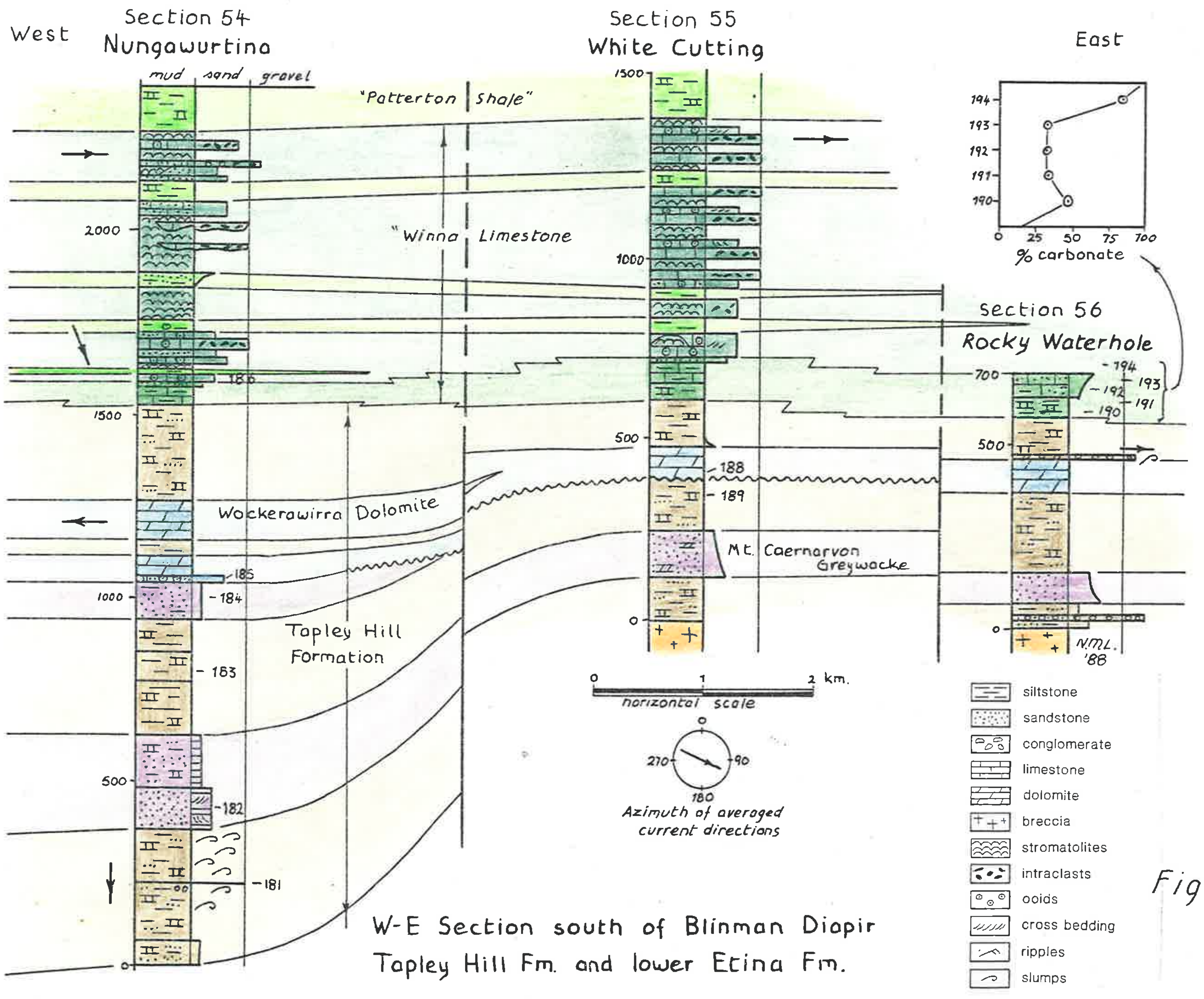

West
Section 54
Nungawurtina
mud sand gravel
Section 55
White Cutting
East
"Patterton Shale"
"Winna Limestone
Wockerawirra Dolomite
Mt. Caernarvon Greywacke
Tapley Hill Formation
Section 56
Rocky Waterhole
% carbonate
0 1 2 km.
horizontal scale
Azimuth of averaged current directions
siltstone
sandstone
conglomerate
limestone
dolomite
breccia
stromatolites
intraclasts
ooids
cross bedding
ripples
slumps
N.M.L. '88
W-E Section south of Blinman Diapir
Tapley Hill Fm. and lower Etina Fm.

Figure 30

8/. The character of the Wockerawirra Dolomite along section 55 is quite different from that to the west. Clean, massive, well cemented dolomite with a weak fenestral texture suggests that there may have been exposure at this level during sedimentation. This would account for the marked thinning noted in 7/. above. A similar massive dolomite was developed against the Enorama Diapir, (Chapter 5, 9/.).

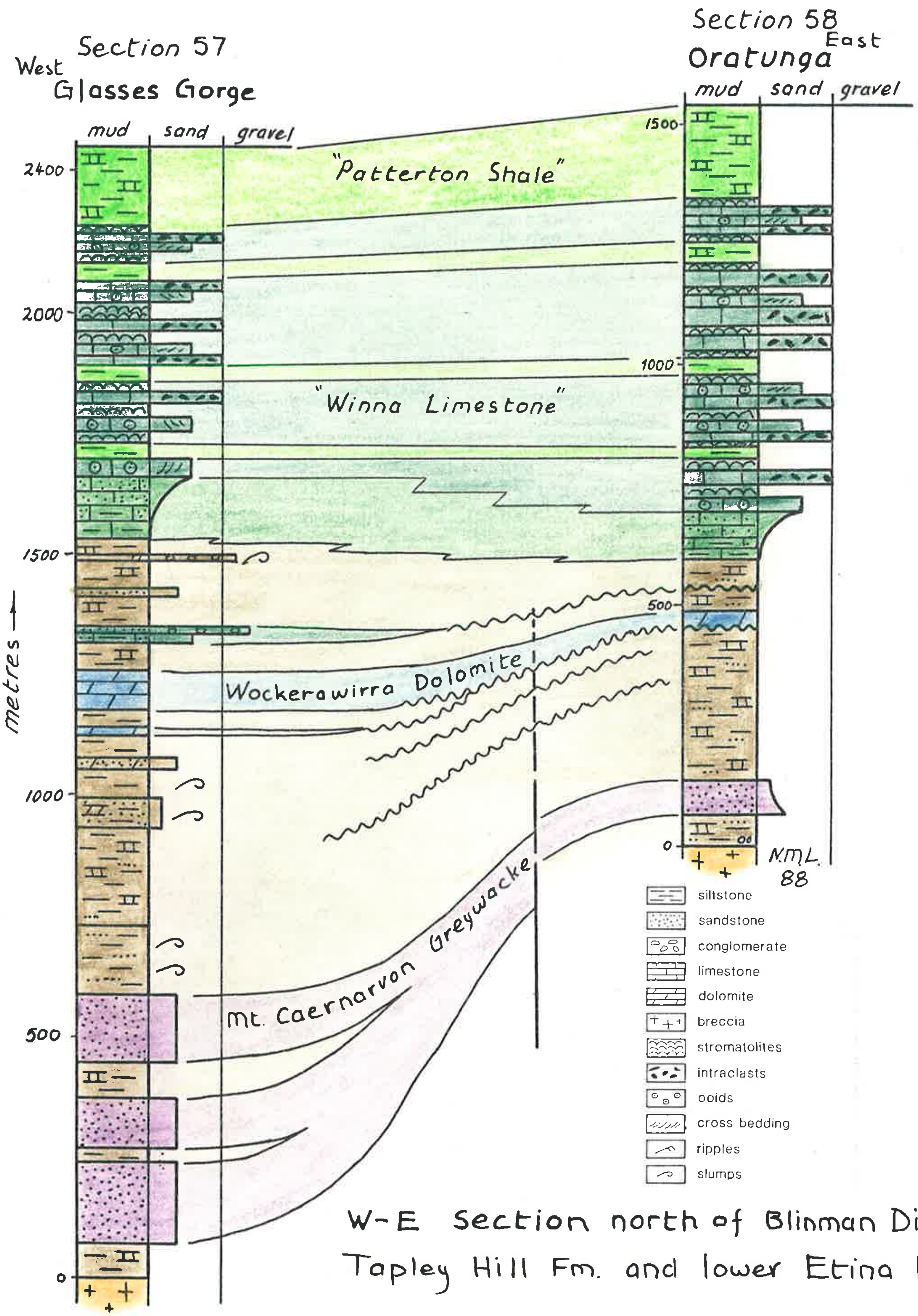
9/. As the sea level rose at the end of the Wockerawirra Dolomite deposition, slumping reworked the sediment and carried some diapiric detritus into the basin east of the diapir in the vicinity of section 56. The movement was toward 090°, directly away from the diapir.

Features 10 - 13 are depicted on Fig.31, a cross section parallel to Fig.30 but drawn along the northern margin of the diapir from the secondary peripheral sink to the shelf on the east. This section show gross similarities to the southern extension of the sink but with variation of individual members.

10/. The coarser facies of the Tapley Hill Formation, the Mt. Caernarvon Greywacke, is particularly well developed through Glasses Gorge, measured as section 57. The beds sit vertically against the diapir contact and form a substantial topographic ridge. The vertical orientation makes low angle unconformities and lateral facies changes particularly obvious on the aerial photographs of the area. Lenses of deeper water shale in the central part of the secondary peripheral sink pinch out to the east toward section 58. The three thick bands of greywacke, (actually sublithic feldsarenite, samples 819-86, -126), thin and merge to the east. The facies changes appear gradual and unaffected by faulting. The only faults in the area are east of Oratunga Homestead, away from the zone of marked thinning.

11/. The Tapley Hill Formation shales between the Mt. Caernarvon Greywacke and the Wockerawirra Dolomite also thin to the east. Much of the thinning is achieved by non-deposition on the eastern block. A series of para/unconformities can be traced across the hinge zone on the margin of the secondary peripheral sink. These disappear into the sink. Intervals of shale, usually sandy shale, within the sink, show evidence of synsedimentary slumping.

12/. Photo-interpretation and field mapping show erosional unconformities have developed above and below the Wockerawirra Dolomite near section 58, east of Oratunga H.S.. The dolomite has been removed altogether between section 58 and a point east of Blinman township.

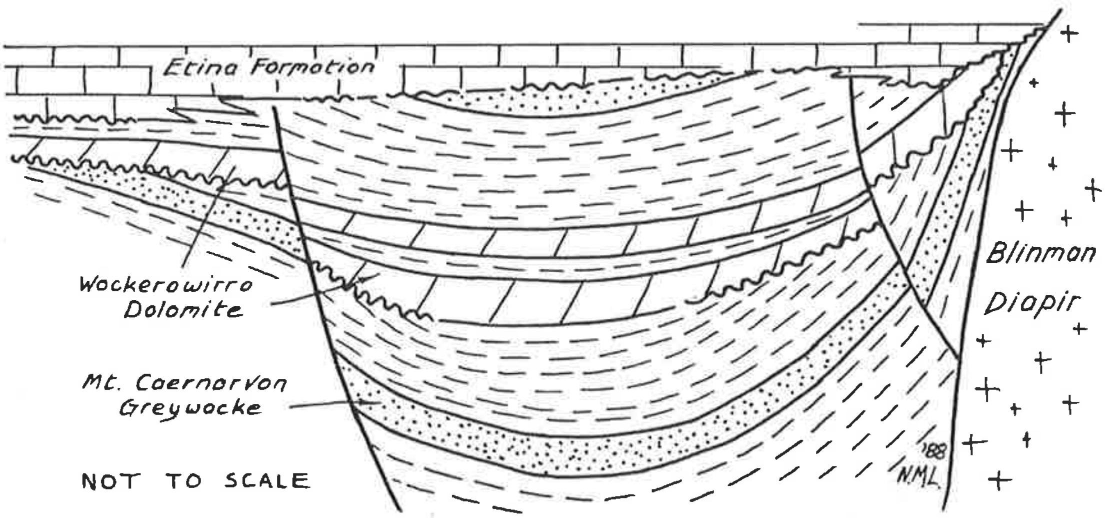


W-E Section north of Blinman Diapir
Tapley Hill Fm. and lower Etina Fm.

Figure 31.

13/. A lens of sandy limestone, similar in appearance to the limestones of the Etina Formation, appears in the shales 150m below the contact between the Tapley Hill Formation and the Etina Formation. This material was reworked to its present position but shows that conditions somewhere in the area must have been shallow enough for limestone deposition to have commenced. The lens thins laterally to the east and west to where a paraconformity developed. There is no evidence for deposition of such limestone within the Tapley Hill Formation in the present areas of outcrop. The source limestone was probably deposited in the shallow area over the top of the diapir. The sand and associated granules incorporated in the lens are of diapiric origin, adding weight to the theory of the early onset of limestone deposition over the diapir.

14/. The country to the west and southwest of the diapir is very steep and rugged and local landholders recommended against working in the area alone. However, the steep gorges give a third dimension to the geology mapped from aerial photographs. The Blinman to Parachilna road takes advantage of the slightly subdued relief along a complex fault zone through the area and this provided some control to the photo-interpretation. Fig.32 is a summary of the relationships interpreted in the area. There is a thicker sequence in a subsidiary peripheral sink west of the diapir, (see Fig.29). Thinning onto the diapir is achieved by erosional unconformities and non-deposition.



Relationships within the Tapley Hill Formation West and Southwest of Blinman Diapir. (based on photointerpretation only)

Figure 32.

The Wockerawirra Dolomite is in unconformable contact with the Mt. Caernarvon Greywacke south of Mount Elkington, against the SW margin of the diapir and possibly further west on the other side of the secondary peripheral sink, near Oratunga Creek. The Etina Formation sits unconformably on parts of the Tapley Hill Formation. This is shown by the preservation of a sandy unit at the top of the Tapley Hill Formation in the centre of the subsidiary peripheral sink.

15/. The diachronous nature of the base of the Etina Formation can be seen in several places around the Blinman Diapir. Bed tracing proves that the onset of limestone and lime-rich siltstone deposition was earlier to the east of the diapir than in the sink. This is shown on Figs.30 and 31 and inferred on Fig.32, (see also Chapter 5, 10/.).

16/. Three thin beds of deeper water calcareous shale, siltstone and minor sandstone occur within the "Winna Limestone". As mentioned in Chapter 4, these are continous over a wide area and were probably related to sea level fluctuations within the basin. These beds pinch out where they most closely approach the diapir, east of Blinman. This may be similar to the way in which the same bands pinch out near the Enorama Diapir, (Chapter 5, 12/.), or it could be due to uplift along the ENE-WSW sinistral transverse fault which parallels the Blinman to Wirrealpla road, (see Enclosure 1). The latter consideration may have had some influence as the isopachs of the overlying Wundowie Limestone, (Fig.14), show extension along the fault trace. An additional thin shale bed outcrops near the base of the "Winna Limestone" in the secondary peripheral sink along section 54, (Fig.30), indicating that deeper water conditions persisted there.

17/. The base of the "Patterton Shale" grades into a very calcareous siltstone and silty limestone around the western and southern margins of the diapir. This facies is well developed near Angorichina Hostel where the unit outcrops closest to the diapir. A similar facies outcrops in the westernmost parts of the study area, near section 42 and Yanyanna Hut, where the whole sequence shows signs of shallowing toward the western margin of the basin. The shallowing near the hostel is astride the fault system mentioned in 16/. above, and may be due in part to movement along the fault. The shallowing at the base of the "Patterton Shale" extends across the southern extension of the secondary peripheral sink near Gum Creek H.S. and across to Mount Emily. This is one of the first signs that activity on the Blinman Diapir paused and may have ceased during deposition of the Etina Formation.

Analysis of the current direction data collected along sections 54, 55 and 56, as shown on Fig.30, gives some idea of the timing of development of the secondary peripheral sink. Sediment transport, as shown by synsedimentary slumping, at the base of section 54, is to the south, away from the diapir and along the axis of the sink. Current directions higher in the Tapley Hill Formation, within the Wockerawirra Dolomite, show supply of sediment from the shallow areas east of the Patterton Fault westward into the sink. Currents in the ooid shoals near the base of the Etina Formation are axial to the sink, southwards away from the diapir. Currents at the top of the "Winna Limestone" are to the east, across the sink and showing no indication of its existence. Similar eastward currents are seen at this level on section 55.

The limestones of the overlying Wundowie equivalent all show show currents directed eastward, from 080° to 150°. The outcrops of Wundowie Limestone are probably too far from the Blinman Diapir to show any direct influence but the isopachs covering all the area around the diapir, show no influence (Fig.16).

Fig.30 shows that thickening into the secondary peripheral sink west of the Patterton Fault occurred during deposition of the Tapley Hill Formation but the reverse was true halfway through the "Winna Limestone". The areas that were shallow, with thinned sediments, east of the diapir, became deeper with thicker sedimentation. The same pattern is evident north of the diapir, (see Fig.31). It was about this time that the Enorama Diapir became particularly active, changing from the pillow stage of intrusion to the true diapir stage. South of the Blinman Diapir, the Patterton Fault was pivotal in this change of sedimentation patterns.

Coats, (1964b), mapped in an "axis of upturning" around the entire perimeter of the Blinman Diapir. This is the position where there is a rapid change in the dip of the surrounding sediments towards the vertical. A close look at the sequence where it approaches the contact anywhere around the diapir will show that the dip increases in a series of stages. Each progressive stepwise dip increase is bounded by a bedding parallel unconformity, the natural consequence of viewing the numerous progressive unconformities developed against the diapir in plan.

Although the secondary peripheral sink of the Blinman Diapir developed to the full extent, unlike the Enorama Diapir, very little detritus was derived from this diapir. It appears that the Blinman feature was never fully exposed at the surface during deposition of the surrounding sediments but was always mantled by a veneer of those sediments. The upper surface of a large intrusion would not be a simple smooth dome but might be expected to consist of a number of apophyses as shown by Murray, (1968). One or two of these fingers of breccia may break the surface to supply a small amount of debris while the bulk of the intrusion remains buried.

The southern margin of the Blinman Diapir has been displaced, thrust to the northeast by movement along the major sinistral wrench fault that connects the Wirrealpa Diapir to the Angorigina Diapir then enters the Blinman Diapir at Blinman South. About 600m of horizontal displacement can be seen in the vertical beds near the diapir along the Blinman to Wirrealpa road. This sinistral fault re-emerges from the diapir in its southwest corner. Horizontal displacement of steeply dipping beds near the Angorichina Hostel is in the order of 2,400m. The dextral step in the fault across the diapir means that substantial compression must have occurred with left lateral movement along the fault. Approximately 1800m of this movement was "absorbed" by the diapir, as the southern and southwestern edge was thrust over the breccia. The extension of the Patterton Fault acted as a shear on the eastern side of the thrust sheet.

CHAPTER 7

ORAPARINNA DIAPIR

The Oraparinna Diapir is a large, polygonal breccia body, 6km by 8km in outcrop. Like the Blinman Diapir, it is situated on the axis of the N-S anticline that dominates the Central Flinders Zone and also sits astride an ENE to WSW throughgoing sinistral wrench fault. The Oraparinna and Blinman Diapirs have several features in common apart from their structural setting. They are the two largest diapirs in the study area and were active at about the same time. Both are now seen in plan view as the outcrop in the centre of culminations along the same anticline. Both are surrounded by lower Umberatana Group sediments, dominantly Tapley Hill Formation. The Oraparinna Diapir is linked to the Enorama Diapir by a narrow neck of breccia outcrop, (see Enclosure 2).

There is steep upturning of the suurounding sediments around 80% of the diapir perimeter. Plate 7b of the SE margin of the diapir, is a view looking south with diapir outcrop in the middle of the scene and to the right. The triple peak in the centre is vertically dipping Yudnamutana Subgroup and Wilyerpa Formation with the diapir contact at the base of the right hand side of the hill. Mount Caernarvon is the broad hill to the left of the peak and the dip of the greywacke diminishes further east, up through the Tapley Hill Formation.

Plate 7a is a view south from the Asbestos Mine, along the neck that joins the Oraparinna to the Enorama Diapir. Steeply to vertically dipping Holowilena Ironstone outcrops in the foreground and along the flanks of Lizard Ridge to the left. Limestones of the Etina Formation form the ridge in the right centre of the scene and are pulled up to be steeply dipping against the diapir which outcrops along the line of bushes from the right foreground to the centre of the scene. The Oraparinna Diapir is the subdued outcrop from the centre of the scene to the high blue range in the background, Mt. Caernarvon and The Bunkers.

Dalgarno, in Dalgarno (1983), described a series of conglomerates interbedded with graphitic shales of the Tindelpina Shale Member over an interval of 100m in outcrop 500m east of Linkes Mine. He ascribed the origin of the coarse clasts to reworking from the Sturtian glacials across the Appealinna Fault, activated by repeated uplift of the core of the diapir. The conglomerates could have been shed from over the uplifting diapir/pillow with the fault cutting the outcrop at a later date.

Many of the relationships seen against the Enorama Diapir near the

Asbestos Mine are repeated against the Oraparinna Diapir to the SE near Panta Well. The most noticeable of these is the unconformity at the base of the Tapley Hill Formation.

The Tapley Hill Formation is thick in the vicinity of the Oraparinna Park H.Q. but thins rapidly northward to the contact with the diapir. All sub-units within the formation record this thinning. The Mt. Caernarvon Greywacke thins and becomes vertical against the contact. Two thin bands of Wockerawirra Dolomite pinch out toward the contact. Several beds between the Mt. Caernarvon Greywacke and Wockerawirra Dolomite pinch out and are eroded by an unconformity at the base of the main band of the dolomite north of the park headquarters. Similarly, an unconformity developed in the same part of the sequence where it nears the diapir contact from east of Mt. Caernarvon, northward toward the Barytes Mine.

The Oraparinna Diapir contains some large rafts, particularly of basic volcanics and dolerite. A map included in Johns (1969) shows an outcrop of melaphyre/dolerite 4000m by 3000m. It is uncertain whether this is a single raft as more detailed mapping by McGain and Bettles in the same report suggests that the larger area is an agglomeration of rafts of similar lithology. There is one single raft of heavy mineral banded siltstone and sandstone 2800m long by up to 600m wide.

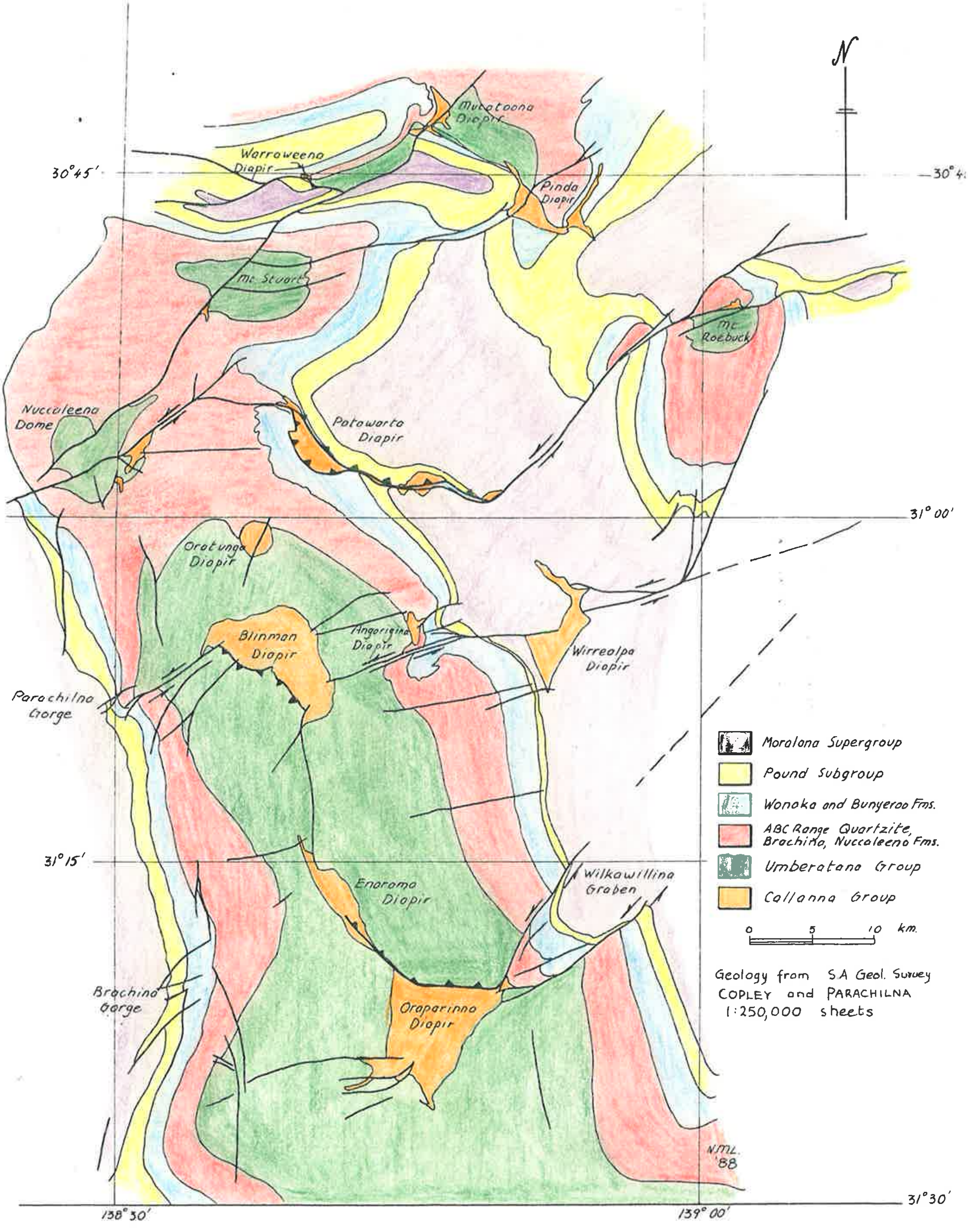
The southwest corner of the diapir shows apparent stoping of blocks of Tapley Hill Formation into the diapiric breccia. Near the margin of the diapir, breccia can be seen injected along a series of faults emanating from the diapir, to almost surround blocks of Tapley Hill Formation. Further into the diapir, similar blocks are completely isolated and surrounded by breccia. Small blocks of hematitic tillite have been stoped into the diapir near section 52, (see Fig.22).

Breccia injection along faults is also seen in the eastern corner of the diapir where the bounding faults of the Wilkawillina Graben coalesce and enter the diapir. The faults in the SW corner are part of the same system, a major throughgoing sinistral wrench.

It has been suggested, (W. Nijman, pers comm., 1986), that the Wilkawillina Graben is a flower structure associated with the wrenching. A simple graben theory does not explain why the beds from the Etina Formation to the Nuccaleena Formation are upturned along the northern margin. The area of the graben, while being a negative feature through much of the lower Cambrian as shown by increased thickness within the Hawker Group, (Dalgarno and Johnson, 1965) was also positive around the Proterozoic to Cambrian boundary. There was non-deposition or erosion of the Rawnsley Quartzite and Parachilna Formation. Such alternations are distinctive features of block movements in wrench regimes.

The fault which forms the northern margin of the graben shows left lateral movement. This explains the apparent upturn of the Umberatana Group sediments against it. Folding of the Cambrian sequence across this fault suggests that at least part of the movement occurred in the Middle Cambrian. The Balcoracana Formation is folded and shows mega slumps, visible on aerial photographs, directed toward the graben axis. The overlying Pantapinna Sandstone is unaffected.

Some of the left lateral movement on the graben-bounding fault was taken up by thrusting developed along the NE margin of the Enorama and Oraparinna Diapirs. These thrusts form the boundary of the diapirs along the narrow neck that joins them and continue eastward to Panta Well. Repetition of the Holowilena Ironstone with the inclusion of slices of diapiric breccia was seen near section 52 and is illustrated in Fig.33. The thrust continues NW of the Asbestos Mine into the Enorama Diapir. Plate 7, looking north, is a view of the thrust with the plane of the fault dipping east. The thrust folds and faults the partially flow disrupted Callanna Group sequence.



Tectonic Setting of some Central Flinders Diapirs

Figure 33.

CHAPTER 8

DIAPIRS NORTH OF BLINMAN

Two small outcrops of breccia are shown as diapirs within 10 km north of Blinman on the Parachilna and Blinman geological maps, (Dalgarno et al., 1964 and Dalgarno and Johnson, 1966). One of these outcrops, the Oratunga Diapir, definitely is a diapir and the other, the Glasses Gorge Breccia, definitely is not.

Oratunga Diapir

This almost circular diapir was fully described in an AAPG Bulletin paper, (Lemon, 1985). A reprint is included in this thesis as Appendix II. The main features of the diapir are evident in the map of the area and the palinspastic reconstruction extracted from that paper.

Fig. 34 is a map if the area showing the diapir outcropping within a sequence ranging from Etina Formation to Brachina Formation which generally dips gently to the NNE. A curved secondary peripheral sink wraps around the western and northern margins of the diapir, showing the development of the sink to have reached a peak in the Moolooloo Member of the lower Brachina Formation. Upturn, onlap and progressive unconformities mark the eastern boundary of the diapir. All these features were modelled in a sand box experiment where one side of the initial pillow and diapir was fault bounded.

An interesting feature of the map concerns the disposition of Tertiary or Quaternary gravels. These only outcrop along Willigon and Witches Creeks, upstream from the diapir. It appears that the diapir was a high in recent times, acting to dam back these creeks and deposit the gravels. The present day outcrop of the diapir is one of subdued relief, surrounded by the higher, more resistant, country rocks. The only way for the diapiric breccia to be a positive feature would be for it to be reactivated and pushed up to form an effective, albeit temporary, dam. While the evidence for such late movement of a diapir in this case is somewhat tentative, post-Delamerian diapirism at Leigh Creek is proven in the chapter on the "Telford Diapir".

Fig. 35 is a successive palinspastic reconstruction of the diapir. The sediments surrounding the feature show no inclusions of detritus derived from the diapir. The pillow and diapir remained buried throughout the depositional history of the surrounding sediments. In this way, the Oratunga Diapir has a similar history to the Blinman Diapir. Fault movement in the basement is thought to have initiated the Oratunga pillow then diapir.

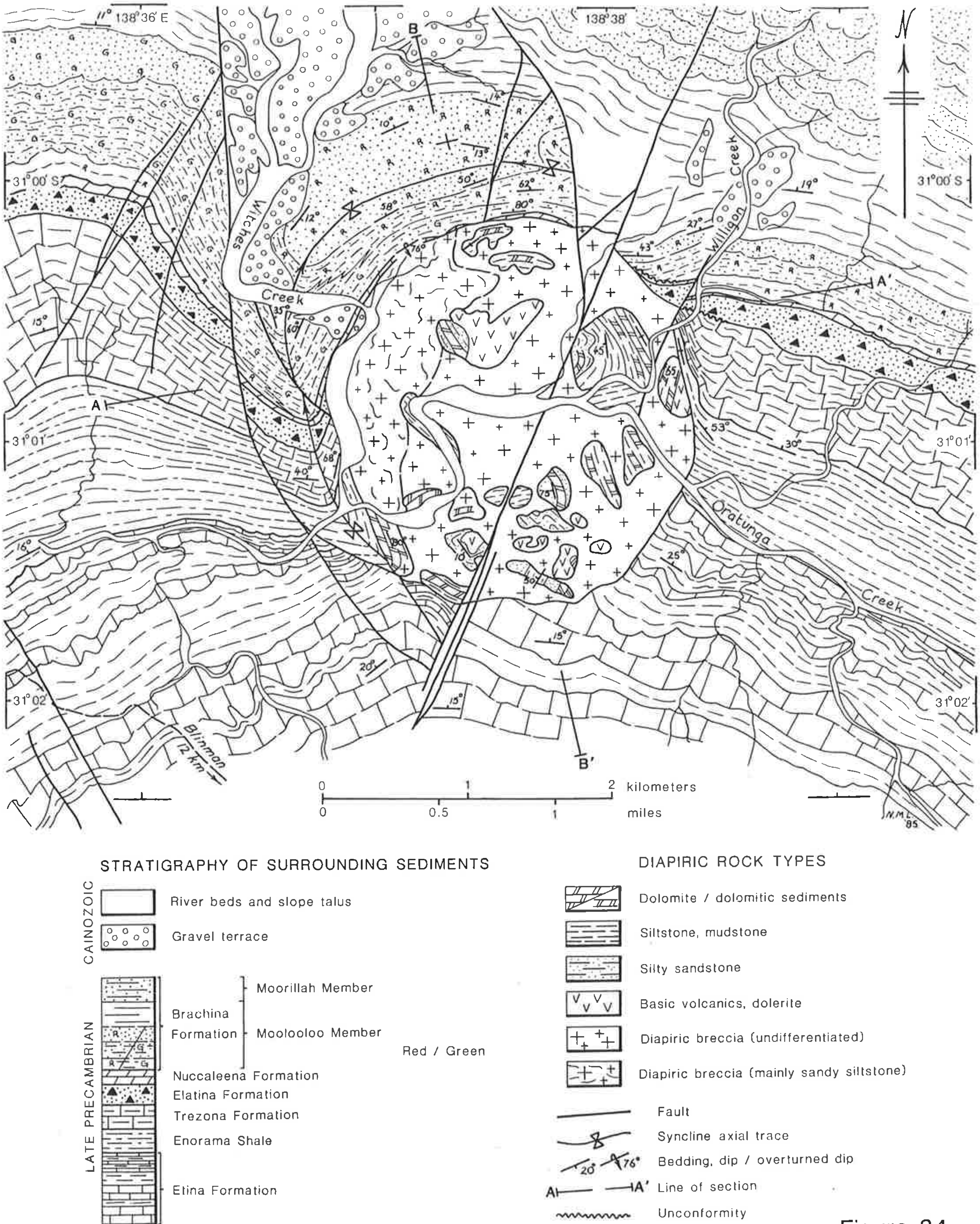


Figure 34

GEOLOGICAL MAP - ORATUNGA DIAPIR

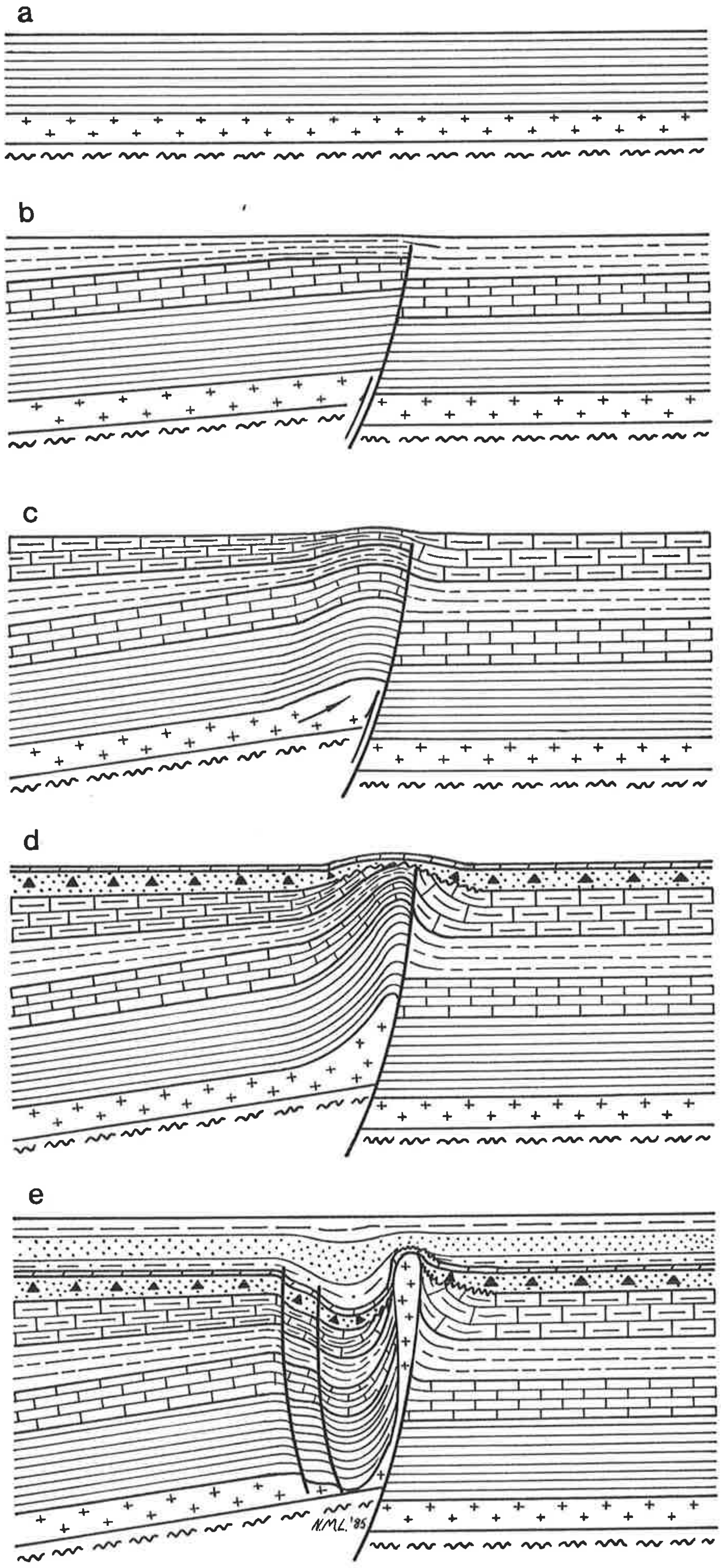


Figure 35

see Fig.34 for legend

PALINSPASTIC RECONSTRUCTION of the DEVELOPMENT of the ORATUNGA DIAPIR

Glasses Gorge Breccia

A small body of breccia at the northern end of Glasses Gorge, halfway between the Blinman and Oratunga Diapirs, was mapped as a diapiric breccia by Dalgarno et al., (1964), (see Enclosure 1). Field mapping could find no evidence for this interpretation. The outcrop in question sits atop gently dipping limestones and calcareous shales of the Etina Formation. All of the outcrop is quite siliceous, resulting in stark relief. Clasts in the breccia show concentric bleaching, parallel to the clast boundaries, associated with silicification. Intense silicification also permeates the Etina Formation shales. Silcrete, probably of Tertiary age, caps the lower western and northwestern flanks of the hill.

The breccia outcrops across a fault zone which trends NNE and passes through the Oratunga Diapir. The original brecciation may have been associated with this fault or it may have been a collapse breccia associated with karst development in the Etina limestones. The silicification leading to preservation of this breccia is most probably related to a silcrete profile which is sporadically preserved as 10-20 square metre outcrops elsewhere in the study area, usually over sandy limestones.

CHAPTER 9

WIRREALPA AND ANGORIGINA DIAPIRS

The Wirrealpa and Angorigina Diapirs both lie along the Eregunda Fault, a major ENE trending sinistral wrench that links the two diapirs,

which may have played some part in the initiation of movement of the diapirs and probably controlled the timing of that movement (see Fig.33). As suggested by Dishroon et al., (1983), diapiric movement can be triggered by wrenching. These two diapirs moved in the Early Cambrian, as evidenced by thickening of sediments near them. The same fault system continues to the west where it intersects the Blinman Diapir causing thrusting along the margins by stepping sideways through the diapir, (see Chapter 6).

Angorigina Diapir

This diapir is a largely fault bounded breccia body, (see Enclosure 1). A nearby graben filled with Early Cambrian sediments suggests that movement occurred then. There is no influence on nearby outcrops of late Proterozoic ABC Range Quartzite, Bunyeroo Formation or Wonoka Formation, save for some upturning against the diapir and this is restricted to the eastern margin. The present outcrop of the breccia is in contact with even earlier rocks, the Trezona, Elatina, Nuccaleena and Brachina Formations. Because the diapir did not move until the Cambrian, the present outcrop is not so much that of a diapir but rather the feeder neck or throat to the diapir. The fault bounded contacts give some idea of how the intrusion pushed its way through the more lithified strata deeper in the sedimentary pile.

There is an asymmetric syncline about 5 km across located south of the diapir, (see Enclosure 1). The rocks forming the syncline, the Brachina Formation, ABC Range Quartzite, Bunyeroo and Wonoka Formations, show no synsedimentary influence of the proximity of the diapir. The folding is much later than the deposition of these units. The syncline is elongate in a NE-SW direction which is contrary to all other trends in the area.

The Central Flinders Zone was largely protected from intense deformation during the Delamerian Orogeny, (Preiss, 1987). The first generation Delamerian folds are broad N-S features, produced in response to largely E-W compression. The broad anticline along which the Upalinna, Oraparinna, Enorama and Blinman Diapirs outcrop is a typical example. The second generation Delamerian folding in the Central and Northern Flinders, was a result of mainly N-S compression. Again, the Central Flinders Zone was only weakly folded, producing large scale plunge reversals of the earlier folds. Tight E-W folds of this event are produced in the Northern Flinders Zone, north of the Beltana-Warraweena-Pinda line, (see Figs.5 and 33). Left lateral movement along the Eregunda Fault would be expected to produce an en echelon series of doubly plunging folds with a NW - SE orientation as is the case with the Wirrealpa Diapir, (W. Nijman, pers comm., 1985).

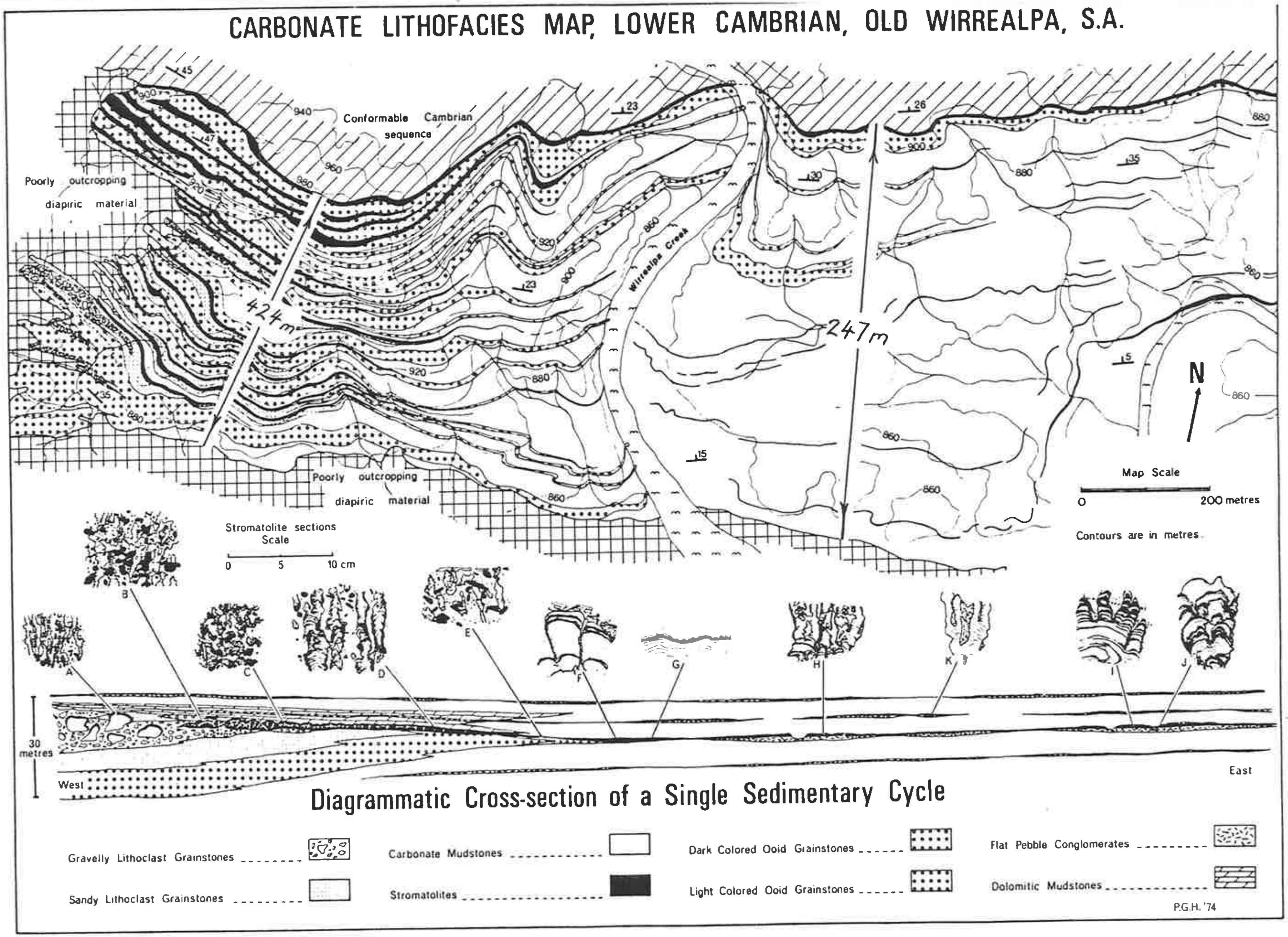
The syncline between the Angorigina Diapir and Carey Hill is locally developed with no extension beyond the immediate area and with no repetition in the Central Flinders Zone. It is the representation of a secondary peripheral sink at depth, ie., below the level of active sedimentation.

A marked graben developed east of the Angorigina Diapir and north of the main Eregunda Fault system, (see Enclosure 1). Thickening of the Woodendinna Dolomite into the graben shows that it developed during the lower Cambrian. The thickening is not as marked as shown on the map as the dips flatten in the area around Erina Water, (Love, 1984). The graben may be the NE part of the Angorigina - Carey Hill syncline through which faults developed as movement on the Eregunda Fault continued.

The graben may well have simply developed in response to transtensional movement along the Eregunda Fault but this would not explain the incipient folding as shown by the dip flattening in the centre of the graben. It appears that the graben is at least in part associated with the secondary peripheral sink of the Angorigina Diapir.

Wirrealpa Diapir

The Wirrealpa Diapir, outcropping east of the Angorigina Diapir, bears some similarity to the Oraparinna-Enorama structure in that it consists of a large, equidimensional, polygonal southern block with an elongate NW extension. Rapid facies changes across the the Wirrealpa Diapir, (Dalgarno, 1986), together with the inclusion of a considerable amount of diapir derived detritus in the surrounding sediments, show that the diapir was active during the Early Cambrian. As only Cambrian sediments outcrop near this diapir, it is difficult to show when the intrusion was initiated and for how long it was active. Sediments around the diapir were mapped in detail by Haslett, (1975). He ascribed different origins to different parts of the breccia. Haslett recognized the gradational nature of the sediments against the NE side of the NW extension of the diapir. Relatively deep water, well sorted, carbonate-rich, fine grained sediments pass laterally into "ill sorted, non-carbonate megabreccia" against the "Callanna outcrop".



Modified from Haslett, 1975

Thickness variation in Cambrian sequence, adjacent to Wirrealpa Diapir Figure 37

It was hard to distinguish between the Callanna breccia and the Cambrian talus derived from the breccia but Haslett shifted the boundary shown on the Blinman 1:63,360 map, (Dalgarno et al., 1964) further west. Numerous cycles were mapped through this sequence, each representing an influx of clastic material displacing the carbonate facies out into the basin. This can be explained by pulses of diapiric activity, as is the case against the Enorama Diapir, (Chapter 5, 16/., 17/., 18/. and 20/.). Haslett used fossil criteria to show that, while deeper water sediments were being deposited to the NE of the NW extension, shallow water carbonates and archeocyathid reefal limestones were being deposited to the SW of the breccia finger and to the east of the main body of the diapir. These also had Callanna detritus included within them.

The Eregunda Fault separates the main body of the diapir from the NW extension and there is evidence that this fault also separated shallow water sediments in the south from deeper water sediments to the north throughout the lower Cambrian. Reef limestones persisted east of the main block of the diapir and south of the fault while a thicker sequence of deeper water turbidites, fore reef talus breccias and slope facies limestones, the Parara Limestone, was deposited north of the fault, (Roche, in Dalgarno, 1986).

Detailed mapping within the southern or main part of the Wirrealpa Diapir was undertaken by W. Nijman. He followed Haslett's suggestion that much of the Callanna Group within this block is in sequence and both the stratigraphy and structure can be reliably mapped. This mapping showed a pre diapir repetition of Callanna stratigraphy across several recumbent folds, stacked by westward directed low angle thrusting. Nijman, (pers comm., 1985), suggested that later left lateral movement along the Eregunda Fault and its extensions was responsible for further compression within the Callanna sequence. The same sinistral movement raised Callanna sediments in the core of a growing anticline, the NW extension of the Wirrealpa "Diapir", to shed detritus into the basin adjacent.

Sections produced by Preiss (1985), across the Worumba Anticline, show much of the Callanna sequence to be intact but tightly folded. Parts of the sequence have been completely remobilized and diapirically intruded. There is some incipient thrusting, in this case eastward-directed. The Wirrealpa structure could well be similar to that of Worumba with thrust induced repetition of the sequence.

The mechanism explained and illustrated by Haslett (in Dalgarno, 1983), reproduced here as Fig.36, both imply thinning of sediments onto the NW or Donkey Bore extension of the diapir. The reverse is true. Applying a simple trigonometric construction to the carbonate lithofacies map of Haslett, (1975), (reproduced here as Fig.37), shows 424m of sediment deposited about 300m east from the diapir contact compared with 247m deposited within the same marker horizons, 1000m further east. This geometry is similar to that displayed within the Etina Formation and Enorama Shale adjacent to the Enorama Diapir, (see Chapter 5), and is that modelled around syn-sedimentary diapirs.

The timing of some of the features mapped by Nijman may postdate the lower Cambrian deposition of the units containing the Callanna detritus. Incipient wrenching may have initiated diapirism with continuing movement buckling and thrusting the Cambrian and Callanna sequences respectively at a later date. Relationships around the Wilkawillina Graben to the south show that a major part of the sinistral movement along the bounding faults occurred during the Middle Cambrian (see Chapter 7).

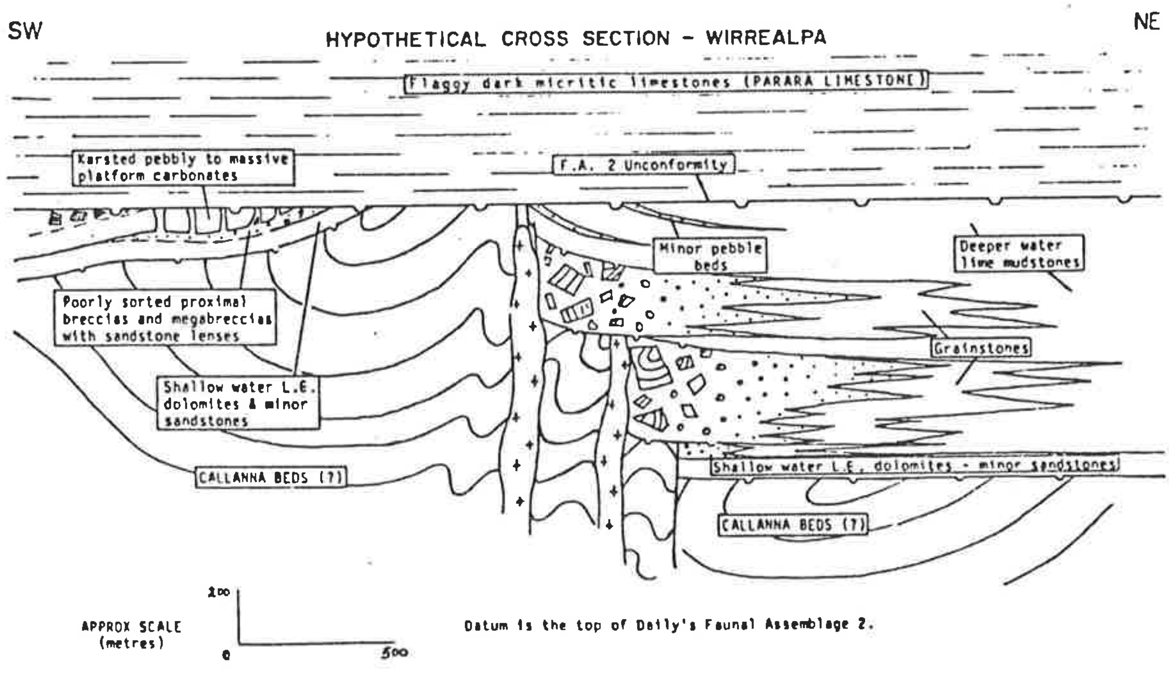


Figure 36. Hypothetical cross section of the Wirrealpa Diapir. (Diagram taken from Haslett, 1983).

CHAPTER 10

DIAPIRS ALONG THE NARINNA FAULT AND EXTENSIONS

A number of generally small breccia bodies outcrop along the line of the Narinna Fault from Mt. Roebuck, past Patawarta Hill, to the Nuccaleena Mine area, (see Fig.33). Sinistral wrenching along this fault is indicated by the displacement of structural and stratigraphic features. Differing amounts of displacement on various features suggest that the fault continued to move over a long period of time and also establishes a relative time frame for the development of those features.

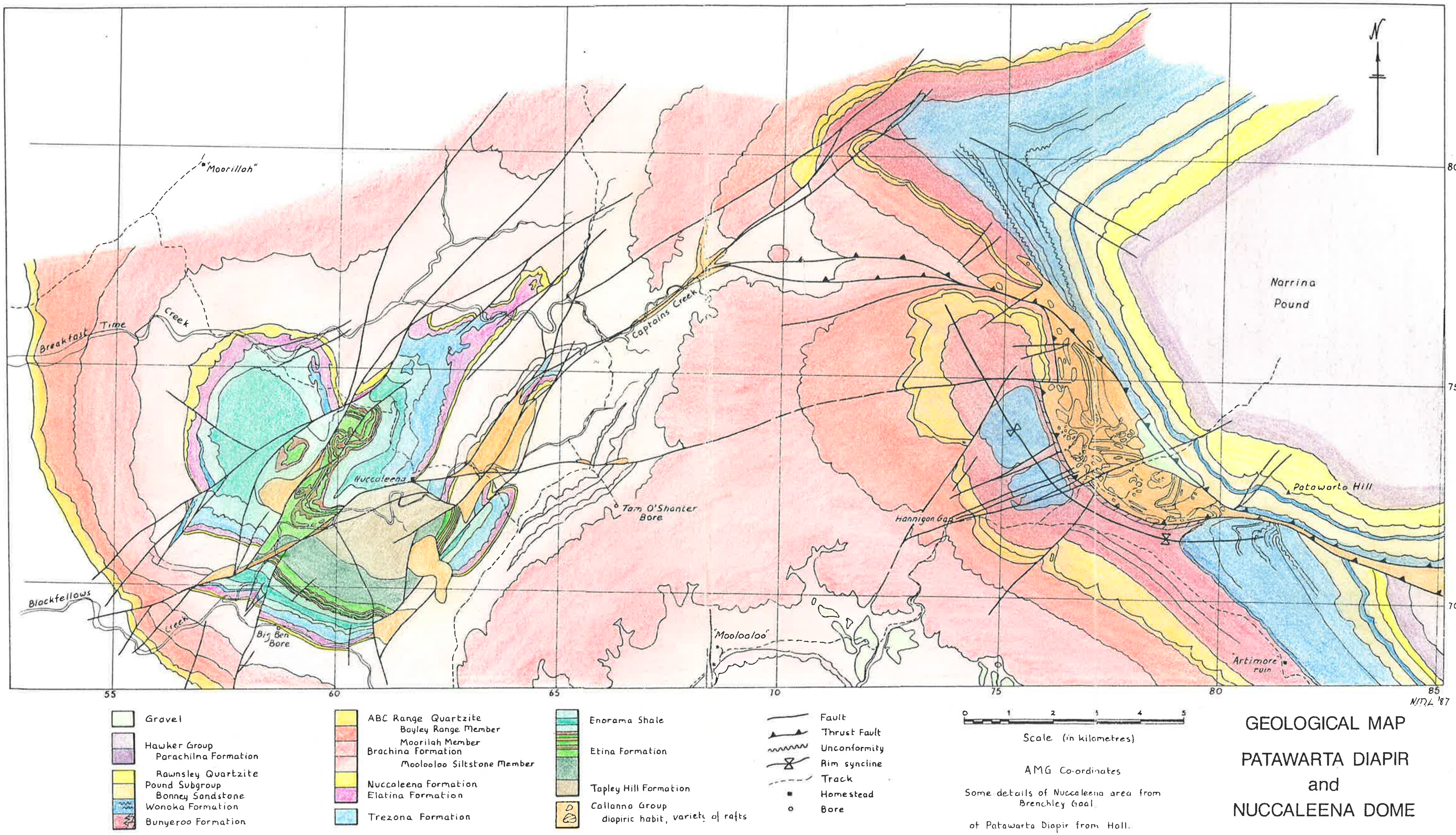
About 4,800m of movement is indicated by the displacement of the Mt. Roebuck Dome, 3,000m by the displacement of the Precambrian-Cambrian contact and 2000m by displacement of the first stage Delamerian axis of the Narinna Syncline. This suggests that doming around Mt. Roebuck occurred early in the basin history, possibly related to an underlying pillow or diapiric intrusion. Evidence for a similar origin to the Nuccaleena Dome is presented below.

Patawarta Diapir

This diapir is a crescent shaped outcrop of breccia, situated 14 km north of Blinman, adjacent to the prominent Patawarta Hill. This "slice" of diapir is sandwiched between two thrust faults which are part of the extended Narinna Fault system. Details of the geology around the diapir are shown in Fig.38. A narrow neck of diapiric breccia joins this diapir to two smaller breccia bodies around Ann Hill and Point Well H.S.. Detailed mapping has been done in the area by Hall (1984) and Townsend (1983) to elucidate the nature of copper and barite mineralization, respectively, within the diapiric breccia and its rafts. The detail of inclusions shown in Fig.38 is from Hall et al., (1986).

A secondary peripheral sink developed around the southern and southwestern margins of the diapir. The gentle regional dips of the Wilpena and Hawker Groups to the NE are interrupted around the diapir, as shown in the cross section, Fig.39. The Bunyeroo and Wonoka Formations sit vertically against the diapir contact. Steep ridges of ABC Range Quartzite outline a pound around the secondary peripheral sink. Flat bedded mesas of Wonoka Formation outcrop in the centre of the rim syncline between Hannigan Gap and the diapir.

Hall (1984) mapped a thick conglomeratic dolomite lying vertically along the SW margin of the diapir and showed it to be a facies of the



GEOLOGICAL MAP
PATAWARTA DIAPIR
and
NUCCALEENA DOME

Figure 38.

Bunyeroo Formation. The clasts within the conglomerate were all derived from the diapir, showing its exposure at the time. The conglomerate is cemented by yellow dolomicrite, similar to conglomeratic dolomites developed in other shale units adjacent to the Enorama Diapir. These shales include the Enorama Shale (Chapter 5, 20/., 24/. and 26/.), the "Patterton Shale" (15/.) and the "I-A Shale", (18/.).

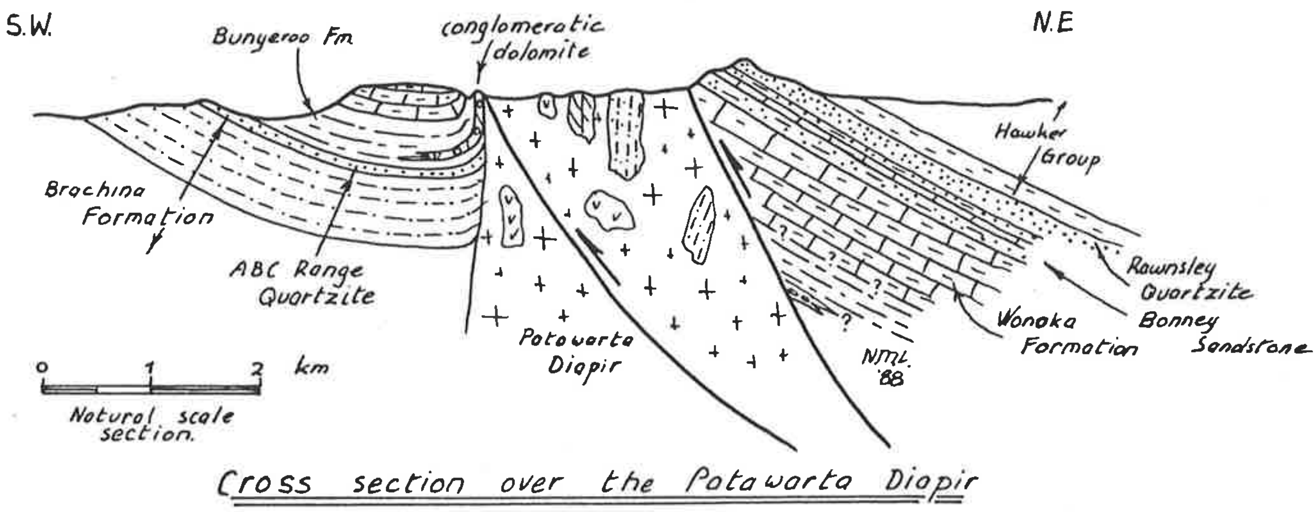


Figure 39.

The conglomeratic dolomite is diachronous within the stratigraphy and is present from at least the middle of the Bunyeroo Formation between the mesas mentioned above and the top of the Bunyeroo Formation in contact with Wonoka Formation 4 km to the east. Such a local development of this facies adjacent to a diapir is more clearly seen in the Enorama Shale next to the Enorama Diapir, (Fig.27), and also occurs within the Bunyeroo Formation in contact with the Beltana Diapir, (Fig.40, Chapter 11 and McPherson, 1984).

Diapiric activity continued on into the Wonoka Formation. Upturning, with subsequent development of local unconformities and onlap by higher stratigraphic units, is evident at several levels within the Wonoka Formation at both the NW and SE ends of the present diapir outcrop. Coats (1973) records diapiric detritus included in this formation along the NE contact of the diapir and to the NW of it. The diapir was still exposed toward the top of the Wonoka Formation.

The commencement of pillow or diapir movement is difficult to determine in the thick sequences of the Brachina Formation. There is some suggestion of thinning in the ABC Range Quartzite at the NW end of the diapir. Diapiric movement apparently ceased during deposition of the Bonney

Sandstone. Sub-units of this formation are traceable on aerial photographs past the diapir without any appreciable change in thickness or observable change in facies. This then suggests that the emplacement of the breccia extended from the time of deposition of the ABC Range Quartzite through to the base of the Bonney Sandstone.

The size of the secondary peripheral sink and the extent of influence in the Wonoka Formation suggest that the diapir was much larger than the present outcrop. The Narinna Fault has a right handed or dextral step through the Patawarta Diapir as shown on the tectonic sketch on the Copley 1:250,000 map, (Coats, 1973). This geometry is shown in detail on Fig.38 and in summary on Fig.33. In the same way as a thrust sheet has partially roofed over the Blinman Diapir by wrench movement against a step in the fault, the Patawarta Diapir is now nearly completely roofed over, leaving just a crescent of what may have formerly been a near circular diapir, (see Fig.38).

Nearly all of the movement along the Narinna Fault was absorbed by squeezing the Patawarta Diapir and roofing it over. Although the fault system emerges from the NW end of the diapir, there is very little displacement along it in this area. Additional left lateral movement is indicated along the Captains Creek Fault where it intersects the syncline of Wonoka and Bunyeroo Formations west of Narinna Pound.

Nuccaleena Dome

The Nuccaleena Diapir is but one of a number of small breccia bodies associated with the Nuccaleena Dome, a culmination of Umberatana and Wilpena Group sediments outcropping 25 km NW of Blinman. These breccia bodies fall into two classes; those with discordant contacts with the surrounding sediments and those clearly injected along fault zones. Fig.38 shows the geology of the dome and its relationship to the Patawarta Diapir. The tectonic setting map, Fig.33, shows that the Nuccaleena area is cut by both the NE trending Mt. Stuart Fault and the extension of the Narinna Fault where it emerges from the Patawarta Diapir and joins the Captains Creek Fault.

Detailed section measurement in the area was done by Brenchley-Gaal (1985) to determine the timing of movement on the numerous faults and to build up a tectonic history of the area. He concluded that certain faults were active during the time of deposition of the Etina Formation and Enorama Shale with renewed activity between the deposition of the Trezona and Elatina Formations. He also ascribed the formation of the dome to an interference fold between the two stages of the Delamerian Orogeny which was later cut by late to post Delamerian faulting, often reactivating earlier faults.

Sections measured through the middle Umberatana Group show considerable thickening of the Etina Formation and Enorama Shale in the fault block north of Big Ben Bore, compared with the next fault block east, between the elongate Nuccaleena Diapir and the much smaller Nuccaleena South Diapir. While the thickness of the overlying Trezona Formation varies dramatically between the various fault blocks, this is mainly due to erosion on the unconformity between the Trezona and Elatina Formations. Thicknesses of inter-Trezona facies in the bottom half of the formation are very consistent between the blocks. Erosion has removed the Trezona altogether on the westernmost blocks, placing Elatina Formation in contact with the Enorama Shale. The preserved thicknesses of Trezona Formation generally increase to the east but in an up-down stepwise manner. Thicker intervals are preserved across the top of the dome than on the flanks.

It would appear that the entire Nuccaleena Dome is underlain by a large pillow structure. Inflation of the pillow has led to the formation of a crestal graben, (Currie, 1956), allowing thickening of the Etina Formation and Enorama Shale across the top of the dome while thinning the section on the flanks. The same situation is evident over the Blinman Diapir during deposition of the Tapley Hill Formation, (see Chapter 6). Upward movement of the dome halted during deposition of the Trezona Formation before reactivating during the hiatus between the Trezona and Elatina Formations. The crestal graben continued to form during this period, allowing greater preservation of the Trezona Formation in some of the central fault blocks compared to the flanking blocks.

The Nuccaleena and Nuccaleena South Diapirs pierce the Umberatana Group sediments and are apophyses from the pillow, rising to interact with sediments higher in the stratigraphy. The present outcrops of these breccias are therefore the feeder necks to those diapirs rather than the diapirs themselves. The discordant contacts with the surrounding sediments support this theory.

The presence of a buried pillow or diapir beneath the dome can be inferred from the way so many of the more regional faults are directed toward the dome. The same "strain sink" phenemenon can be seen around many of the diapirs in the Flinders Ranges. This thesis shows that the Enorama, Oraparinna, Blinman, Patawarta, Wirrealpa, Beltana, Warraweena, Mucatoona Hill and Pinda Diapirs also acted as "strain sinks", focussing faults and absorbing much of the movement along them.

Much of the movement along the Narinna Fault has been absorbed by the Patawarta Diapir but it does emerge from the western end of that diapir to join the Captains Creek Fault and intersect the Nuccaleena Dome. Compression associated with left lateral movement has reactivated diapiric breccias in the vicinity of the dome to inject it along any zone of weakness in the area, particularly along the faults active at the time, (see Fig.38). Linear breccia outcrops are evident along the Captains Creek Fault and its extensions to the SW of the dome. Small patches of breccia are also evident along the fault joining the Nuccaleena Diapir directly to the Patawarta Diapir, just north of Tam O'Shanter Bore. The injection of breccia along many of the faults crossing the dome also infers a large source such as a pillow or diapir beneath the dome.

Brenchley-Gaal (1985) and others, eg. Preiss (1987), have suggested that the Nuccaleena Dome is a culmination caused by interference folding bewteen the two stages of the Delamerian Orogeny. The second stage Delamerian event does not have a great influence on the Central Flinders Zone, (see Chapter 3), but does penetrate south from the North Flinders - Central Flinders Zone boundary. The synclinal bulge on the western corner of Narinna Pound, (Figs.33 and 38), is the result of second stage Delamerian folding. The Nuccaleena Dome, however, displays the wrong orientation to have been caused solely by the interaction of Delamerian events. Its NE-SW elongation is at odds with the D1 event, which has a NNW orientation in the area, (see Fig.33), and the E-W D2 event. It is most likely that the doming is in large part due to an underlying pillow or diapiric intrusion. This may have then provided a site for a later interference culmination.

CHAPTER 11

THE BELTANA - PINDA LINE

The geological character of the Adelaide Geosyncline, both structural and sedimentological, changes dramatically across a line drawn east from the Beltana Diapir, through the Warraweena, Mucatoona Hill (new name) and Pinda Diapirs to Mt. Roebuck, (see Fig.33). This is also the boundary between the Central and Northern Flinders Zones of Rutland et al., (1981) (see Fig.5). The fold style south of the line is dominated by broad N-S folds of the first generation Delamerian event, (Preiss, 1987). Much tighter folds with an E-W orientation of the second event are evident north of this line. A series of very tight synclines have been thrust into juxtaposition against the Central Flinders Block along this line, (Scotford, 1984). The tight second generation fold style is only partially transmitted across the boundary. The ellipsoidal outcrop of the Umberatana Group in the Mt. Stuart Anticline, (Fig.33), is a transitional structure between the Northern Zone and the open N-S folds of the Central Zone. This progressive change can also be seen by considering the outcrop shape of the combined Bunyeroo and Wonoka Formations on the same figure.

The facies interpretation placed on the interglacial sequence by Preiss (1987) and the author in Chapter 3, suggests that the boundary zone was a hinge line during Umberatana Group sedimentation. Deeper water Amberoona Formation shales outcrop to the north while shallow water Angepena Formation and equivalent Etina Formation siltstone, limestone and dolomite are more prevalent to the south. Haines (1987) and Scotford (1984) both showed the zone to be a hinge line in terms of thickening and depth of water during the sedimentation of other formations. Sections measured by Scotford show marked thickening of the Brachina Formation across this hinge. Coats (1973) and Preiss (1987) suggest this zone is the facies interface between the Brachina Formation and the deeper water Ulupa Siltstone to the north. Detailed sedimentology of the Wonoka Formation by Haines (1987) shows a marked thickening to the north from a dominantly carbonate shelf facies to a dominantly clastic deeper water facies. The regressive Wonoka Formation progrades across the hinge.

The zone was tectonically active during deposition of Units 2 and 3 of the Wonoka Formation, (Haines 1987). Downfaulting to the north steepened the local sea floor gradients causing slumping and debris flows. Diapiric activity became evident during the deposition of Units 8 - 11, (Haines, 1987). A hinge line such as this is a common site for diapirism as shown by Emery, (1980) and Cashman and Popenoe, (1985). Sediment loading across the hinge pushes a potentially mobile layer at depth back up the slope to the fault controlled hinge where pillows form against the hinge to ultimately rise as diapirs. It appears that diapirs were active along the Beltana - Pinda line from at least the time of deposition of the Tapley Hill Formation through to the Early Cambrian.

The Beltana Diapir

The Beltana Diapir, (Fig.40), is one of the larger diapirs in the Flinders Ranges, outcropping near the western margin, just south of Leigh Creek. The present outcrop is a rather irregular shape, elongate over nearly 20 km in a N-S direction and up to 5 km wide. The surrounding sediments show near conformable contacts along the entire 20 km western margin. The eastern margin shows tectonic contacts, especially in the NE segment.

The basal Wilpena Group Nuccaleena Formation, is the oldest unit outcropping in the vicinity of the diapir. The extent of this unit is very restricted and does not show any diapir influence during sedimentation. The overlying Brachina Formation is well developed but restricted to a "trough" on the western side of the diapir between the northern and southern "bulges" of the diapir. The map of the area, Fig.40, shows this trough just east of Mt. Bayley. The dip in this area is regular and to the west so that plan view is in effect a slightly exaggerated palinspastic cross section. The Brachina Formation thickens into the centre of the trough with detritus shed from both the northern and southern parts of the diapir. Conglomerates developed within the Moorillah Member, especially where it is in contact with the diapir. McPherson (1984) also found evidence of thinning and shallowing within the ABC Range Quartzite at either end of Mt. Bayley Range, near the northern and southern lobes of the diapir. Detritus shed into the Brachina Formation occurs at different levels next to each lobe and it may be that the Beltana Diapir was two separate structures early in its history.

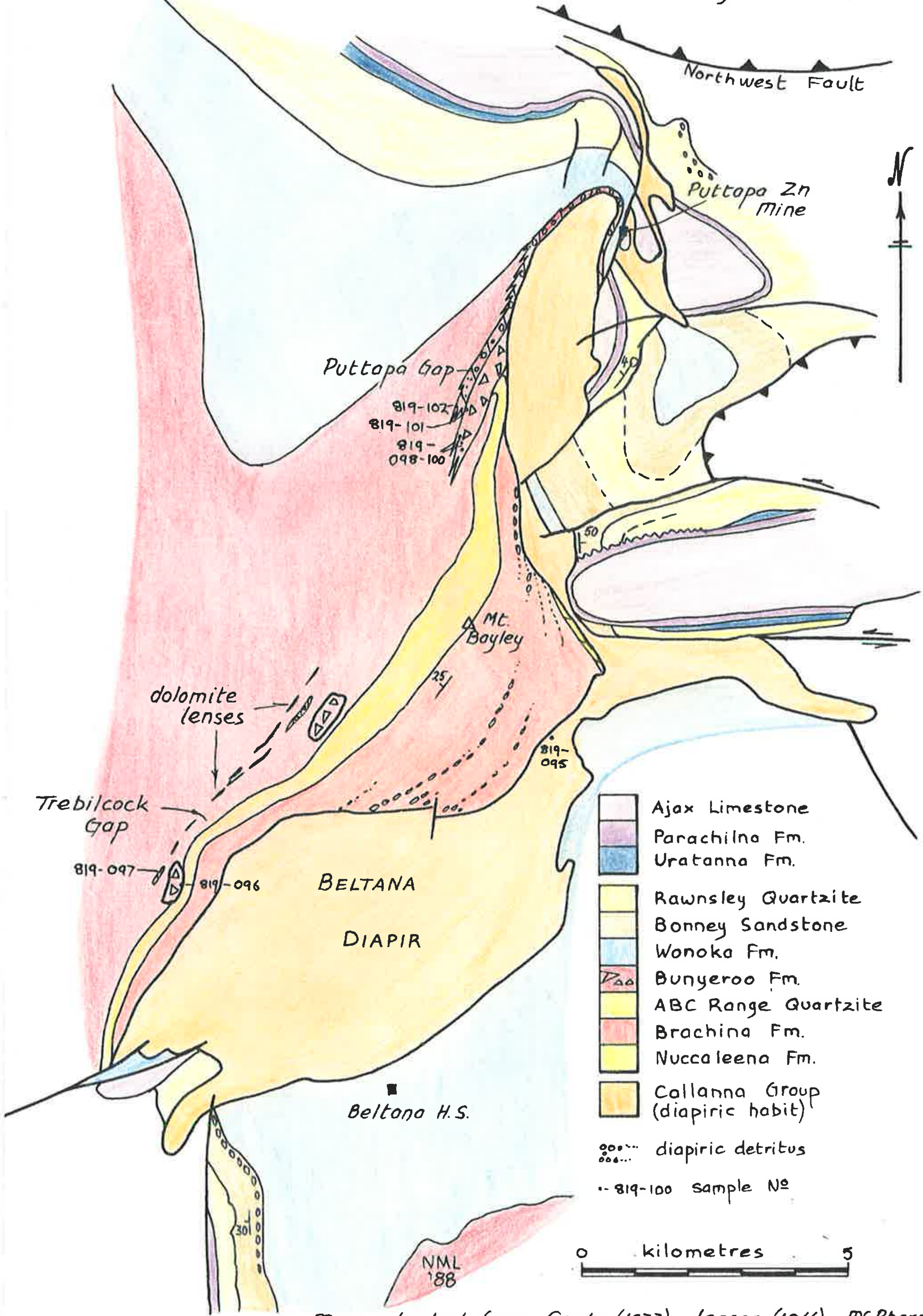
Three major lenses of Callanna Group breccias outcrop within the Bunyeroo Formation, just above the contact with the underlying ABC Range Quartzite. The largest lens outcrops near Puttapa Gap with two smaller lenses north and south of Trebilcock Gap. All the lenses are adjacent to the main lobes of the diapir. McPherson (1984) outlined three hypotheses as to the origin of the lenses:-

1/. Diapirically intruded, as shown by Coats (1973) and Leeson (1966).

2/. block faults

3/. intra-Bunyeroo Formation gravity driven mass transport deposits.

Figure 40.



Map adapted from Coats (1973), Leeson (1966), McPherson (1984).

BELTANA DIAPIR

Although he eventually decided on block fault emplacement, more recent mapping by Abbott (1986) has found good evidence for large scale slumping into the Bunyeroo Formation from the flanks of the diapir. Further evidence found by the author also supports that theory.

The northern lens at Puttapa Gap grades from a massive breccia, indistinguishable from the diapir, north of the road, to conglomerates, fining to the south, south of the road. These conglomerates are clearly interbedded with the Bunyeroo Formation. The ABC Range Quartzite was overturned by drag as the massive slump moved into the basin. The northern lens now outcrops as a near longitudinal section through the slump.

The two southern outcrops are transverse sections through separate slumps. Scouring at the base of the southernmost lens has eroded down into the ABC Range Quartzite. Sample 819-096 shows the quartzite brecciated while only partly lithified. The subrounded clasts are virtually indistinguishable from the sandy matrix. The lens north of Trebilcock Gap lies entirely within the Bunyeroo Formation but like the southern lens, shows very disturbed bedding within the surrounding Bunyeroo Formation.

Dolomicrites are particularly common within the Bunyeroo Formation in the vicinity of the diapir. Around Trebilcock Gap there are many lenses from 2 to 60m long and up to 2m thick. Lenses composed purely of dolomicrite are interbedded with the shales with planar tops and bases. Some dolomicrites are conglomeratic with obvious scoured bases. Sample 819-097 shows the conglomerates to be diapir-derived. The dolomicrite was derived from the vicinity of the diapir and pulses of movement of the diapir swept detritus, together with a dolomicrite slurry, into the adjacent shale depositing basin. The same mechanism occurred in the shales around the Enorama Diapir, (Chapter 5, 15/., 18/., 20/. and 26/.).

At Puttapa Gap, a very thick lens of dolomite thins southward away from the diapir contact. There is also a facies change within this unit, from conglomeratic near the contact to clean dolomicrite south of the old road and railway line.

North of Puttapa Gap, the Bunyeroo Formation progressively onlaps the northern lobe of the diapir, northward to the EZ Zinc Mine. A conglomeratic dolomite facies is locally developed on the contact which is clearly diachronous, maintaining its geographic position with respect to the diapir right through the upper half of the Bunyeroo Formation and perhaps into the overlying Wonoka Formation. The conglomerate clasts are all of diapiric origin. This is a repeat of the situation against the Patawarta

Diapir, where the Bunyeroo Formation is again involved, and near the Enorama Diapir, where dolomite is equivalent to the Wundowie Limestone and Enorama Shale.

Coats (1973) shows inclusion of diapiric detritus in sediments adjacent to the diapir continued through the Wonoka Formation and up into the Pound Subgroup. South of Beltana H.S., Leeson (1966) shows detritus in the Bonney Sandstone. Movement of the diapir continued after the Precambrian - Cambrian boundary. Photo-interpretation shows upturning of Bonney Sandstone and Rawnsley Quartzite along the eastern side of the diapir, east of Mt. Bayley. The overlying Parachilna Formation is in paraconformable contact away from the diapir but distinct angular contact next to the diapir. The intervening Cambrian Uratanna Formation was only deposited and/or preserved away from the diapir.

Preiss (1985) refers to Cambrian archeocyathid limestone occurring as xenoclasts within the Beltana Diapir, thereby proving post Early Cambrian movement. The area NE of the Beltana Diapir has been complicated by late or post Delamerian thrusting. Several dish-shaped areas of upper Wilpena Group and lower Cambrian sediments have been stacked one over the other by thrusting from the east and northeast. These thrust sheets have overridden the diapir from the Zinc Mine south to a point east of Mt. Bayley. The xenoclasts in the mine area may be parts of a thrust slice pushed over the diapir which became remobilized by the new loading to inject around the allochthonous slabs.

The "Warraweena Diapir"

This rather small diapir, which outcrops about 2 km NE of Warraweena H.S., was described by both Scotford (1984) and Haines (1987) and given the name by Haines. The present outcrop is less than 1 km across and is flanked by synsedimentary contacts with the Wonoka Formation to the north and east and by fault contacts with the Pound Subgroup to the south.

Haines (op cit.) describes evidence of exposure and erosion of the diapir with the inclusion of detritus in lenses of carbonate in Units 8 to 11 of the Wonoka Formation adjacent to the diapir. There is local stromatolite development around the diapir and several locally developed channels of conglomerate leading away from the structure. Units 9 to 11 are all dolomitized in the vicinity of the diapir. According to Haines, the Warraweena Diapir and others along the same trend, were islands during the deposition of Units 9 to 11 and these, together with the raised sea floor in the area, provided an effective barrier system between a shallow carbonate shelf to the south and deeper water, more clastically dominated, open marine sedimentation to the north.

Scotford (op cit.) inferred activity on the Warraweena Diapir from a locally developed unconformity between the Sturtian tillite and the Tapley Hill Formation and another between the Balcanoona and Elatina Formations. However, the latter is very widespread and not neccessarily related to diapirism. The Brachina Formation thickens markedly across the hinge zone in the area with the inclusion of diapiric detritus to show that at least one local diapir was exposed at the time.

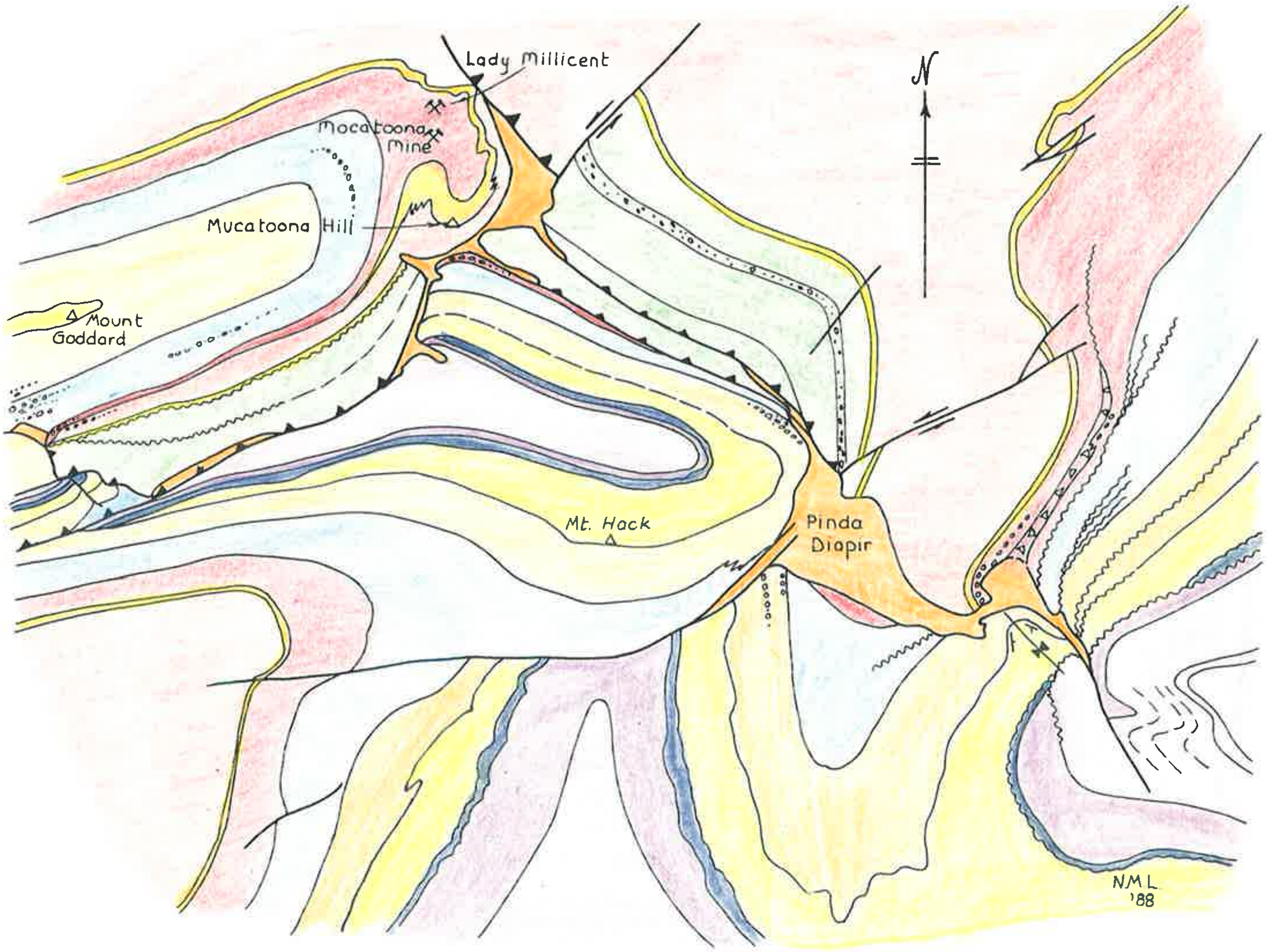
Scotford (op cit.) also demonstrated late to post Delamerian thrusting in the area and suggested that much of the Warraweena Diapir was roofed over by movement of the entire Mt. Goddard Syncline to the southeast.

Mucatoona Hill Diapir (new name)

A large, irregularly shaped outcrop of Callanna Group breccia outcrops immediately east of Mucatoona Hill. Most of the marginal contacts are intrusive or faulted except along the westen side of the outcrop, where the Brachina Formation appears conformable. Coats (1973) shows an irregular downwarp at the eastern end of the otherwise simply folded Mt. Goddard Syncline, (see Fig.41). Mapping by Scotford (1984) showed marked facies changes within the ABC Range Quartzite and Bunyeroo Formation in this area which he interpreted as the secondary peripheral sink of the adjacent diapir. The ABC Range Quartzite is very thin along the northern limb of the Mt. Goddard Syncline, virtually absent along the southern limb but dramatically thicker into the proposed sink. An unusual black shale facies developed within the normally redbed Bunyeroo Formation in the sink. Local high sulphide contents of this facies led to the accumulation of copper mineralization, briefly exploited by the Lady Millicent and Mocatoona Mines. Scotford also records the shedding of detritus from this diapir into the surrounding sediments of the ABC Range Quartzite, Bunyeroo Formation and Bonney Sandstone.

The strain associated with the thrusting illustrated by Scotford (1984) has also concentrated in and around this diapir. A large sinistral fault, that brings Brachina Formation into contact with Umberatana Group sediments, forms the SE contact of the diapir. The NE margin is probably overthrust, much in the manner of the Patawarta and Enorama Diapirs.

Figure 41



Hawker Group: Parachilna Fm.; Uratonna Fm.
Rawnsley Quartzite
Bonney Sandstone
Wonoka Fm.
Bunyeroo Fm.
ABC Range Qtz.
Brachina Fm.
Nuccaleena Fm.
Umberatana Group
Callanna Group (diapiric habit)
diapiric detritus
unconformity

0 2 4 6 8 10
kilometres

Mapping by photointerpretation with data from Scotford (1984), Coats (1973) and Haines (1987).

GEOLOGY AROUND THE PINDA AND MUCATOONA HILL DIAPIRS

Pinda Diapir

Although time prohibited a field visit to this diapir, the outcrop in the area is particularly good and photo-interpretation provides an excellent record of almost continuous movement of the Pinda Diapir from the Bunyeroo Formation to the Early Cambrian Hawker Group. Figure 41, modified from Coats (1973), shows local upturning of all sediments against this diapir from the Tapley Hill Formation to the Hawker Group. The Bunyeroo and Wonoka Formations thin dramatically toward the diapir which was probably most active during the deposition of these two units. Locally developed unconformities with upturn and onlap are particularly evident in those two formations as well as between the Bonney Sandstone and Rawnsley Quartzite and at the top of the Rawnsley Quartzite. Inclusions of diapiric detritus within nearby outcrop of the Bunyeroo and Wonoka Formations and Bonney Sandstone show evidence of exposure of the Pinda Diapir.

Similar evidence indicates exposure at the same times of all the diapirs along the Beltana - Pinda line. A large tongue of debris to the north of the Pinda Diapir in the Bunyeroo Formation could be an elongate intrusion, a moraine from a salt glacier or namakier, a sedimentary talus breccia or a massive slump. The intrusion theory is unlikely as, unlike any other situation in the Flinders Ranges, the breccia lies entirely within the plane of bedding with no cross cutting relationships. Namakiers are only known from, and only possible in, subaerial conditions, (Talbot and Jarvis, 1984). The Bunyeroo Formation is a marine deposit, most probably deep water marine. A talus breccia or slump deposit is the most likely origin.

The inclusion of massive debris lenses into the sediments near the base of the Bunyeroo Formation is not unique as it occurs near both the Pinda and Beltana Diapirs and may well occur elsewhere, as yet undescribed. This stratigraphic level is near that of the impact ejecta layer within the Bunyeroo Formation, (Gostin et al., 1986). It may be that the associated meteorite impact in the Gawler Ranges (Williams, 1986), triggered a seismic event which initiated massive slumping of the meta-stable slopes around diapirs active at the time. This is pure speculation and detailed bed tracing would be required to prove the theory.

On the south side of the diapir, the Bonney Sandstone shows rapid thinning onto the diapir but the overlying Rawnsley Quartzite thickens in the same area. This, together with a rotation of dip, indicates the development of a peripheral sink during the deposition of the Pound Subgroup. This is probably a tertiary sink as indicated by its small size and the fact that it developed after the main period of intrusion.

The basal Cambrian Uratanna Formation was deposited away from the structure but pinches out near the diapir. The overlying Parachilna Formation onlaps the Uratanna Formation but still thins over the diapir.

As with many other diapirs in the Flinders Ranges, especially those along major fault lines, the Pinda Diapir has accepted much of the syn- and post-Delamerian strain. Large faults seeking easy passage through the sedimentary pile terminate in the diapir. The NW corner of the current breccia outcrop has been roofed over by a thrust developed where a sinistral wrench makes a dextral step. This compression has also reactivated the diapir to inject along zones of weakness, particularly the faults that were active at the time. This is also the case with the nearby Mucatoona Hill Diapir.

CHAPTER 12

FAR NORTHERN FLINDERS AND WILLOURAN RANGES DIAPIRS.

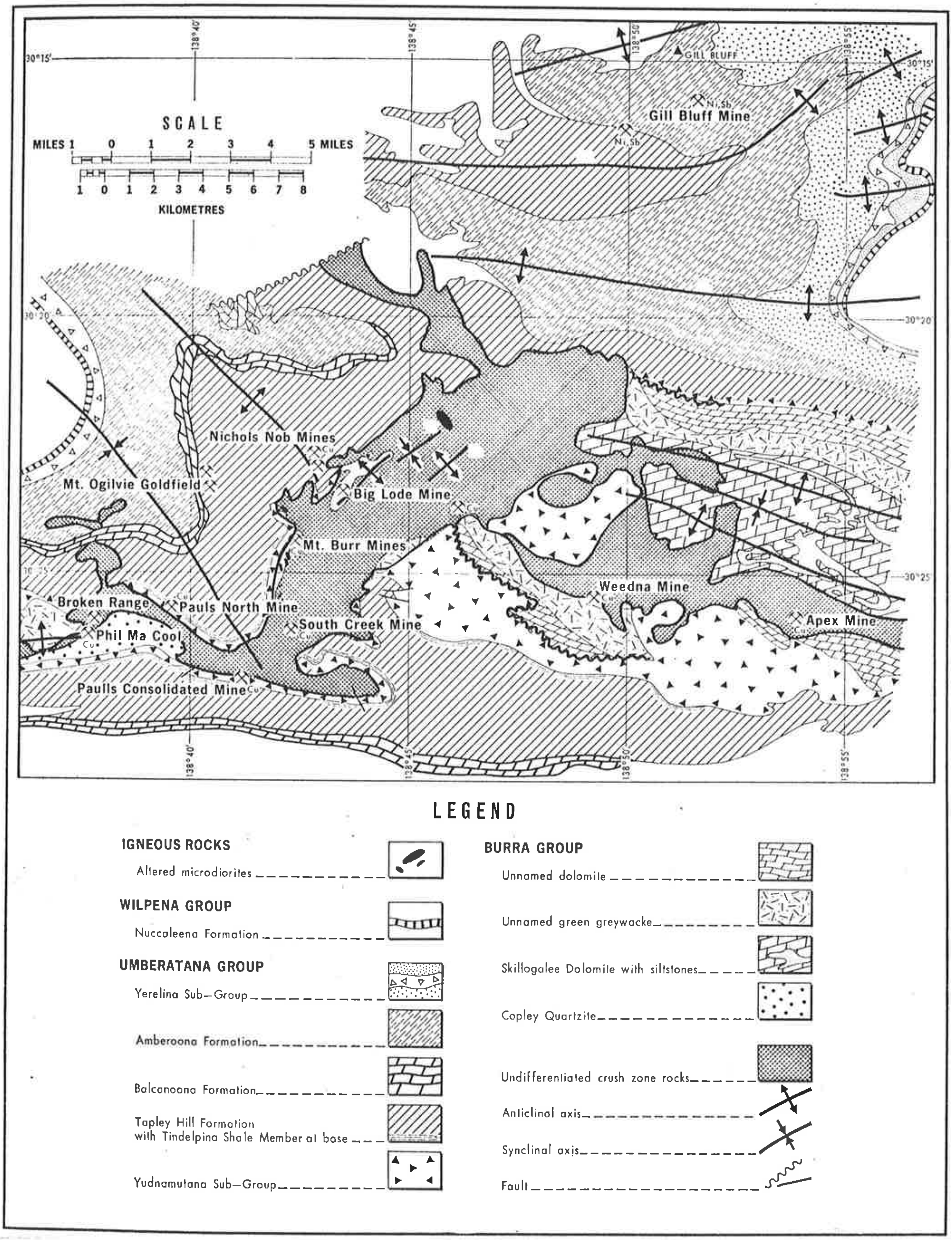
A number of large areas of breccia are shown on the maps of the very northern Flinders Ranges, northeast and east of Leigh Creek, and of the Willouran Ranges. These have several characteristics in common. They all have irregular outlines, are surrounded by outcrop of the lower parts of the Adelaidean stratigraphy and include, or rather surround, very large blocks of in-sequence stratigraphy, usually of Burra Group rocks.

The Burr "Diapir".

The Burr Crush Zone, as it is referred to by Barnes (1972), is one such large area of rocks of diapiric affinity outcropping over an irregular area, in this case up to 40 km long and 15 km wide. It is one of the largest postulated diapirs in the Flinders Ranges and occupies the central western portion of the Yankaninna Anticline, (Coats, 1973). Unlike all the other diapiric areas discussed above, the rocks outcropping around this breccia, especially at the eastern end, are dominantly Burra Group, well down in the stratigraphy of the Adelaide Geosyncline. Basal Umberatana Group rocks outcrop around parts of the western end of the breccia. There is no evidence in any of the surrounding sediments of inclusions of diapiric detritus.

Some contacts, especially those against the Burra Group, are markedly discordant. Contacts against rocks higher in the stratigraphy, mainly tillites of the Yudnamutana Subgroup, and the overlying Tapley Hill Formation, show contacts more like those expected around a diapir with steep upturning of the bedding. This upturning is particularly evident all around the contact from the Big Lode and Mt. Burr Mines to the Paulls North Mine and back to the South Creek Mine, (see Fig.42). Upturning of this nature around such an irregular contact is very difficult to explain by fold events but much easier to envisage if the breccia flowed upwards in this area dragging the adjacent beds with it. Upturning of the Burra Group with subsequent onlap of the Yudnamutana Subgroup in the NE corner of the main breccia outcrop and south of the Weedna Mine may indicate the initial pillow stage of movement.

Coats, (1973), shows the breccia to be a diapir but Barnes, (op. cit), preferred an interpretation with the breccia consisting dominantly of Burra Group rocks brecciated in situ by at least three stages of folding. Most of the larger blocks of country rock now partly or completely surrounded by breccia can be correlated with Burra Group outcropping undisturbed nearby. LANDSAT imagery shows subcontinuous, although complexly folded, sedimentary



BURR "DIAPIR"

map modified from Barnes (1972)

Figure 42.

units comprise much of the breccia. Coats, (1973), shows parts of what Barnes called breccia to be almost unbroken Callanna Group rocks.

In the strict sense of the word, this breccia body is not a diapir. It is, however, intimately associated with diapiric activity. The level of erosion across the Yankaninna Anticline has revealed the root zone or source area to a diapir which may have been active as late as the Cambrian. The upper levels of the stratigraphy where the characteristic synsedimentary diapiric influences may have been observed are now all stripped away. A diapir probably rose in the vicinity of the South Creek Mine as indicated by the local upturning of adjacent sediments. The rest of the breccia area represents the exposed source horizon together with large blocks of the sequence immediately overlying the source (the Burra Group) collapsed down as mobile material was withdrawn. Dykes and fingers of breccia flow around the collapsed blocks to give the appearance of large rafts. The area between the Big Lode and Weedna Mines is the culmination of the Yankaninna Anticline where the oldest rocks can be expected to be exposed. A secondary peripheral sink would have developed above this evacuation zone. The area of evacuation is so large that it may well have sourced more than one diapir in the region.

The recognition of the largest "rafts" in the Burr "Diapir" as Burra Group was what led Barnes, (1972), to conclude that most of the breccia was derived from the Burra Group. The mobile layers have usually been correlated with the Callanna Group, (Preiss, 1987), and these immediately underlie the Burra Group and could be expected to source the breccia under the evacuation model proposed above. There is, however, no reason why some Burra Group rocks are not associated with diapirism. The Skillogalee Dolomite is a shallow water sequence probably deposited in highly saline conditions, certainly with a salinity sufficient to precipitate magnesite. Exposure levels are very common within this formation and given as the reason for the ubiquitous intraformational magnesite and dolomite conglomerates, (Upphill, 1979). It is not unreasonable to expect evaporite deposition somewhere in the basin during these periods. It does appear in the Burr area, however, that blocks of Skillogalee Dolomite have collapsed into the evacuation zone.

Other "diapirs" of the far northern areas

The "Lyndhurst Diapir", 20 km to the northwest of the Burr breccia, has a similar irregular geometry and may represent a continuation of the evacuation area. There is a discontinuous line of small breccia outcrops linking the two areas. However, the rocks surrounding the Lyndhurst breccia are higher in the stratigraphy and the present outcrop may represent the lower levels or feeder necks to one or more diapirs developed higher in the stratigraphy.

Many of the areas of breccia outcrop in the Willouran Ranges could be similar to the Burr evacuation area. While only one brief field visit was made to the Willouran Ranges, field mapping by the Regional Survey of SADME shows many similarities. The rocks in sequence in the area are dominantly Callanna and Burra Groups, the lower parts of the Adelaidean stratigraphy. Large irregular areas of breccia surround and sometimes isolate large "rafts" of country rock. The Witchelina area shows Curdimurka Subgroup or upper Callanna Group rocks intimately associated with extensive areas of breccia, (Coats, 1973). Murrell (1977), named the breccia the Breadon Megabreccia but found many problems trying to fit it into the stratigraphy as it often showed cross cutting as well as sill-like intrusive contacts and appeared at several levels in the stratigraphy.

The low level of the stratigraphy now exposed by erosion in this area adds weight to the theory that many of these breccia outcrops represent the feeder or source level to diapirs that were active higher in the stratigraphy and that evacuation has led to the collapse, or rather settling down, into the vacated area, of very large blocks of the upper parts of the Callanna Group and the overlying Burra Group.

CHAPTER 13

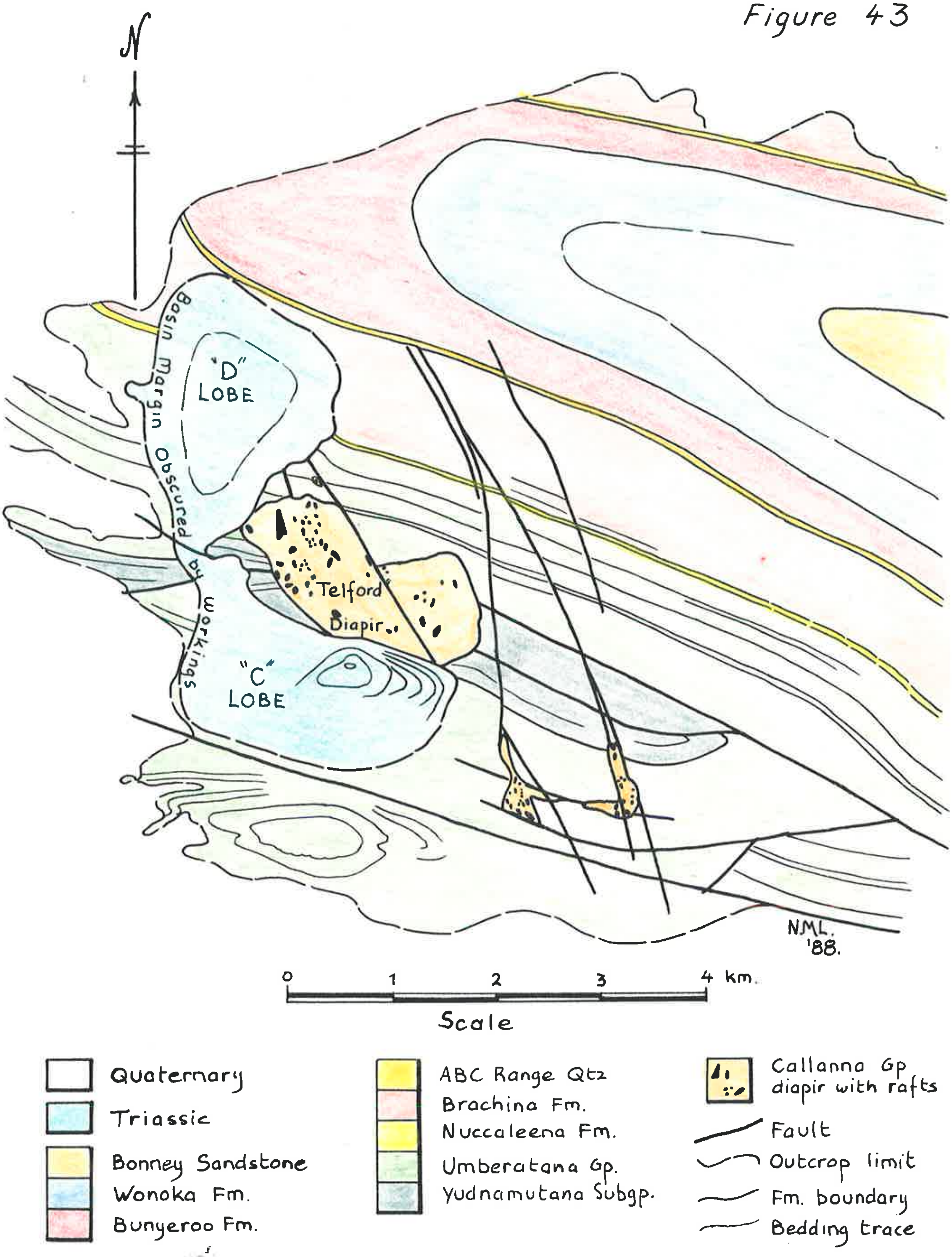
TELFORD DIAPIR (new name)

During investigations by the author on behalf of the Electricity Trust of South Australia, (ETSA), it became obvious that the preservation of the Triassic coal measures at Leigh Creek is intimately associated with diapirism. At Leigh Creek, four small basins, 1.6 to 6 km in diameter, preserve between 120m and 1100m of uppermost Triassic and lowermost Jurassic sediments. The four basins are roughly aligned in a north-south direction, almost perpendicular to the Delamerian folds in the underlying Adelaidean sequence. Although there is an increase in fault intensity in the "basement" in the vicinity of the basins, there appears to be very little or no correlation between the Triassic basins and the folded Adelaidean sequence. The basins have developed over a variety of different formations ranging from the Yudnamutana Subgroup through the rest of the Umberatana Group to halfway through the Wilpena Group. The basins overlie areas of steep dip, shallow dip, synclines and anticlines.

C and D Lobes, at the northern end of the line of basins, typify the lack of correlation between the basins and the "basement", (see Fig.43). A mechanism to create a basin and/or to infold that basin into a fully lithified sequence is necessary to explain the present day existence of the coal measures. The answer to that appears to lie with with the proximity of diapir outcrops to each of the coal basins. The situation around the biggest basin, B Lobe, is somewhat obscured, however, by extensive Quaternary cover to the NW of the basin with only two small outcrops of breccia protuding through the cover.

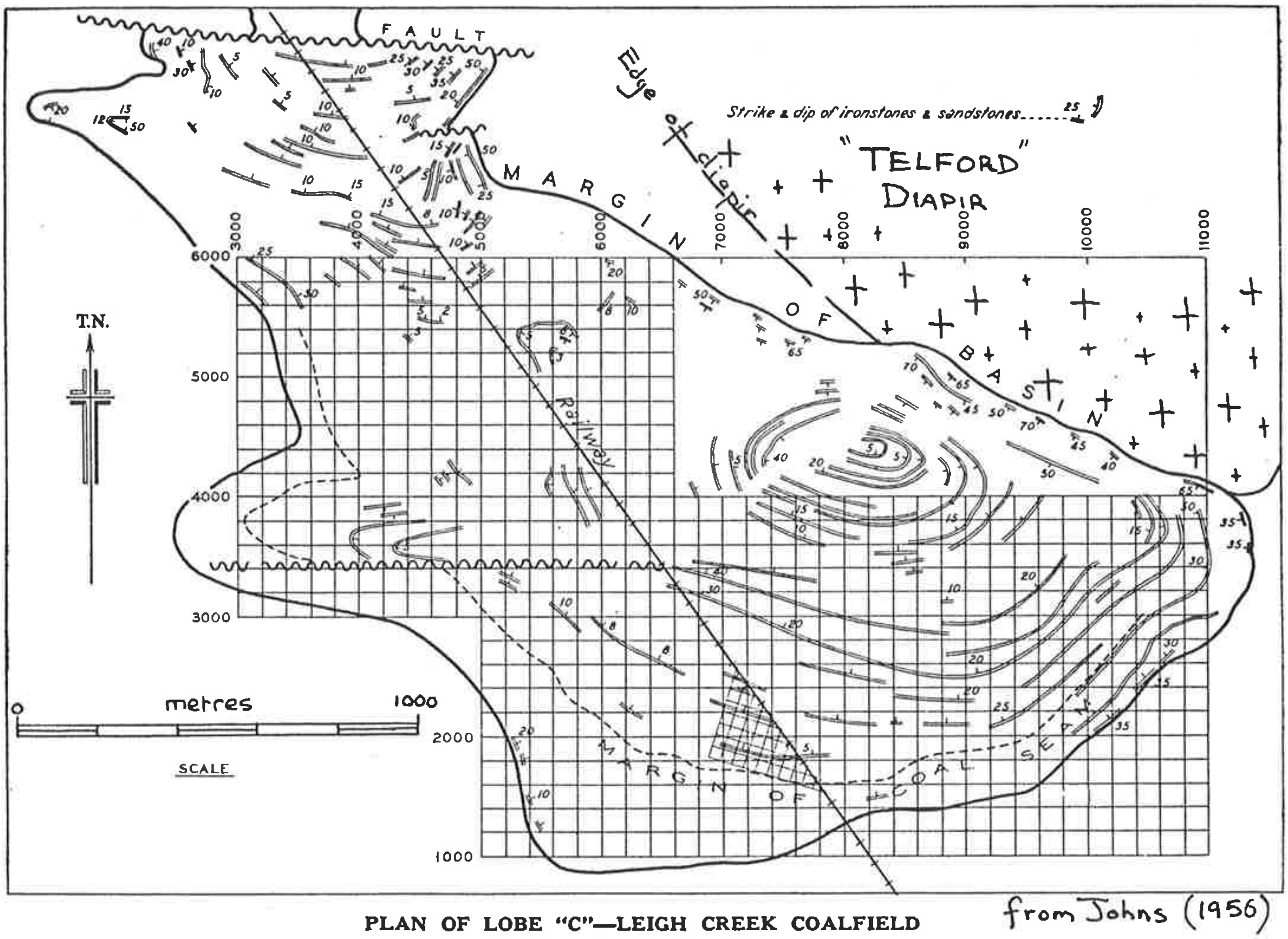
The North Field, ie. C and D Lobes, is all but surrounded by Adelaidean outcrop. The striking feature of the setting of these two basins is the proximity of the "Telford Diapir", an outcrop of breccia between the two lobes, (see Fig.43). The margins of these two basins, and most of the original surface geology, have since been covered by stripping operations to mine the coal. The original mapping of Johns, (1956), shows the internal structure of C Lobe and forms the basis of Fig.44. The basin is asymmetric with the coal measures generally dipping toward the basin centre but the depocentre offset to the NE with very steep dips along part of the northern margin. Dips within the basin are generally in the order of 5°- 20° with steepening at the basin margin to 30°-35° . However, along part of the northern margin, the dips rise to 60°-70°. This is precisely that edge of the basin in contact with the "Telford Diapir". The marginal dips change dramatically where the diapir contact meets the basin at a high angle in the

Figure 43



TECTONIC SETTING ~ "C" and "D" LOBES, LEIGH CK.

eastern corner but change gradually where the diapir margin approaches the basin at a lower angle from the NW. This proof of diapir movement either during or after the deposition of the coal measures is incontravertible.



PLAN OF LOBE "C"—LEIGH CREEK COALFIELD
Showing structural geology

Figure 44. Original surface mapping of C Lobe prior to mining operations.

The tectonic setting of C and D Lobes, (Fig.43), shows the relationships of the basins to the diapir. The coal basins are a peripheral sink to the diapir. D Lobe, further from the diapir and protected by a "buffer" of Adelaidean rocks, is sub circular and almost symmetrical in section. C Lobe, as mentioned above, is clearly structurally asymmetric. The basin fill is also asymmetric, indicating the timing of the diapir movement. The facies along the northern edge of C Lobe is coarser grained with no coal deposition. This shows that the diapir had an influence on the basin even during sedimentation. It is highly likely that the formation and preservation of tha Triassic basins was facilitated by diapir movement.

Sand box modelling was done in an attempt to reproduce the geometry of C and D Lobes around te "Telford Diapir". The only way to approximate the geometry was to have a diapir already in situ in the "Adelaidean sequence" and to remobilize it. This means the sink produced is in effect a tertiary peripheral sink. While the photos of the experiment, (Plate 7), show the vertical exaggeration inherent in all the models constructed, the near symmetrical nature of D Lobe, slightly away from the diapir margin, is in sharp contrast to the asymmetry of C Lobe, with a downfaulted block within the basin and sharp upturning on the contact. Both these features are shown in Fig.44, the map from Johns, (1953). The differences in the development of the sink on either side of the diapir are not an artifact of the model but due to different rates of infeed to the diapir from either side of the structure. The present situation at North Field is more accurately modelled by lowering the surface a little by erosion.

Deposition on the continent of Australia during the Late Triassic to Early Jurassic was unusual. This was a period of widespread non-deposition and unconformity. The only other sediments of this age in the eastern part of the continent are in small basins beneath the Eromanga Basin, the Peera Peera Formation, (Moore in Moore and Mount, 1982), and the basal Bundamba Group in the Clarence Moreton Basin in SE Queensland and NE New South Wales, (Day et al., 1974). Tectonic conditions different from those applying over the widespread area of non-deposition are required to explain the local preservation around Leigh Creek.

In summary, this model of Triassic sedimentation requires the following conditions:-

1/. A diapir emplaced in the Adelaidean sequence either during sedimentation of that sequence or during the subsequent Delamerian Orogeny,

2/. A mechanism to reactivate the diapir during the Triassic. This may have been afforded by compression reactivating the Northwest Fault, 5-10 km west of Leigh Creek, with subsequent increased loading of the original source beds or by compression transferred to the synclinal hinge of a fault bend fold associated with the Northwest Fault thrust.

3/. Continued movement of the "Telford Diapir" after reactivation, through the Late Triassic and into the Early Jurassic. The tertiary peripheral sink of the diapir created and preserved local basins. All four basins may have been partially interconnected but each had a separate subsidence history. The movement stopped before the Late Jurassic as sediments of this age unconformably overlie the coal measures of the

Copley Basin or A Lobe.

Confirmed diapir movement as late as the Jurassic has considerable implications as to the nature of the diapirs. Only two types of formations are known to be involved in diapirism; evaporites and overpressured shale. It is highly unlikely that a shale unit would remain overpressured through over 400 million years, a two phase orogeny and the mild metamorphic event associated with that orogeny. Only evaporites would retain their potential mobility over that time and through those events. The Callanna Group source formations must have contained extensive evaporites even though no direct evidence for such rocks has yet been found.

CHAPTER 14

GEOCHEMICAL SIGNATURE AROUND DIAPIRS.

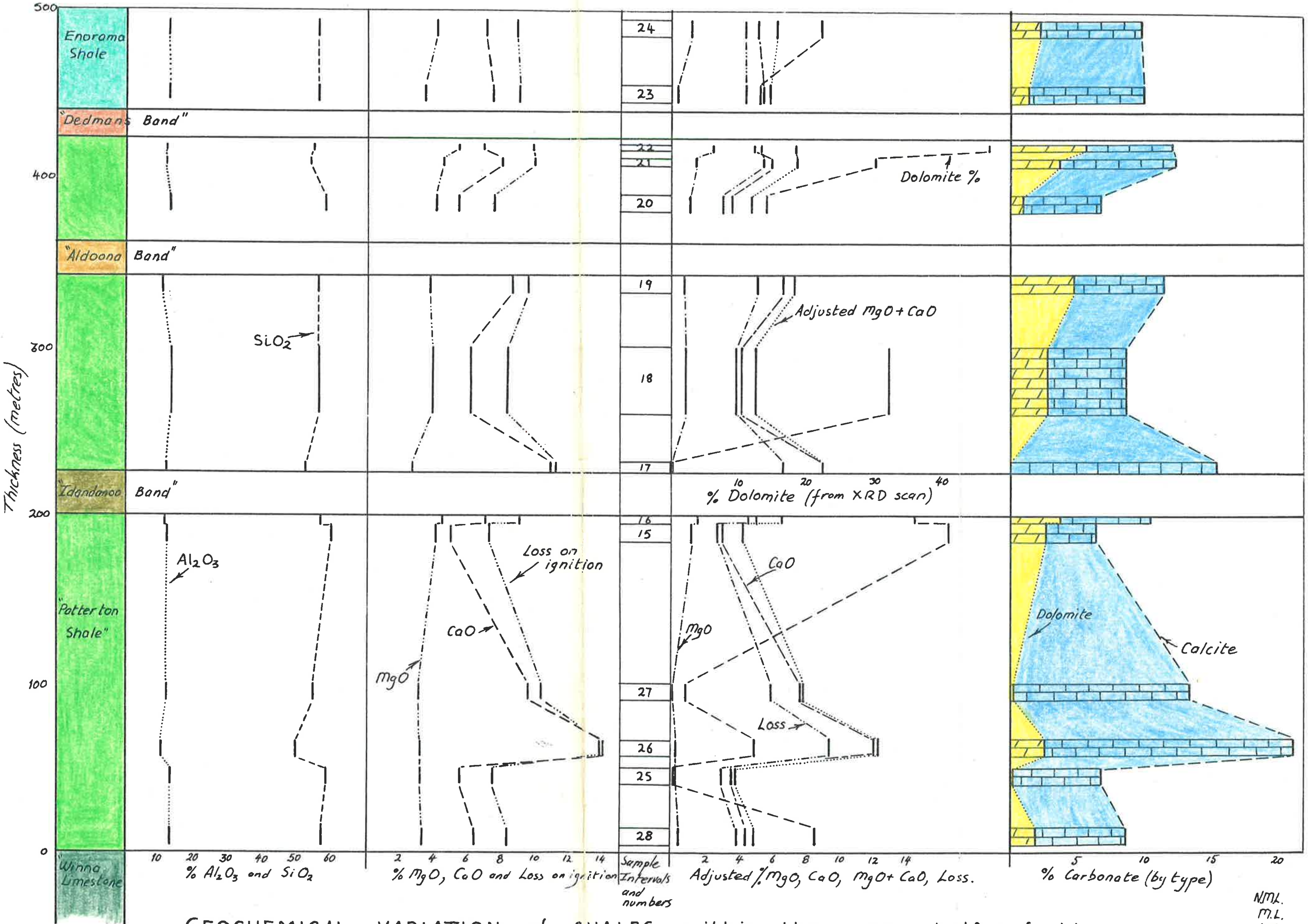
In order to detect a geochemical change in sediments in the vicinity of diapirs, the background variation away from the structures needed to be determined. The background geochemistry was evaluated in terms of whole rock geochemistry, total carbonate content, dolomite to calcite ratios and the purity of calcite and dolomite with respect to iron and magnesium. No aragonite was detected in any of the samples.

Whole rock analyses were done by x-ray fluorescence (XRF). Total carbonate was determined by cross plotting CaO, MgO and loss on ignition (LOI), against peak heights from x-ray diffraction (XRD) traces. Eventually carbonate content was estimated by plotting the ratio of XRD peak heights of quartz plus feldspar on calcite plus dolomite on a curve determined from a combination of the XRF and XRD data. Dolomite to calcite ratios were determined from XRD peak height ratios plotted on the Tennant-Berger (1957), correction curve (see also Royse et al., 1971). This curve was slightly modified for the in-house equipment by Singh (1986), by measuring a set of pre-mixed standards. Iron and magnesium contents were estimated from XRD "d" spacing determinations plotted on a series of correction curves drawn from the spacings reported from accurately analysed minerals in the Mineral Powder Diffraction File (McClune and Macguire, 1980). Iron in dolomite was determined from a plot of the dolomite-ankerite series. Iron and magnesium both have similar ionic radii and so influence the "d" spacing of calcite in the same way. Staining, as described by Dickson (1965), of both acetate peels and thin sections allowed discrimination of iron from magnesium in calcite.

Total carbonate content

The upper part of the Etina Formation was sampled around Sections 1 and 18 to determine the background geochemistry in the study area away from the diapirs. Whole rock analyses were done on 14 bulk shale samples from the "Patterton Shale" and Wundowie Limestone equivalents. Using the technique outlined above, percentages of dolomite and calcite were calculated. Progressive values through this calculation and the final results are presented as Fig.45.

The final column on Fig.45 shows how dolomite, calcite and total carbonate vary through the stratigraphy. The total carbonate content varies with water depth. As the sea shallowed toward the deposition of the stromatolite, ooid and intraclast limestone bands, carbonate content



GEOCHEMICAL VARIATION of SHALES within the upper half of the ETINA FORMATION (samples from Sections 1 + 18)

Figure 4.5.

increased. This shows in natural outcrop as higher ground, more resistant to erosion. Carbonate content was at a minimum midway between limestone bands. The exception to this is a prominent band near the base of the "Patterton Shale". This is a record of partial shallowing within the basin. Limestone deposition is recorded at this level where the sea shallowed to near exposure around the Blinman Diapir.

The dolomite content steadily increases from the base of each shale band to the top. This is probably due to exposure of the sediments during the hiatus which occurs near or at the base of each of the limestone bands of the Wundowie equivalent. Incipient dolomitization permeated down from the exposure surface.

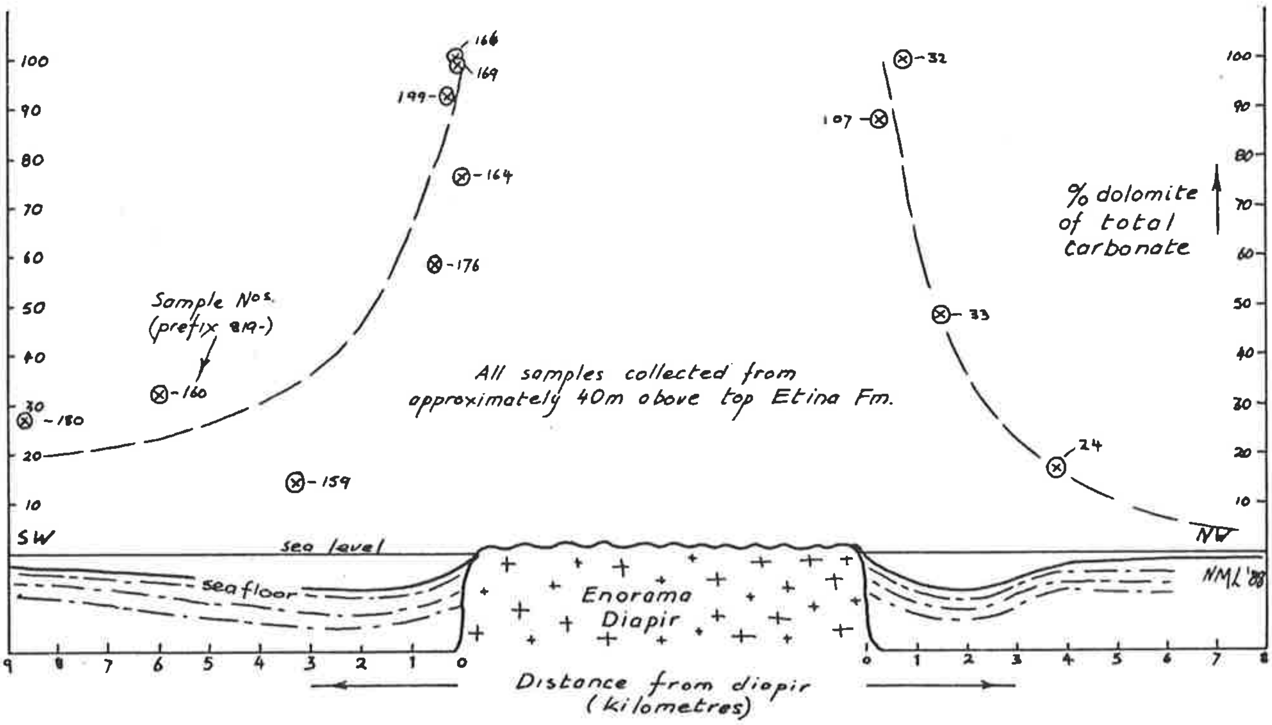
The data from samples 819-014 to -028 was plotted against the ratio of XRD peak heights of quartz plus feldspar over calcite plus dolomite. This, together with ratios from samples with a visual estimation of carbonate content from thin section, formed a curve against which the XRD results from other samples could be plotted. A suite of samples was collected across the base of the Etina Formation near Rocky waterhole, SE of Blinman. Figure 30 shows a plot of the carbonate variation determined in this way. The deeper water calcareous shales in the study area have a background carbonate content of around 8%-10%. This rises toward the limestone bands in the section and there is a thick transition interval between the Tapley Hill Formation and the Etina Formation. This transition is evident throughout the study area. Acid bottle testing below Section 46, measured on the western side of the geosyncline at Depot Flat, suggests that the carbonate increase toward the base of the Brighton Limestone equivalent is more gradual over a longer interval.

Calcite-dolomite ratios

Figure 7 of Section 46, at Depot Flat, shows a very good example of a shallowing upward carbonate unit, from deep water stromatolites interbedded with shales at the base to ooid shoal limestone and eventually fenestral supratidal dolomite at the top. Subsidence balanced against sea level fall spread this sequence over 130m. The dolomite content of the total carbonate fraction for 9 samples through this sequence is also plotted on Fig.7. The thin carbonate lenses interbedded with shales at the base contain up to 50% dolomite. This may be due to dewatering of the shales supplying magnesium to dolomitize the calcite deposited in the stromatolites at this level. Dolomitization of the carbonates in the sabkha environment at the top of this unit extends into the underlying units in two ways. Dolomitization permeated down from the exposure level to alter sediments already deposited.

It is this mechanism that is proposed to explain the same dolomite enrichment below the bands of the upper Etina Formation. This is superimposed on a small amount of dolomite included as small chips and intraclasts washed from the sabkha out to the ooid shoal area during sedimentation.

It is against this background that the dolomite content in the shales around the Enorama Diapir was measured. Knowing that dolomite is likely to be associated with exposure levels within the stratigraphy, a suite of samples was collected from 40m above the base of the Enorama Shale from sediments deposited during rising sea levels. Samples could not be collected from the middle interval of the Enorama Shale as the green, reduced, blocky weathering shale has almost no carbonate content. Figure 46 shows a sharp rise in the dolomite proportion of the total carbonate content within 1-2 km of the diapir contact at this stratigraphic level. The presence of the diapir either caused dolomitization of the carbonates in the sediments or supplied dolomite in detrital form to the sediments. Figure 27 shows that dolomitic algal reefs "grew" on the contact at this stratigraphic level. Samples 819-161, 162, 166 and 169 suggest dolomitization of limestones occurred. The inclusion of already dolomitized detritus in the surrounding sediments suggests that this dolomitization occurred very early in the diagenesis of the reefs.



DOLOMITE VARIATION of CARBONATE CONTENT in the ENORAMA SHALE

Figure 46.

The dolomicrite matrix to many of the conglomerates washed from the diapir. This, together with the dolomicrite slumps into the surrounding shales, suggests that there was a supply of dolomite mud over or around the diapir. The same dolomitic conglomerates and dolomicrite slumps are seen in other deeper water shale units around the Patawarta, Beltana, Blinman, Oraparinna and Enorama Diapirs. This indicates that the diapirs modified the geochemistry of the waters in their immediate vicinity to produce dolomicrite.

Calcitic micrite is abundant in the late Precambrian sequences of the Adelaide Geosyncline. Haines (1987), drew the conclusion that inorganic precipitation of carbonate mud as "whitings" was the main source of carbonate supply in the Wonoka Formation. This precipitation is facilitated in warm and shallow waters with additional precipitation induced by carbon dioxide extraction by photosynthetic organisms such as cyanobacteria. Evidence of the abundance of these organisms is seen in the thick stromatolitic limestone sequences. The geochemical environment around a diapir, especially during times of higher sea level, was such as to dolomitize this whiting very early in its formation and prior to final deposition, or to directly precipitate dolomite whiting.

It appears that a supply of dolomicrite was ponded over the diapir and released during periods of diapiric activity. Details of this are presented in the chapter on the summary of sedimentation models.

Distribution of Iron and Magnesium in Carbonates

Routine staining of limestone slabs for acetate peels and of thin sections showed that some formations are dominated by iron rich calcites and others by iron poor calcites. The staining results were quantified to some extent by using the plots of calcite "d" spacing against composition. However, the results were only used in the description of the formations generally with no work done on the variation around diapirs.

The limestones and shales of the Etina Formation and the slightly older Brighton Limestone equivalents are dominantly green in colour with iron present in the relatively reduced Fe^{++} form. Under reducing conditions, iron is also accepted into the calcite lattice. Precipitation of calcite in more oxidizing conditions inhibits the inclusion of iron into the lattice, perhaps as Fe^{+++} has the wrong charge to replace Ca^{++}. Stromatolitic limestone commonly stains royal blue, indicating a high iron content, while intraclastic limestone, often reworked flakes from stromatolites, stains a violet colour and ooid limestones stain magenta. While all these facies are developed in relatively shallow water, the organic content in the stromatolites could control the Eh conditions and therefore the iron content of the calcite. It also appears that iron can be excluded from calcite as it recrystallizes under oxidizing conditions.

As the conditions of deposition shallow toward the top of the Brighton Limestone equivalents at Depot Flat, the iron content of the calcite drops away, (see Fig.7). The stained peels across this interval change from royal blue to magenta. While the iron content of the co-existing dolomite was not quantified, it appears that iron is removed from calcite and taken up by dolomite during dolomitization.

Samples of limestone from the upper bands of the Etina Formation show a variation of iron content induced by exposure. Reworked clasts on the disconformity surfaces within each band show violet and red stains indicative of low iron contents when compared to the blue colours of the overlying stromatolitic and even intraclastic limestones.

The limestones of the Trezona Formation, particularly those from the bottom half of the formation, are quite different from those of the Etina Formation. They are red and brown in hand specimen with free iron oxides giving the strong colours. The bright red colour of the intraclasts in the "heiroglyphic" limestone is an extreme example of this. Despite the high overall iron content of these limestones, samples stain magenta and carmine, indicating virtually no iron in the calcite lattice at all. Even the stromatolitic limestones show this feature. It appears that once iron concentration reaches a certain level, the iron separates into its own oxide-hydroxide phase rather than be included in the co-precipitating calcite.

Geochemical studies around the Enorama Diapir show a progressive change toward the structure. This suggests that an island was exposed in the area thereby adding weight to the diapir theory.

CHAPTER 15

GEOPHYSICAL EXPRESSION OF DIAPIRS

In the case of the Adelaide Geosyncline, the main geophysical information available over the diapirs is in the form of regional aeromagnetic and gravity surveys. Two detailed gravity surveys were conducted over the Blinman Diapir and several local ground magnetic surveys.

Aeromagnetics.

Regional aeromagnetic surveys were conducted over the Flinders Ranges by the Bureau of Mineral Resources for the South Australian Dept. of Mines. Although originally published at 1:63,360 scale, regional compilations were made and the Parachilna 1:250,000 sheet was published in 1966, (Whitten, 1966).

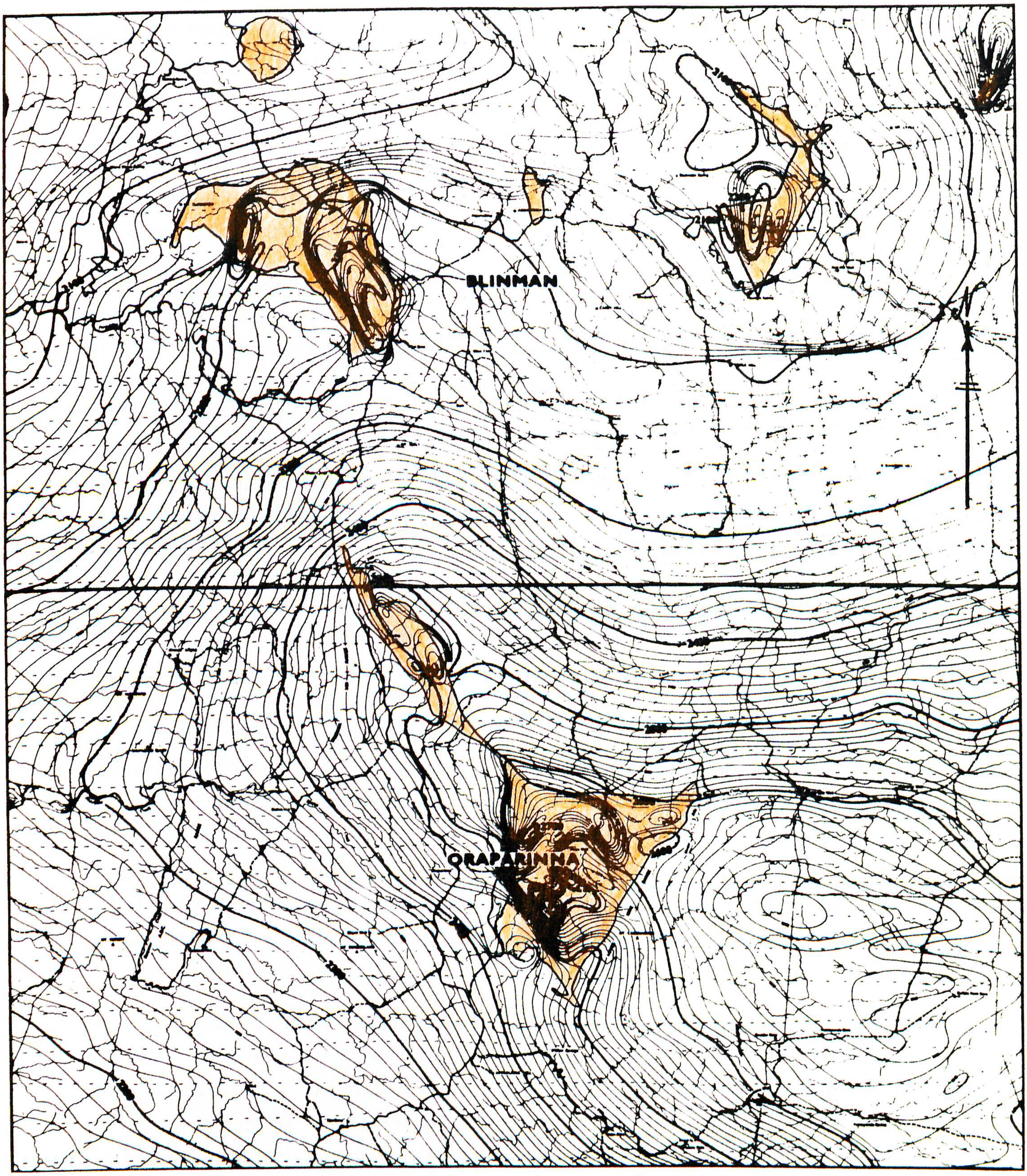
The majority of anomalies on this sheet are very broad, deep seated, basement related features. One such broad anomaly wraps around the Oraparinna and Enorama Diapirs, suggesting that there is either a deep positive magnetic anomaly below, or that the basement is shallower in this area or a combination of both these influences.

Figure 47 is an extract from the Parachilna aeromagnetic map and clearly shows the position of the larger diapirs. A distinct high frequency response is superimposed on the broad contours of the deeper anomalies. This is largely due to exposed rafts of dolerite, basalt and rare blocks of metamorphic basement, (Mumme, 1961). These have a higher magnetic susceptibility than the surrounding sediments and locally focus the magnetic field. These blocks have been carried to the surface by the intrusion of the diapirs. There is no reason for the diapirs to show a magnetic anomaly other than from the xenoclasts they carry.

Gravity

The published regional Bouguer gravity anomaly maps show virtually no sign of variation coincident with the outcropping geology. The regional grid, approximately 7km square, is far too coarse to detect the diapirs. The single reading on the Blinman Diapir shown on the 1:250,000 scale map suggests a local low but the single reading on the Oraparinna Diapir indicates a local high.

The intrusion of a diapir requires low density material to be overlain by higher density material with gravity as the main driving force.



Magnetic contours from SADME plan - Parachilna
Geology from Dalgarno and Johnson, 1966.

0 5 10 15 20 25

kilometres

diapir outcrop

Figure 47.

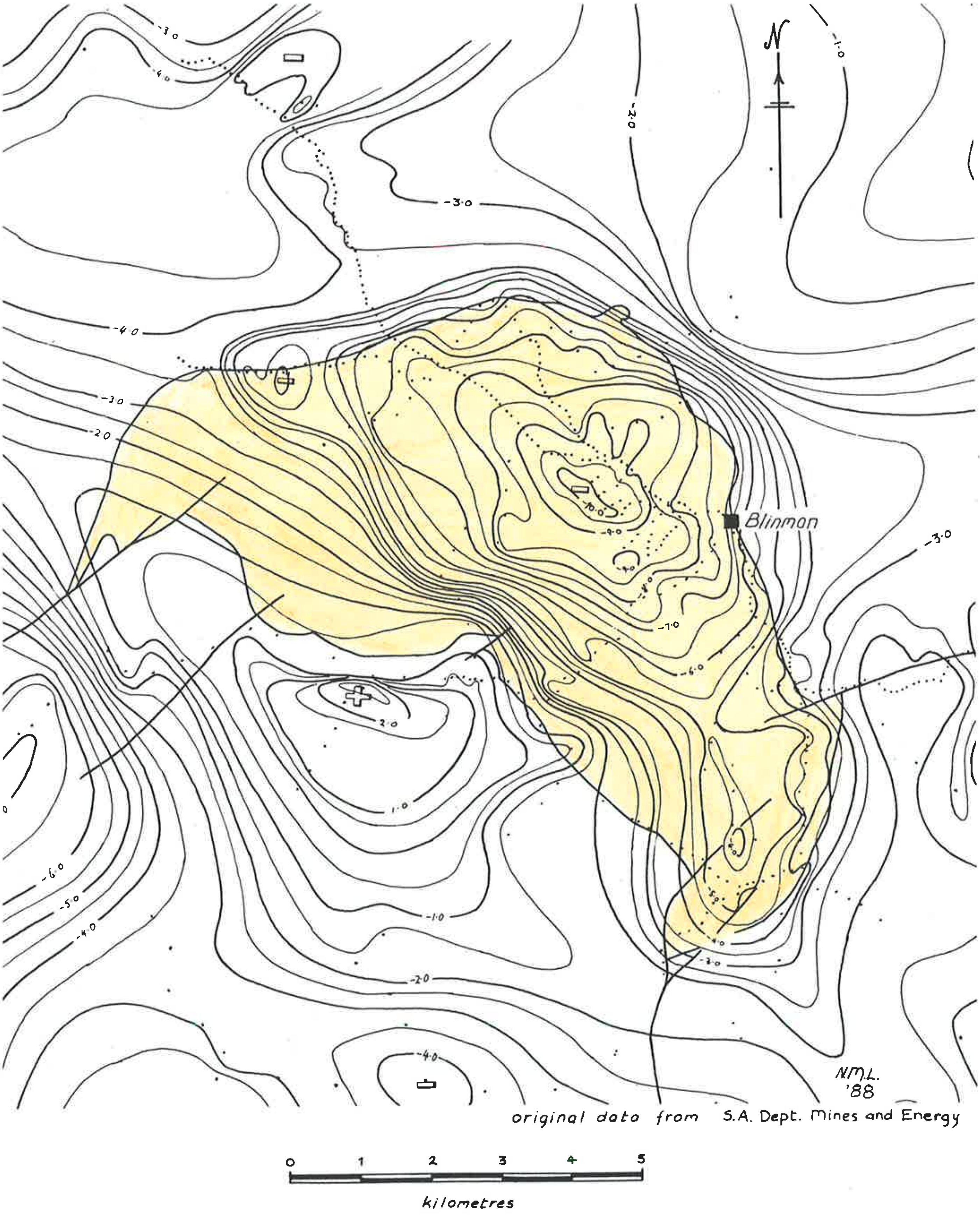
AEROMAGNETIC MAP ~ TOTAL INTENSITY

This implies that each diapir should have an associated negative Bouguer gravity anomaly. However, this is not always the case. Active salt plugs in Iran have both positive and negative anomalies associated with them, (Kashfi, 1983). This is thought to be related to the number of higher density xenoclasts within them and the degree to which the salt has been removed by dissolution. Another reason for the variation in gravity response could be the relative proportions of halite and anhydrite (SGs 2.2 and 3.0 respectively) left in the remaining levels of each diapir after erosion.

Compilation maps at 1:1,000,000 and 1:2,000,000 scale show a broad, elongate positive anomaly, roughly coincident with the axis of the geosyncline through the Central Flinders Zone. This may be due to a different basement type and density beneath this area or may be related to an increase in the percentage of carbonates in the total sedimentary section across this area. The latter may be the case as the Central Flinders Zone was a carbonate shelf for a large part of the Umberatana Group deposition. This becomes apparent when comparing the sequence to that exposed north and south of the central zone.

A detailed gravity survey was conducted over the Blinman Diapir by Mumme (1961), and this was followed by a recent SADME survey. The author has contoured values from the preliminary data set of the recent survey and this is shown as Fig.48. Close spaced readings, down to 100m apart, were taken along roads in the Blinman area and superimposed on a more regional data set. The contouring of these unevenly distributed points is biased towards the areas where most readings were taken but no account was taken of the outcropping geology. Despite this, there is good correlation between a negative anomaly and the diapir. The gradient steepens markedly across the boundary of the diapir where readings were taken. This correlation is less clear in areas of sparse readings as the basic rules of evenly spreading contours between available stations were followed.

Despite the strong correlation between the contours and the diapir margin, only one traverse, that extending northwest from the town through Glasses Gorge, crossed the diapir boundary at a high angle in an area not affected by major faults. Modelling of the data along this line was done using an interactive computer modelling program. The only factor known in the production of the models was the position of the contact between the diapir and the country rock. Variables included the relative densities of the two blocks in the model, the thickness of each block and the angle of the contact between them. Figures 49a and b show two relatively successful attempts at modelling.



BOUGUER GRAVITY ANOMALY over the BLINMAN DIAPIR

Figure 48.

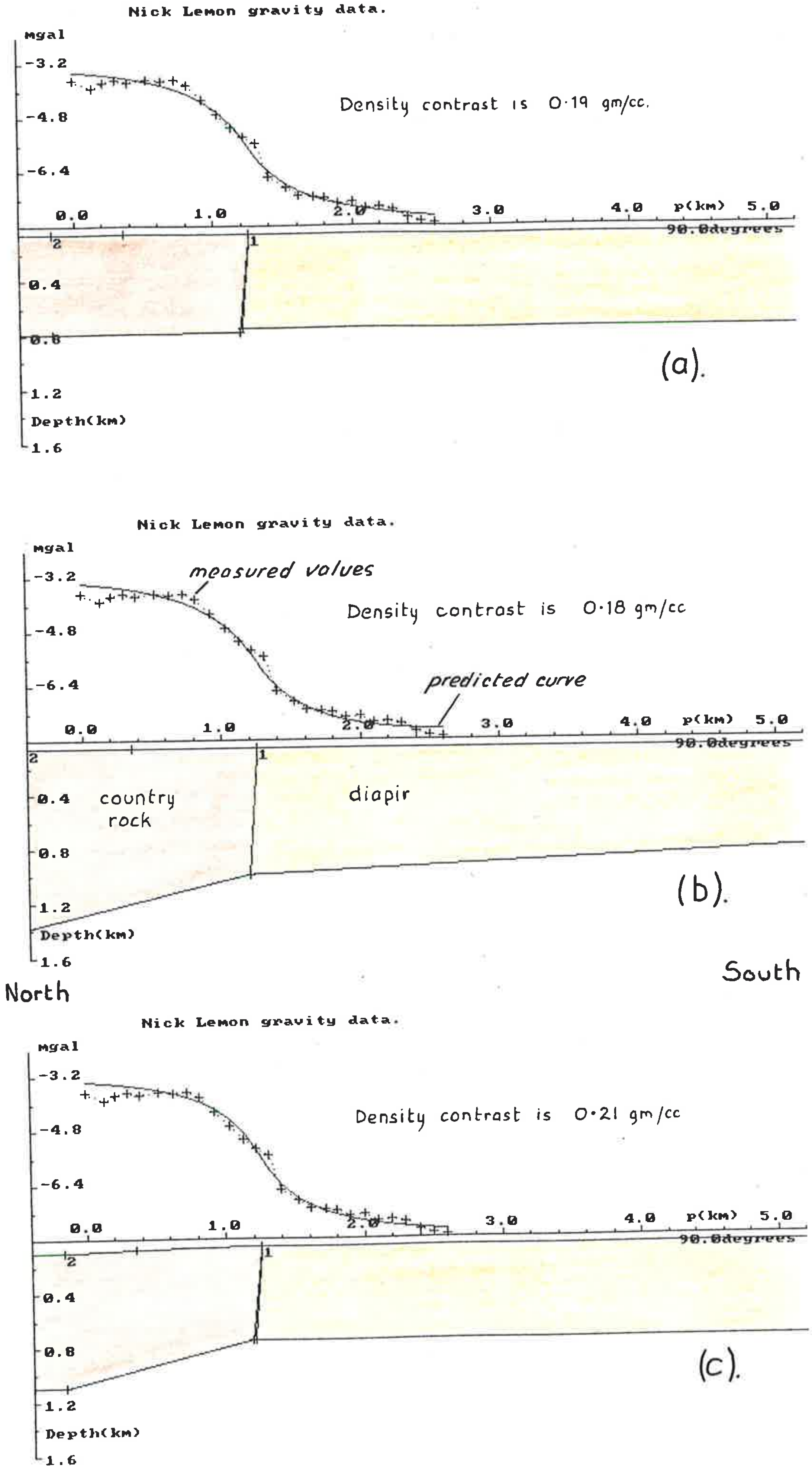
Figure 49a uses two near rectangular slabs with a density contrast of 0.19 grams/cc. The shallow depth of the slabs was required to reproduce the sharp angles on the profile. A steep northerly dip of the contact provided the best fit of the curves.

Another model was run to simulate the diapir being sourced from deeper in the section. To model this, a lower density contrast of 0.18 grams/cc was required. This, together with the greater thickness of each slab, smoothes out the curve, especially on the upper side. Fig.49b shows this model. This model takes into account the fact that the contact occurs just off the crest of a regional anticline and that the section thickens away from the contact. The modelled top end of the curve, however, is a lot flatter than the measured profile despite angling the contact more to improve the fit. The measured profile would be even steeper if terrain corrections were taken into acount. The stations on the diapir side of the contact are all situated on a relatively flat, but elevated, plain. The road along which the readings were taken plunges into a steep sided gorge from the contact into the country rock and continues to lose elevation away from the diapir.

Figure 49c is an attempt to combine the best features of the other two models. It is interesting to note that a greater density contrast, 0.210 grams/cc, is required to make the curve fit when the logical restrictions derived from field mapping are placed into the model. This model also allows to some extent for the expected terrain corrections by pushing the modelled curve above the measured curve.

Many other variations were modelled but the best fit was always achieved with the contact dipping steeply to the north. This is the slope expected on the flank of a very mature pillow or at the base of a diapiric stock. Either of these situations is viable for the Blinman "Dome". The latter is favoured since a secondary peripheral sink formed during the deposition of the Tapley Hill Formation.

Mumme (1961), modelled the Blinman Dome as a vertical cylinder 6,000' high surrounded by sediments. He tried two models using density contrasts of 0.12 and 0.22 gm/cc. The lower value, 0.12, provided the best fit but measurements collected from hand specimens collected in the area suggest a contrast in the order of 0.17 gm/cc. The country rock averaged 2.62gm/cc and the diapiric rocks varied greatly around an average of 2.45 gm/cc.



COMPUTER GRAVITY MODELLING
Glasses Gorge Traverse

Figure 49.

Figure 48 shows another interesting effect. The negative anomaly over the diapir is not nearly as prominent where the large "Eregunda" fault system enters the diapir near the Wirrealpa road turnoff south of Blinman. Movement along the fault is post diapiric. Most of the faults in the district act as water conduits, with most local springs astride faults. Concentrated water movement through the diapir may have dissolved the evaporites, leading to a higher bulk density and consequent rise in the Bouguer gravity anomaly.

Geophysical techniques can be a useful adjunct in the study of diapirs. Magnetic surveys can detect areas of diapiric breccia, provided the breccia contains rocks of a higher susceptibility than the country rock. Gravity surveys will point to areas of low density rocks, such as evaporites, but the absence of a negative anomaly does not preclude the presence of a diapir.

CHAPTER 16

NATURE OF THE BRECCIAS AND SOURCE BEDS

The distinctive nature of the outcropping areas of breccia has been noted by all geologists who have worked on them in the Flinders Ranges. It is quite a change to cross the boundary from the well ordered sequence of the surrounding rocks into an area of diapir. The irregular surface of the diapir is cut by numerous small creeks with no preferred orientation. They are commonly hidden by dense stands of mallee eucalypts. The topography is dominated by small pointed hills of basic volcanics and dolerite with larger ribbed hills of brown weathering, yellow dolomites and occasional sandstones. The surface of the topographically more subdued areas is covered by a regolith-like calcrete cemented breccia. Numerous small breakaways and deeper creeks show this capping to be only 1m thick, commonly covering grey siltstones and mudstones. These weather easily and fresh samples, when observed, show highly disrupted bedding and incipient dolomitization. The majority of the suite of sediments within the diapir are easily weathered, almost as if they were dissolving from the myriad breakaways that flank every creek and gutter.

Traverses through the Enorama, Oratunga and Angorigina Diapirs showed a number of features common to nearly all the breccia areas. Contorted and brecciated shale facies dominate the outcrop where there is close to 100% exposure along major creeks. This is in stark contrast to the rocks exposed in plan over a diapir. Differential weathering and erosion hides the presence of the shales and highlights the rafts of resistant rock types and the areas that have been dolomitized. The easily weathered rock is commonly a mid grey shale/siltstone which is either intensely folded or brecciated (see Plate 7). When brecciated, dolomite and chlorite are seen to infill between the blocks and progressively replace up to 25% of its volume, (samples 819-66, 67, 68). Red dolomitic shales also behave very incompetently and appear to "flow" between rafts and larger blocks of breccia. These shales were originally dolomitic and are often seen near outcrops of sabkha-like dolomites.

Large rafts of rock can remain relatively intact in the breccias. They are commonly composed of the more competent and resistant rock types such as well cemented sandstones, massive dolomites, basalt and dolerite. Reliable stratigraphic sequences can be measured from the largest rafts and thick sections of the sequences involved in the breccia formation can be compiled by matching overlapping sequences between rafts. Mount (1980), and Preiss (1980, 1985), compiled such sequences from the Worumba and Arkaba

Diapirs and found a close correlation with sequences described from the Callanna Group. Preiss (1987), shows this correlation between the sequences involved in many of the breccias. The correlation between the units involved in the breccias and the sediments of the Callanna Group has been noted by many previous workers.

Rafts grade into the surrounding breccia through a zone of progressive breakup, usually associated with a facies change in the original sedimentary sequence. The boundaries are a lot sharper around the igneous rafts as there is a greater contrast in the competence of the rocks. Where two rafts are in close proximity, the rocks between them commonly show intense brecciation due to the relative motion between the rafts. Dolomitization of the breccias does occur but not to the degree inferred by many previous workers who often refer to the "diapirs" as areas of dolomitic breccia. Sample 819-049 shows partial dolomitization of an area of intense brecciation and a nearby sample, -051, shows complete replacement by dolomite with just the faintest trace of the original breccia texture revealed in a stained peel. Sample -055 is from a typical knobbly dolomitic breccia outcrop and -171 shows the extent to which dolomitization can alter what was originally a coarse clastic sequence.

The suite of rock types included in the breccia, both as rafts and as more finely comminuted material, is quite varied and includes grey shales and siltstones, red dolomitic mudstones, coarse, poorly sorted, clastic redbeds, massive dolomite, dolomitic sandstones and siltstones, sabkha-style dolomite, halite casted, heavy mineral laminated, fine sandstones, dolerite, amygdaloidal basalt, granite, schist and granite gneiss. Copper mineralization is common but iron mineralization as specular hematite is ubiquitous.

A remarkably similar suite of rocks has been described by Kent (1979), from the exposed salt plugs in southern Iran. The size ranges from abundant small inclusions to rafts up to 3 and 4 km across. The suite includes:-

basement rocks	mylonite, tonalite gabbro, migmatite-granite, and schist.
sedimentary rocks	limestone, dolomite, shale, cherty limestone, sabkha dolomites, sandstone and conglomerate
igneous rocks	tuff, ignimbrite, pillow lavas and the most common, green dolerite, which was intruded into the mobile sequence prior to movement.

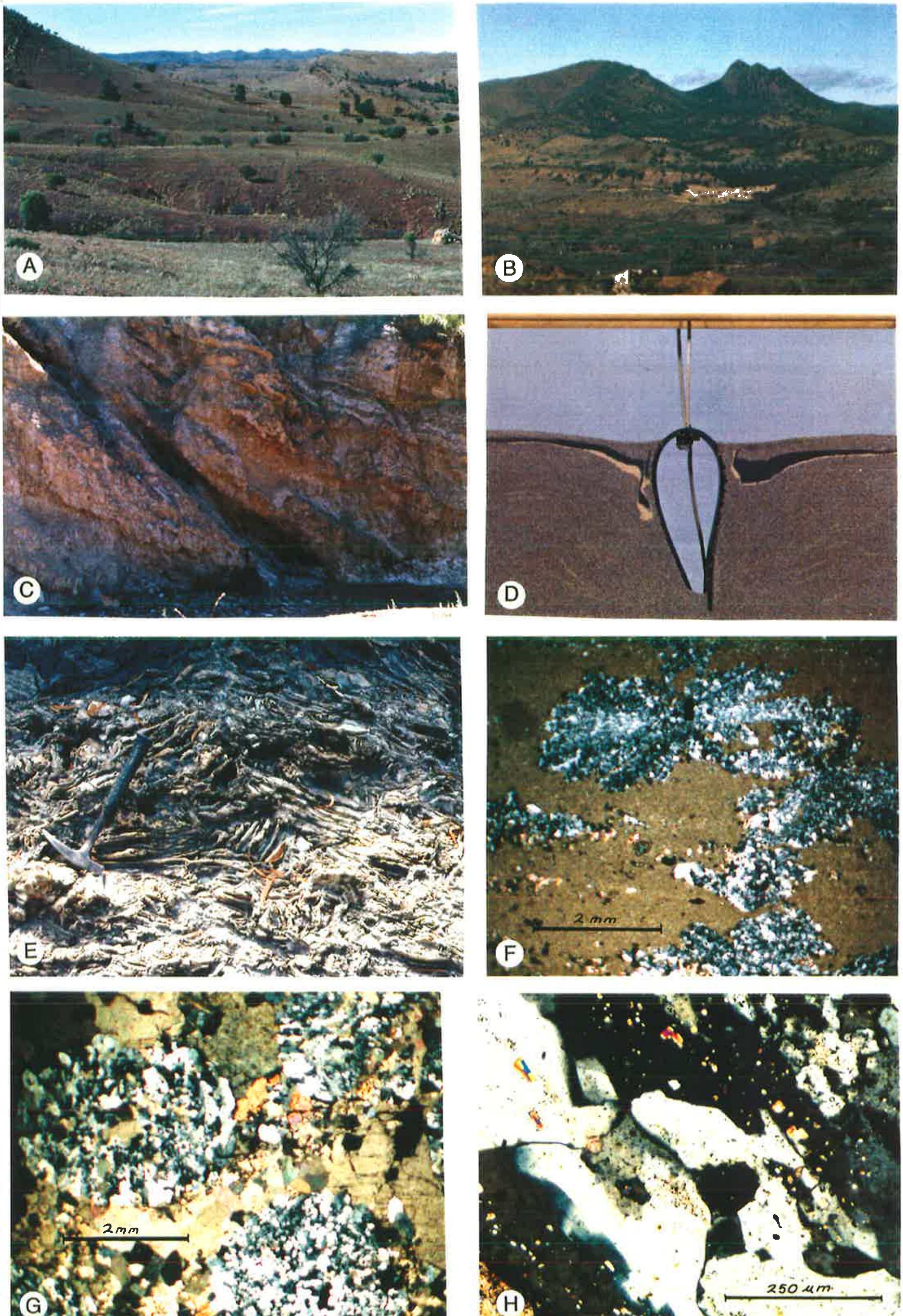
Although a range of minerals has been found in the salt plugs, specular, botryoidal and massive hematite is dominant. Malachite is often found in chloritic veins.

Areas of poor outcrop, directly related to evaporites, gypsum and anhydrite, have been recognized in the Enorama Diapir. A large raft, with bold outcrops of sabkha-style dolomite at one end, has been mapped near Dedmans Bore. Striking silica psuedomorphs of gypsum rosettes are common in the dolomite (see Plate 7) and these become more abundant to the south until they dominate the rock. At this stage, a "chicken-wire" texture, typical of anhydrite, is preserved in the siliceous outcrop. The outcrop becomes far less prominent further south and a large area, 500m by 50m, of rubbly ground indicates a parent rock with low resistance to erosion. This rubble is interspersed with fist-sized nodules of silica with gypsum and anhydrite textures and psuedomorphs. Thin sections show relict anhydrite trapped in the silica (819-30, 35, 36 and 139, Plate 7). This is conclusive evidence of more extensive evaporites associated with the diapirs than the ubiquitous halite casted sandstones found in most of the breccias. If it were not for the fact that the suite from Iran is found surrounded by halite and anhydrite in presently active salt plugs, the same controversy as to their origin and emplacement as accompanies the Flinders Ranges breccias would also surround them.

The nature of the Callanna Group and their sedimentary setting provides some insight into the possible reason for their inclusion into diapiric breccias.

Preiss (1987), discusses the useage of the term "geosyncline" with respect to the sediments of the Adelaide Foldbelt and agrees that, in its broadest definition as a large repository of a thick sedimentary successsion, the Adelaidean basin is a geosyncline. An earlier paper, (Preiss, 1983), notes the similarity between the Adelaidean sediment package and the type Atlantic passive margin as described by Watts (1981). Such a passive margin sequence is a major part of a geosynclinal sequence.

The rift nature of the Callanna and Burra Group sediments, the lower Adelaidean units, has been commented on by Preiss (1983, 1987), and von der Borch (1980). Rowlands et al. (1980), describe the Callanna sequence in the Willouran Ranges as graben-controlled sabkha and playa sediments. Pseudomorphs of the sodium carbonate mineral suite, typical of continental early rift deposits, are common. Kinsman (1975), estimates an 80% probability that physical restriction to marine influx will occur in a developing rift. As evaporitic conditions were known to be operational


A
B
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2 mm
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during Callanna sedimentation, the same probability applies to the existence of a salt sequence at the base of the Adelaidean. Kinsman's proposition is that geosynclines should be commonly floored by evaporites.

Thick salt sequences can occur at two levels in a rift; associated with the earliest playa and salina environments and again at the level of the first marine influx. This is discussed in the chapter on Diapir Recognition and Modelling; the location of diapirs. The vast majority of the Callanna Group is known from outcrops around the margins of the present foldbelt. While extensive evaporites have not been observed from these areas, such sequences are more likely to have developed in the central parts of the basin where they are now covered by later sediments.

The lower half of the sequence in the Central Australian Amadeus Basin is the time equivalent of the Adelaidean sequence and the unit thought to be equivalent to the Callanna Group, the Bitter Springs Formation, is known to contain evaporites, (Wells, 1979, and Froelich and Kreig, 1969). These evaporites have been mobilized into salt anticlines and diapirs, (McNaughton, 1968, Wells, 1976 and Cook, 1971).

Only salt and shale are known to behave diapirically. The modelling of Bishop (1978), predicts that extrusive shale diapirs will not be common but that salt diapirs will erupt to the surface if there is a sufficient source of supply. Entrained diapiric debris in surrounding sediments is common around most Flinders Ranges diapirs where those sediments deposited during the diapir stage of movement are still preserved and exposed nearby. However, as mentioned above, there is a considerable amount of highly contorted shale in many of the breccia outcrops and it is possible that overpressured shale also behaved diapirically to move along with salt in the early formed diapirs.

The similarity in fold style between the Mt. Lofty - Olary belt of the Adelaide Foldbelt, (a combination of the South Flinders Zone, Houghton Anticlinal Zone, Kanmantoo Trough and Inner Nackara Arc on Fig.5) and that of the Jura, implies the possibility of a decollement at the level of the Callanna Group, (Rutland et al., 1981). Evaporite sequences provide the most common decollement surfaces. Murrell (1977), attributed many structures in the Callanna and Burra Groups in the Willouran Ranges to soft sediment movement with mobility enhanced by intercalated evaporites.

The source beds to the Flinders Ranges diapirs have remained potentially mobile for a considerable period of time. The Callanna Group was deposited at around 800Ma. at the latest, (Fanning et al., 1986), and diapirs were active until the Middle Cambrian, about 300Ma. later. The same rocks were mobilized/remobilized during the Delamerian Orogeny between 460-500Ma. (Milnes et al., 1977). Evidence of movement has also been found coincident with the Triassic deposition in the coal basins at Leigh Creek around 210Ma. and it is possible that movement caused damming of creeks during the Tertiary and Recent. This suggests that the beds maintained their mobility over 600 million years and possibly 750 million years. Shale would certainly have dewatered and lost its overpressure during that time, especially as that period included a major orogeny and a mild metamorphic event.

CHAPTER 17

SUMMARY: MODELS FOR FLINDERS RANGES DIAPIRS

Catalogue of Diapiric Features

A large number of features directly attributable to diapirism and salt-like movement were found during field mapping. Many of these features have been previously described in the literature but a number of new features have also been found. Some of these features are inferred by earlier workers but now direct evidence has been found in the study area.

Previously described features found during mapping include:

a/. Thinning of the sequence towards the axis of a developing pillow.

b/. Numerous unconformities in the sequence adjacent to a growing structure. These unconformities are more widespread during the pillow stage and are developed only locally during the diapir stage of movement.

c/. Debris, derived from the diapir and comprised of the insoluble components of it, is included in the sediments deposited around the structures during the period of diapir growth.

d/. Secondary peripheral sinks develop adjacent to active structures and are indicative of the diapir stage of movement.

e/. The sedimentary sequence thickens towards the secondary peripheral sink before thinning rapidly on the immediate contact with the diapir.

f/. Shallowing over a developing structure leads to facies variations, especially the development of carbonate facies in an otherwise clastic sequence.

g/. The modification of facies near a diapir occurs over a considerable vertical extent, up to 4000m in the case of the Enorama Diapir.

h/. The shallowing and subsequent unconformities can be expressed as karst surfaces in a carbonate sequence.

i/. Uplift around the growing structure modifies the current directions and sediment dispersal at times of shallow water.

j/. The upturning of sediments adjacent to a diapir.

New features found by mapping, associated with diapirism, not previously described in the literature are as follows:-

a/. The modification of the chemical environment in the vicinity of diapirs, especially during times of basin wide higher sea level but when the diapir intrusion was able to keep up with the rise and remain exposed.

b/. The pulsating nature of a diapiric intrusion and the controlling influence of sea level fluctuations.

c/. The cannibalization of sediments from the crest of the structure into the surrounding sediments.

d/. At times of lowered sea level, additional section may be preserved in the secondary peripheral sink. Subsidence can either create that small basin while there is no ongoing sedimentation elsewhere, or it can protect a small pocket of sediments from erosion.

e/. Control on the position of the secondary peripheral sink may be determined by the fracture pattern associated with a crestal graben developed during the proce-ding pillow stage.

f/. Sediments are turned upwards against a diapir but there is a noticeable increase in dip down section at the boundary between sediments deposited during the pillow and diapir stages. This feature was predicted from the model experiments.

g/. Thickening into the secondary peripheral sink may be accomplished by listric faulting, concave toward the diapir. This feature was also predicted from modelling.

As mentioned in the earlier chapter on diapir modelling, the following features were predicted from sandbox modelling and might be observed if conditions were suitable.

a/. The expansion then contraction of area of the dis/unconformity associated with a salt dome as it passes through the pillow into the diapir stages.

b/. There is likely to be a sharp jump in the geographic position of the sink between the pillow and diapir stages as no appreciable migration of the primary sink was observed.

Nature of the Source Beds

The diapirs in the Adelaidean sequence in the Flinders Ranges were primarily sourced by salt from an extensive evaporite sequence. While no halite beds have yet been identified in any of the Adelaidean sequences, indirect evidence is substantial. This evidence includes:-

The rift setting of the Callanna Group sediments and the likelihood that evaporites floor the Adelaide Geosyncline

Abundant psuedomorphs halite, gypsum, shortite etc. in the brecciated rocks

Areas of outcrop/subcrop after anhydrite in the breccias

The sustained mobility of the source beds through a considerable period of geological time and through an orogeny and associated mild metamorphism

The implied development of a decollement between the basement and sedimentary pile

The similarity between the suite of rafts and inclusions in the Flinders Ranges breccias and the salt plugs of Southern Iran.

Age of Diapirs in the study area

Salt movement has been classified into three main stages and the most distinctive of these is the diapir stage. Diapir development is relatively rapid when compared to the pillow and post diapir stages so that timing of the movement can be determined by the age of sediments in its most characteristic feature, the secondary peripheral sink. Limited outcrop of that particular level near an outcropping diapir may mask the recognition of such a large feature as the sink. However, there are a number of other features associated with the diapir stage which have a more localized development and may be used to time the movement. These may or may not be developed, depending on the rate of rise of the diapir versus the rate of sedimentation in the surrounding basin. These features include:-

a/. The first appearance of a substantial amount of diapir-derived debris in adjacent sediments,

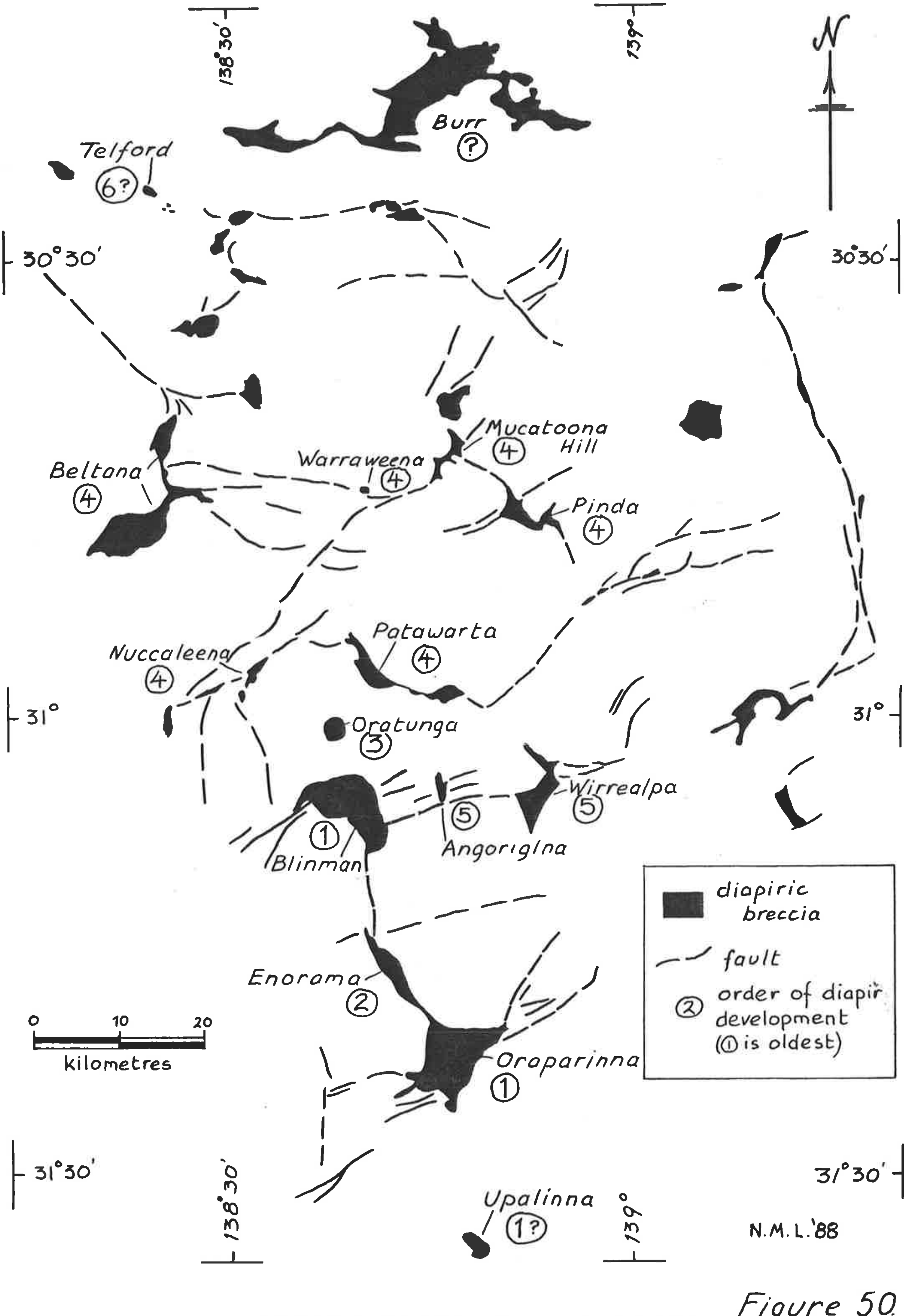


Figure 50

DIAPIR FAMILIES and AGES

b/. A sharp change in the angle of dip of sediments away from the diapir,

c/. Repeated upturning, development of local unconformities and onlap of the overlying sediments.

The disposition of outcrop in the study area prevented the recognition of secondary peripheral sinks around all but the Enorama, Blinman and Oratunga Diapirs. The subsidiary features above became the prime tools in determining the timing of diapir movement. Figure 50 summarizes the ages of most diapirs in the Central Flinders Ranges.

The Blinman and Oraparinna Diapirs are the oldest in the study area. Both of these features developed through the diapir stage during the deposition of the Tapley Hill Formation. These, together with the much smaller Upalinna Diapir, lie along the axis of a major anticline which is roughly coincident with the depositional axis of the basin during the deposition of the Umberatana Group. These are two of the largest features in the Flinders Ranges and could be considered as "mother" stocks, (Trusheim, 1960, Sannemann, 1968). They most probably formed over the thickest evaporite interval in response to Sturtian loading, possibly combined with the major sea level rise that brought on the deposition of the Tapley Hill Formation. All three of these stocks may be formed on a major underlying salt anticline. Mild tectonism recorded between the Burra and Umberatana Groups may have assisted in the initiation of salt movement.

The Enorama Diapir, between the Blinman and Oraparinna Diapirs, was active as a pillow at about the same time as the surrounding diapirs but entered the diapir stage at the beginning of the deposition of the Etina Formation. Diapir movement continued until the base of the Enorama Shale. Loading of the secondary peripheral sinks of the mother diapirs mobilized a different section of the source bed into the Enorama structure.

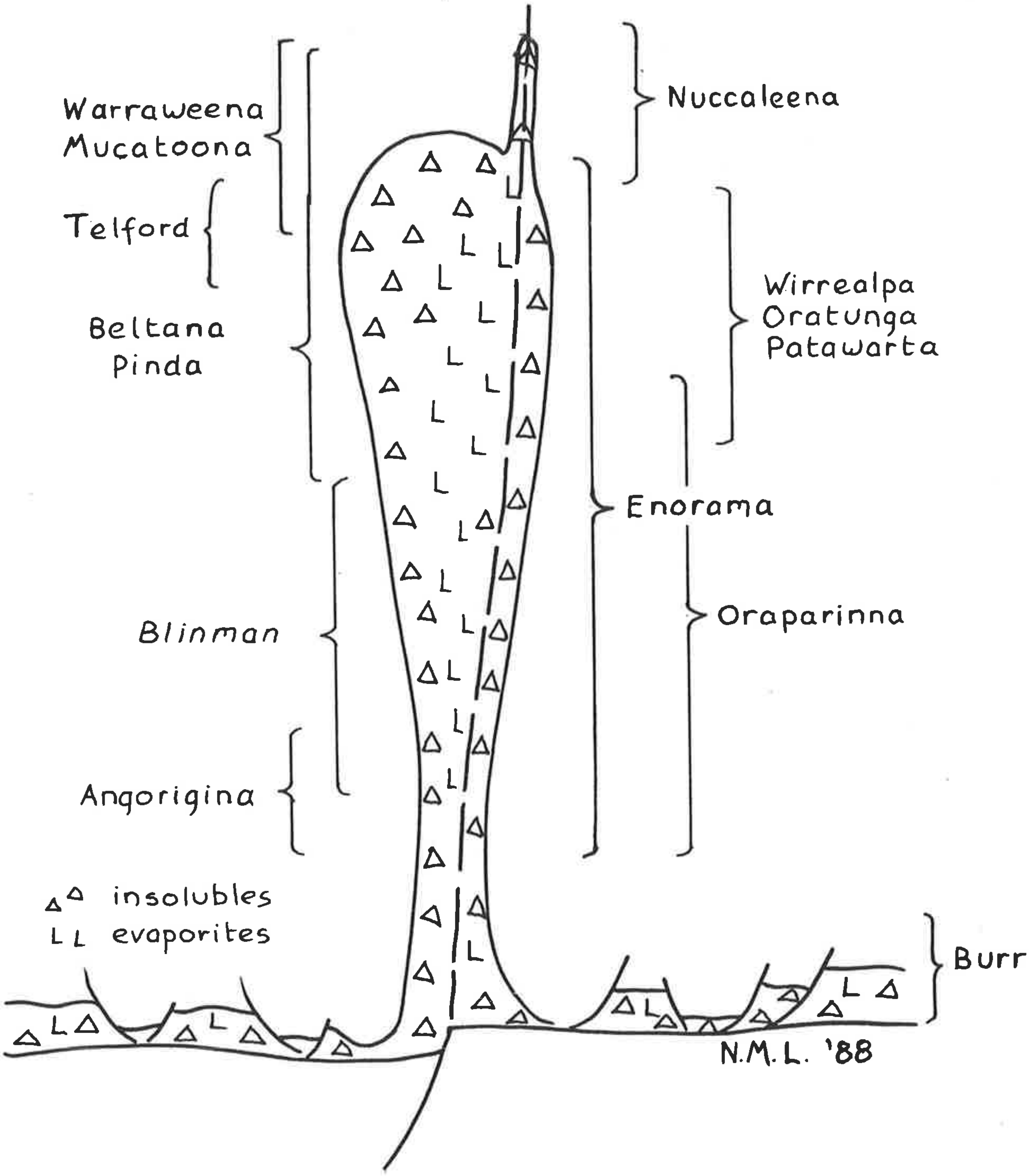
Upturning of sediments with subsequent onlap suggests that the Oratunga Diapir was active from about the time of Trezona deposition and the main secondary sink development culminated during deposition of the lower parts of the Brachina Formation. Loading into the secondary sink of the Blinman Diapir may have squeezed the source layer into a bulge in the vicinity of the developing structure with a deep seated fault responsible for the location and initiation of the main stage of movement. The Enorama and Oratunga Diapirs can therefore be considered as "daughter" diapirs.

A large number of bodies were active as diapirs during the deposition of the Bunyeroo and Wonoka Formations. These all lie along major left lateral wrench faults which appear to cut right across the basin. The Beltana-Warraweena-Mucatoona-Pinda line was a platform to slope margin at that time, (Haines, 1987), and the diapirism could be related to that. However, the Patawarta Diapir on the Nuccaleena-Patawarta-Mt. Roebuck line was also active. It appears that the diapirism and the platform margin were controlled by sinistral wrenching. Bunyeroo and Wonoka sediments outcrop too far from the Nuccaleena and Mt. Roebuck domes to prove activity at that time although the Nuccaleena structure behaved as a pillow during deposition of the Etina to Trezona Formations. Similarly, the Beltana structure was in existence prior to this period of wrench induced diapirism. The Bunyeroo pulse of movement could well be related to the major sea level rise at that time but another overriding control is suggested by the continuation of movement as relative sea levels fell right through to the deposition of the Bonney Sandstone.

Another major sinistral wrench connects the Blinman, Angorigina and Wirrealpa Diapirs. This wrench continues further to the ENE to the Mt. Chambers Diapir. Thickness changes in the Etina Formation, (see Fig.14), suggest this wrench may have been active as early as then, already forming bulges in the source layers. The Angorigina and Wirrealpa Diapirs were active during the Early Cambrian and the Mt. Chambers feature in the Middle Cambrian. Thickness and facies variations during the Cambrian show that this wrench was also a platform margin at the time but it appears that the wrenching controlled the diapirism and the margin, rather than the margin controlling the diapirism.

Exposure levels of Flinders diapirs

Folding and erosion has exposed various diapirs in the Flinders Ranges to different levels. Only a small vertical interval can be observed where a diapir outcrops in a relatively flat lying sequence and is seen virtually in plan view. This applies to the Blinman and Oraparinna Diapirs which outcrop on the crest of an anticline with sediments dipping away in all directions. Diapirs which outcrop in a dipping sequence show considerable vertical extent, such as the Enorama Diapir. Figure 51 shows the approximate level of exposure of all the "diapirs" studied against an idealized model. The Angorigina Diapir was active during the Lower Cambrian but its present outcrop is fault bounded within lower Wilpena Group sediments, representing the neck of the structure. Where the level of exposure is near the level of the secondary peripheral sink, the true diapir



LEVEL of EXPOSURE of DIAPIRS plotted against idealized model

Figure 51.

level can be seen.

Many of the structures show a remobilization of breccia into post-emplacement faults. Such areas of breccia may be better called "injection breccias" with the Thompson Gap Diapir, (Mount, 1975) and several small bodies around the Nuccaleena Dome being good examples. Most of the diapirs in the Flinders Ranges have been remobilized to some extent by later compressional events so that very few of them can be strictly called diapirs.

There are several large, irregular areas of breccia outcrop in the Northern Flinders Ranges. These outcrop within sediments close to the base of the Adelaidean sequence and represent the evacuation of a source horizon. The Burr "Diapir" is a good example of this with large blocks of the overlying Burra Group collapsed down into the evacuation level.

Influence of diapirs on later structural development

The relatively incompetent vertical mass of a diapir in a body of more competent sediments acts as a "strain sink" when a later tectonic stress is applied. While it is difficult to envisage what is the cause and what is the effect, the fact remains that groups of diapirs in the study area are linked by major sinistral faults. The faults may have helped to localize and initiate the diapirs. Alternatively, the presence of zone of weakness in the sedimentary pile may have acted to focus the development of the fractures, (see Fig.50).

Faults active after the emplacement of a diapir enter the breccia on a different line from the exit position. Wrench movement across such a step can lead to either extension or compression. Most of the Flinders breccias show compression as one or more boundaries has become a thrust margin. The moving block may override the breccia or simply remobilize it and force it towards the surface, flattening the body in plan view.

Large salt features at depth, such as anticlines and pillows, will have already bowed up the overlying sediments and may control the position of anticlines, which form from a later compressional event.

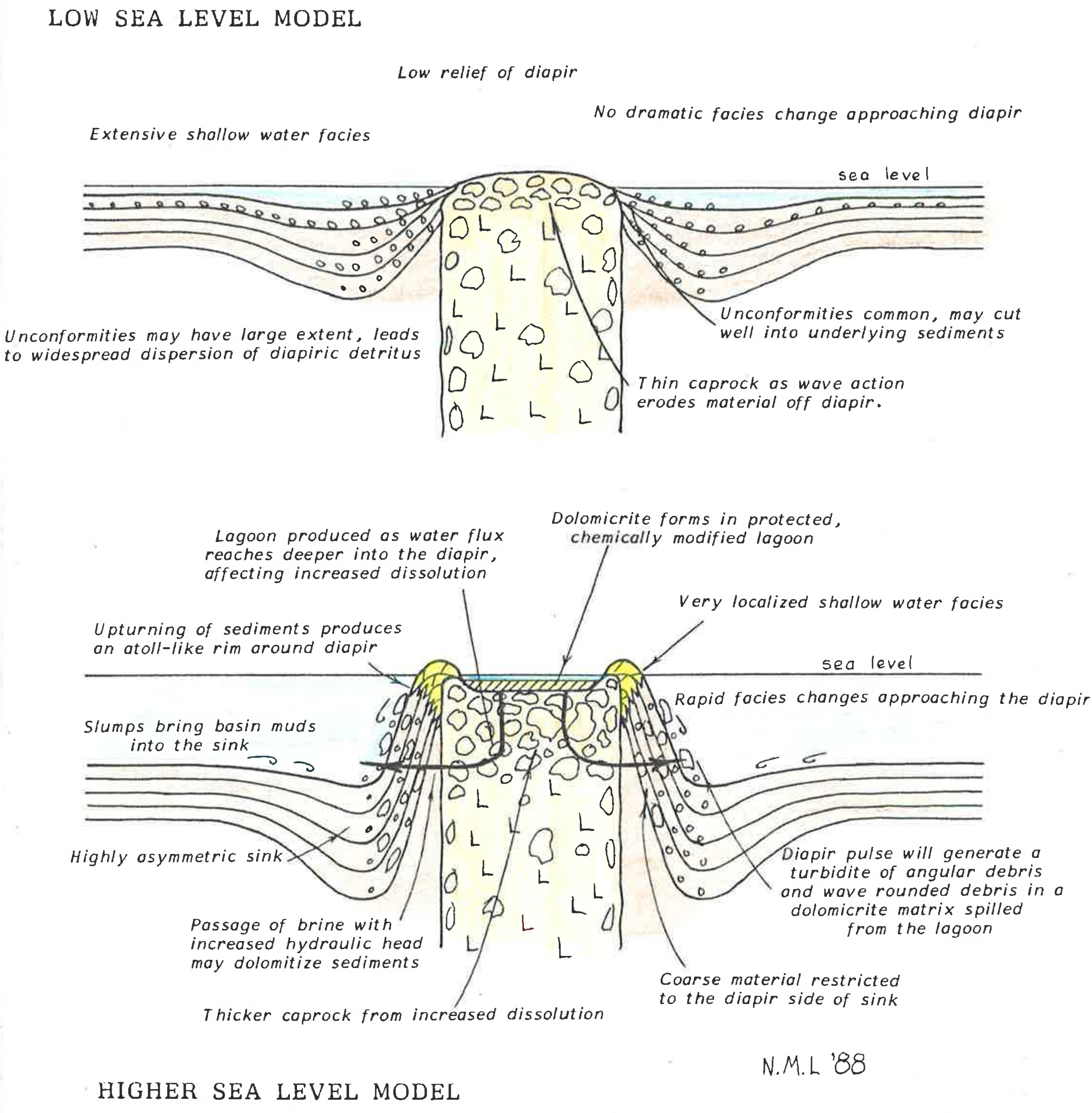
Models for Sedimentary Development around Diapirs

Models for diapir-influenced deposition can be built, based on the features outlined above and other sedimentary features found during the detailed mapping of the study area. The models are in two parts as there are distinct differences in the patterns between times of shallow water and times of raised sea levels. Figure 52 provides a summary of the models.

At times of low sea levels, there will be low relief on the diapir. Subaerial erosion and wave activity will act to remove the insoluble debris from the structure. Decreased loading of the basin due to the sea level drop will slow activity on the diapir and add to the reduction in relief. The caprock is likely to be thin as it has been eroded away. Unconformities will be widespread at this time and detritus will be widely dispersed by tidal currents and perhaps by short rivers. All the debris is likely to be reasonably well rounded as it will have been exposed to wave activity. The water level will be shallow everywhere and so there will be no dramatic facies changes near the diapir. The beach around the structure will be dominated by sand and gravel to the detriment of carbonate sediments. The lack of early cementation will not afford any protection to the caprock.

At times of raised sea level, diapir activity will increase as the depth of water loads the basin and the source horizon. The diapir will have a higher relief off the sea floor as the majority of erosion takes place at sea level. Unconformities will be restricted to the immediate vicinity of the diapir although there will be marked thinning of units up the slopes around the diapir. There will be numerous slumps of diapiric debris down the steep slopes and these will grade out into turbidites. Coarse material will be restricted to the peripheral sink and largely confined to the diapir side of the sink. Rapid shallowing around the diapir will be expressed as rapid facies changes.

Water will circulate through the top of the diapir. As the evaporites dissolve, the density of the water will increase and the depth of the sea floor in the sink will allow the brine to pass through the diapir and upturned sediments. The movement of brine has the potential to dolomitize the surrounding sediments. This water circulation will dissolve the diapir to a greater depth, create a thicker cap rock and, by removing so much material, create a depression over the diapir. Sediments dragged up against the diapir will not dissolve but provide an atoll-like rim to protect the inner lagoon. This rim may be stabilized by carbonate deposition such as a reef. The lowering of the caprock by dissolution below will remove some of the local clastic source and allow carbonate deposition to dominate.



MODELS FOR EXPOSED DIAPIRS

Figure 52.

The protected lagoon inside the atoll may have altered salinities due to the evaporites below. High salinities may lead to the inclusion of evaporites in turbidites adjacent to the diapir. Warm shallow water inside the lagoon may encourage the precipitation of micrite, particularly from a Precambrian sea. The altered chemistry in the lagoon may have allowed dolomicrite to form or the micrite may have become dolomitized after sedimentation by the action of circulating brine.

Diapir-derived sediments at deeper water times will consist of some wave rounded material and angular blocks of breccia, which bypass the atoll rim, mixed in a matrix of dolomicrite spilled from the lagoon. Lagoonal muds may become quite well dispersed around the diapir to give a dolomitic halo to the diapir in the surrounding sediments.

Concluding remarks

There is little doubt that many of the breccia bodies outcropping in the Flinders Ranges are the result of diapiric activity. The Callanna Group sediments are widely accepted as the source beds. Evaporites must have been involved in the diapirism although extensive evaporites in that part of the succession have yet to be proven. The folding and subsequent semi-arid erosion of the region has left excellent outcrop which permits detailed study of the structural and geochemical features of the diapirs. This thesis outlines many of those features and adds to the list of diagnostic features from which diapirs can be recognized. However, many of the diapirs have been the focus of later structural complication so that very few of the breccia bodies in the Flinders Ranges can be truly labelled as diapirs. The most acceptable common name for the majority of them is "diapirically associated breccias".

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APPENDIX I

THE STUDY AREA

This is a description of the study area in geographic, topographic and cultural terms.

THE STUDY AREA

Location

Investigations were carried out over a large part of the Central Flinders Ranges. The area is approximately 120 km north-south by 90km east-west between latitudes 30°30'S and 31°40'S and longitudes 138°20'E and 139° 15'E. Detailed mapping and section measurement were restricted to the area around the Oraparina, Enorama, Blinman and Oratunga Diapirs in the central part of the area defined above, an area of about 1750 square kilometres. Investigations in the larger area consisted of aerial photo interpretation and short field visits. Field work was carried out from June, 1983 to August, 1987.

Geological setting

The study area is in the central northern portion of the Adelaide Geosyncline with outcrop of the upper 3/5 of the geosynclinal fill. A broad north-south trending anticline dominates the main part of the area. The plunge along this structure varies as the bedding dips away from the Blinman, Enorama, Oraparinna and Upalinna Diapirs which intrude along the axis.

Virtually the entire middle Adelaidean Umberatana Group outcrops in the central parts of this anticline. Traverses to the east and west of the anticlinal axis pass through a fairly continuous stratigraphic section up into the Middle Cambrian Lake Frome Group, in all about 8-10,000m of section. Dips in the central part of the area are low (0°- 20°) but steepen to 35°- 40° toward the edges. Local areas of very steep to vertical dips are found adjacent to the diapirs.

Skeletal soils and low vegetation density, together with numerous creeks and gullies, give excellent outcrop exposures, ideal for mapping.

Reasons for choosing this location as a study area include the ease of access, reports of diapir activity at the time of deposition of the upper Etina Formation, the wide distribution of that unit around several of the diapirs in the area and a certain amount of prior local knowledge. Alternations between shale and limestone bands in the upper Etina Formation were largely controlled by sea level fluctuations and this provides some degree of time control otherwise absent in Precambrian sequences.

Access

The area of detailed work is centred on the township of Blinman and well maintained unsealed roads radiate to the west to Parachilna, south to Wilpena Pound and Hawker and east to Wirrealpa. The eastern part of the larger area is served by an unsealed road from Hawker to Martins Well and on to Wirrealpa and points north. The western side is serviced by a major sealed road from Hawker to Parachilna and Leigh Creek. Minor government maintained unsealed roads connect between the major roads but access to most outcrops is via private station tracks or across country.

Land Tenure and Use

The majority of the area is covered by pastoral leases, dominantly used for sheep grazing. The more rugged central area has been classified within the "Class A" area defined by the Flinders Ranges Environmental Survey and Management Plan. The plains to the east and west lie within the "B" classification. The Flinders Ranges National Park covers a large portion of the southern part of the study area and a permit was required to work within the park. The area in the immediate vicinity of Blinman and North Blinman (the present town), is subdivided into freehold blocks surrounded by a common. The pastoral industry is the main industry in the area with an important contribution from tourism. Coal mining for electricity generation is localized in the Leigh Creek area.

Physiography and vegetation

Rolling grassy hills with regular parallel rocky ridges separated by wide flats dominate the central and southern parts of the study area. This zone is flanked to the west, north and east by high, rugged ridges and steep tree filled valleys. Alluvial fans coalesce along the outer edges of the ranges, grading out to sandy plains to the east and west.

Map and Photo Base

The area is well covered by geological and topographic maps. The northern half of the state Geological Survey Parachilna 1:250,000 scale map sheet and the southern half of the Copley sheet of the same series give excellent geological coverage of the whole area. The Blinman and Oraparinna 1:63,360 scale geological map sheets cover the central part of the area where the detailed mapping and section measurement was carried out.

The Lands Department of South Australia 1:50,000 scale topographic maps cover the entire area and were used to locate all samples and traverses with Australian Map Grid co-ordinates. Maps in this series used were:-

Artipena, Beltana, Blinman, Cadnia, Copley, Leigh Creek, Oraparinna, The Bunkers, Wilpena and Wirrealpa.

Lands Department of South Australia 1:40,000 scale colour aerial photography from surveys:- 2488, 2499, 2501, 2502, 2694, 2695, 2696, 2704, 2705, 2716, 2717, and 2718 cover the areas of interest on the Copley and Parachilna 1:250,000 scale map sheets. Field mapping was done onto the photos and transferred to 1:50,000 scale topographic maps.

LANDSAT 4 images 98/81 and 98/82 cover the Copley and Parachilna sheets and were used for broad regional mapping.

Field Techniques

A large part of the project consisted of data collection from the field. I include here a brief description of the techniques used in order that the quality of the data from the various areas can be assessed.

The equivalent to the Wundowie Limestone Member, ie. the upper third of the Etina Formation, was mapped and measured in the greatest detail. Near the Blinman and Enorama Diapirs, this consisted of using a modified Jacobs staff to accurately measure thicknesses across strata with dips varying from 1° to 70°. Repeat measurements across several sections showed this instrument to be remarkably accurate even when 1m of section might be exposed across 500m of outcropdown a gentle dip slope as exposed on section 6. Such repeat sections showed about 1m variation in 80m to 100m of section.

The details within the three limestone bands of the Wundowie equivalent were plotted at a scale of 1cm:1m. Sections were spaced between 2 and 5km. along strike where outcrop permitted. The intervening shales were also measure by staffing but a variable scale plot made to take account of boundaries and variations from the normal well laminated shale deposition. As the project progressed and sections measured further from the Blinman and Enorama Diapirs, the scale of the field plot was changed to 1cm:2m.

Key sections were measured using a Jacobs staff through the Enorama Shale and up into the Trezona Formation, Elatina Formation and Nuccaleena Formation. The distinctive dolomites of the Nuccaleena Formation provide a useful regional marker from which to hang many of the sections. The key sections were plotted at a scale of 1cm:1m. with subsequent sections plotted at 1cm:2m.. Sections through the Enorama to Nuccaleena interval were spaced up to 10 - 15km. apart.

Several sections remote from the Central Flinders were measured to provide a regional background to the sedimentation at the time, uninfluenced by local diapiric activity. For example. a section was measure as far east as outcrop permits at Martin's Well and as close as possible to the Torrens Hinge Zone, the western margin of the basin, near Quorn.

The remainder of the stratigraphic section exposed around the Oraparinna, Enorama and Blinman Diapirs, from the Sturtian tillites up the the middle of the Etina Formation, was measured in six localities. Data was collected along field traverses, plotted onto aerial photographs then transferred as accurately as possible on to the 1:50,000 scale topographic sheets. Using the formula: $x = \sin\theta\,(a + \Delta H/\tan\,\theta)$

where x is the true thickness of the bed,

θ is the average dip of the bed,

a is the horizontal distance perpendicular to strike between the top and bottom of the bed,

ΔH is height of intersection of line of section at the top of the bed minus the height at the bottom of the bed. (May be negative).

Thicknesses measured in this way were checked against several staffed sections and proved to be accurate to within 90% of the staffed value. "Patterton Shale" thicknesses were often measured in this way. Details of how each section was measured is shown in Appendix IV.

Recent 1:40,000 scale colour and black and white aerial photographs are available over 95% of the field area and proved to be an excellent base from which to map. Correlations between sections were commonly made from the aerial photos, particularly in the distinctly interbedded shale-limestone sequences. Where the distinction was less obvious, such as between the Yaltipena Member and the Elatina Formation or within formations, beds were followed by walking or riding. The use of a motorbike allowed up to 50 km. of contacts to be followed per day.

Field mapping, information from measured sections and photointerpretation were combined on a series of overlays on the aerial photographs then transferred to enlargements of the topographic maps. Each boundary was traced on to the final map with continuous adjustment to tie in with the creek intersections, topography and cultural features. The final maps were produced at 1:50,000 scale and are as accurate as possible, without photographic distortion. The final geological maps can be overlain directly on the published topographic maps to allow the construction of sections anywhere using the formula outlined above.

APPENDIX II

Reprint of the paper entitled

Physical modeling of sedimentation adjacent to diapirs and comparison with late Precambrian Oratunga breccia body in Central Flinders Ranges, South Australia.

by N.M. Lemon

which appeared in AAPG Bulletin, Vol.69, No.9, 1985.

Lemon, N.M. (1985). Physical modeling of sedimentation adjacent to diapirs and comparison with late Precambrian Oratunga breccia body in central Flinders Ranges, South Australia. *AAPG Bulletin*, *69*(9), 1327-1338.

APPENDIX III

PETROGRAPHIC DESCRIPTIONS

Petrographic descriptions, together with rock analyses and XRD results, of all samples are included on the enclosed microfiche. To facilitate easy reference, lists of the samples are cross referenced with respect to sample number, collection area, rock type and Australian Map Grid (AMG) co-ordinates.

These lists and an example of the description format are included in type format.

This is a listing of all samples collected for this thesis arranged in numerical order. The accession number prefix for recovery from the University of Adelaide, Department of Geology and Geophysics crypt is 819.

There are two other cross referenced listings; one arranged in order of rock type first then then number and the other in alphabetical order of area and rock type.

NUMBER	AREA	ROCK TYPE	EASTING	NORTHING
819-001	Dedmans Bore	DOLERITE.	278640	6541290
002	Dedmans Bore	BASALT	278590	6541420
003	Mogs Hut	LIMESTONE	274670	6546850
004	Mogs Hut	LIMESTONE	274670	6546850
005	Mogs Hut	LIMESTONE	274670	6546850
006	Mogs Hut	LIMESTONE	274670	6546850
007	Mogs Hut	SILTSTONE	274670	6546850
008	Little Werta	QTZ ARENITE	273010	6547010
009	Little Werta	CONGLOMERATE	273100	6547220
010	Pine Creek	CALC ARENITE	277920	6544730
011	Hostel	LIMESTONE	268150	6553100
012	Hostel	LIMESTONE	268150	6553100
013	Hostel	CONGLOMERATE	268150	6553100
014	White Cutting	SILTSTONE	279340	6551460
015	Gum Creek	SILTSTONE	276420	6546160
016	Gum Creek	SILTSTONE	276430	6546125
017	Gum Creek	SILTSTONE	276250	6546060
018	Gum Creek	SILTSTONE	276400	6545740
019	Gum Creek	SILTSTONE	276370	6545600
020	Gum Creek	SILTSTONE	276300	6545500
021	Gum Creek	SILTSTONE	276250	6545450
022	Gum Creek	SILTSTONE	276230	6545400
023	Gum Creek	SILTSTONE	276100	6545180
024	Gum Creek	SILTSTONE	276120	6545000
025	Mount Emily	SILTSTONE	279080	6547400
026	Mount Emily	SILTSTONE	279100	6547370
027	Mount Emily	SILTSTONE	279620	6547360
028	Mount Emily	SILTSTONE	279080	6547460
029	Dedmans Bore	QTZ ARENITE	277500	6541530
030	Dedmans Bore	DOLOMITE	277440	6541470
031	Dedmans Bore	DOLOMITE	277670	6541450
032	Dedmans Bore	SILTSTONE	277490	6542490
033	Dedmans Bore	SILTSTONE	276880	6542960
034	Dedmans Bore	CONGLOMERATE	278140	6541260
035	Dedmans Bore	DOLOMITE	277880	6541160
036	Dedmans Bore	DOLOMITE	277880	6541160
037	Dedmans Bore	CONGLOMERATE	277760	6541130
038	Dedmans Bore	CALCITE	278620	6541800
039	Dedmans Bore	DIAMICTITE	278250	6541350
040	Dedmans Bore	LIMESTONE	278070	6541420
041	Dedmans Bore	CONGLOMERATE	277940	6541400
042	Dedmans Bore	DIAMICTITE	277940	6541400
043	Guide Hut	LITH ARENITE	284000	6539700
044	Willigon	CONGLOMERATE	269500	6564440
045	Willigon	BRECCIA	272480	6565575
046	Willigon	QTZ ARENITE	272513	6565574
047	Willigon	MUDSTONE	272514	6565573
048	Willigon	LITH ARENITE	272515	6565572
049	Willigon	BRECCIA	272520	6565565
050	Willigon	CONGLOMERATE	272630	6565250

819-051	Willigon	BRECCIA	272670	6565280
052	Willigon	DOLERITE	273180	6565370
053	Willigon	BASALT	273180	6565370
054	Willigon	QTZ ARENITE	273120	6565310
055	Willigon	BRECCIA	273120	6565700
056	Willigon	DOLOMITE	273820	6565720
057	Willigon	QTZ ARENITE	275000	6567000
058	Oratunga	SILTSTONE	274270	6559820
059	Oratunga	LITH ARENITE	274270	6559820
060	Oratunga	GNEISS	277050	6558225
061	Willigon	GOSSAN	272130	6566280
062	Willigon	GOSSAN	273040	6564750
063	Willigon	GOSSAN	273060	6564750
064	Willigon	GOSSAN	272890	6565000
065	Willigon	GOSSAN	272760	6564060
066	Willigon	DIAPIR ROCK	273780	6565070
067	Willigon	DIAPIR ROCK	273780	6565070
068	Willigon	SILTSTONE	273920	6565500
069	Willigon	GOSSAN	274160	6567640
070	Willigon	BRECCIA	273470	6567650
071	Willigon	BRECCIA	273470	6567650
072	Willigon	FELDS ARENITE	271360	6566900
073	Moolooloo	DIAMICTITE	268080	6566420
074	Moolooloo	DOLOMITE	268020	6566520
075	Moolooloo	SHALE	267990	6566575
076	Moolooloo	FELDS ARENITE	267920	6566580
077	Moolooloo	GOSSAN	267430	6566170
078	Moolooloo	DOLOMITE	267150	6565700
079	Moolooloo	BASALT	267000	6565450
080	Moolooloo	SHALE	267710	6564300
081	Moolooloo	SILTSTONE	268120	6564140
082	Moolooloo	SILTSTONE	268370	6564300
083	Moolooloo	SILTSTONE	268000	6565000
084	Moolooloo	QTZ ARENITE	268720	6568440
085	Moolooloo	SILTSTONE	268730	6568120
086	Glasses Gorge	FELDS ARENITE	273320	6560390
087	Mount Emily	CALC ARENITE	279870	6547160
088	Charlies Camp	BRECCIA	269970	6546100
089	Charlies Camp	LIMESTONE	272270	6544050
090	Charlies Camp	LITH ARENITE	271960	6544020
091	Charlies Camp	LITH ARENITE	271960	6544020
092	Enorama	CONGLOMERATE	283150	6533100
093	Enorama	LIMESTONE	283150	6533100
094	Bulls Gap	DIAMICTITE	275000	6540425
095	Puttapa Gap	CONGLOMERATE	252280	6598140
096	Trebilcock Gap	QTZ ARENITE	245190	6590700
097	Trebilcock Gap	CONGLOMERATE	246100	6592360
098	Puttapa Gap	DOLOMITE	251040	6599430
099	Puttapa Gap	DOLOMITE	251050	6599500
100	Puttapa Gap	DOLOMITE	251050	6599770
101	Puttapa Gap	DOLOMITE	251050	6599770
102	Puttapa Gap	SHALE	250910	6599800
103	Dedmans Bore	DOLOMITE	277720	6541650
104	Dedmans Bore	DOLOMITE	277640	6541740
105	Dedmans Bore	LIMESTONE	277680	6541700
106	Dedmans Bore	CONGLOMERATE	277550	6541800
107	Dedmans Bore	SILTSTONE	277420	6541830
108	Bulls Gap	CONGLOMERATE	275070	6540750
109	Bulls Gap	CONGLOMERATE	275070	6540750
110	Dedmans Bore	LIMESTONE	278390	6541150
111	Red Range	CONGLOMERATE	280100	6540770
112	Bulls Gap	FELDS ARENITE	274050	6541670

819-113	Bulls Gap	QTZ ARENITE	274050	6541670
114	Doodneys Well	QTZ ARENITE	288200	6544900
115	Doodneys Well	QTZ ARENITE	288200	6544900
116	Doodneys Well	SILTSTONE	288200	6544900
117	Enorama	CONGLOMERATE	278380	6538900
118	Trezona Bore	CONGLOMERATE	275950	6535080
119	Nildottie Gap	QTZ ARENITE	288720	6561170
120	Nildottie Gap	QTZ ARENITE	288705	6561080
121	Careys	QTZ ARENITE	288070	6556130
122	Careys	QTZ ARENITE	286000	6556675
123	Nuccaleena	DOLOMITE		
124	Charlies Camp	LITH ARENITE	271900	6543980
125	Charlies Camp	MUDSTONE	271900	6543980
126	Glasses Gorge	FELDS ARENITE	273345	6560300
127	Glasses Gorge	DOLOMITE	272700	6561780
128	Glasses Gorge	DOLOMITE	272700	6561780
129	Trezona Bore	DIAMICTITE	276400	6535470
130	Bennett Springs	DIAMICTITE	288760	6545190
131	Bennett Springs	CONGLOMERATE	288760	6545190
132	Dedmans Bore	LITH ARENITE	277850	6542340
133	Dedmans Bore	SILTSTONE	277380	6542520
134	Dedmans Bore	LIMESTONE	277620	6541730
135	Dedmans Bore	LIMESTONE	277620	6541730
136	Dedmans Bore	LIMESTONE	277620	6541730
137	Doodney's Well	LIMESTONE	286650	6546620
138	Asbestos Mine	QTZ ARENITE	283270	6533600
139	Dedmans Bore	DOLOMITE	277430	6541470
140	Bulls Gap	QTZ ARENITE	275070	6540750
141	Bulls Gap	LIMESTONE	275550	6540950
142	Depot Flat	LIMESTONE	778680	6426890
143	Depot Flat	LIMESTONE	778710	6426890
144	Depot Flat	LIMESTONE	778740	6426890
145	Depot Flat	LIMESTONE	778750	6426890
146	Depot Flat	LIMESTONE	778760	6426890
147	Depot Flat	DOLOMITE	778765	6426890
148	Pichi Richi Pass	LIMESTONE	779900	6410300
149	Depot Flat	TUFF	778280	6427000
150	Etina Creek	CONGLOMERATE	274540	6530650
151	Loop Road	SILTSTONE	266290	6462740
152	Loop Road	LIMESTONE	265810	6563000
153	Kirbin Well	BRECCIA	264580	6557450
154	Kirbin Well	BRECCIA	264580	6557450
155	Kirbin Well	LIMESTONE	264670	6557360
156	Brachina Turnoff	LIMESTONE	280130	6531650
157	Brachina Turnoff	LIMESTONE	280070	6531700
158	Brachina Turnoff	LITH ARENITE	279780	6532070
159	Brachina Turnoff	SHALE	279320	6532280
160	Yuonconna	SHALE	277600	6530380
161	Enorama	DOLOMITE	280540	6536080
162	Enorama	CONGLOMERATE	280540	6536080
163	Enorama	CONGLOMERATE	280540	6536080
164	Enorama	BRECCIA	279850	6537000
165	Enorama	DOLOMITE	279630	6537110
166	Enorama	DOLOMITE	279600	6537120
167	Enorama	LITH ARENITE	279610	6537100
168	Enorama	LITH ARENITE	279630	6537050
169	Enorama	DOLOMITE	279750	6537000
170	Enorama	CONGLOMERATE	280552	6533850
171	Enorama	CONGLOMERATE	281830	6534850
172	Trezona Camp	CONGLOMERATE	274540	6530650
173	Trezona Camp	DOLOMITE	274630	6531000
174	Trezona Camp	LITH ARENITE	274500	6530240

819-175	Enorama	LITH ARENITE	280540	6536010
176	Enorama	SILTSTONE	280300	6535950
177	Pumpa Bore	DOLOMITE	284300	6535330
178	Pumpa Bore	LIMESTONE	284680	6536010
179	Pumpa Bore	FELDS ARENITE	284900	6536560
180	Elatina Hut	SILTSTONE	275530	6528450
181	Horns Camp	DIAMICTITE	275000	6554995
182	Horns Camp	LITH ARENITE	274810	6554550
183	Horns Camp	SHALE	275025	6553730
184	Winna	FELDS ARENITE	275200	6552450
185	Winna	LITH ARENITE	275580	6552230
186	Winna	LIMESTONE	275100	6550150
187	Mallee Water	DOLOMITE	281450	6538370
188	White Cutting	DOLOMITE	279175	6551370
189	White Cutting	SILTSTONE	279130	6551420
190	Racecourse	SILTSTONE	280700	6554095
191	Racecourse	SILTSTONE	280740	6554075
192	Racecourse	SILTSTONE	280770	6554050
193	Racecourse	SILTSTONE	280830	6554035
194	Racecourse	LIMESTONE	280890	6554020
195	Dedmans Bore	DIAMICTITE	277890	6541400
196	Depot Flat	SILTSTONE	778615	6426895
197	Depot Flat	LIMESTONE	778620	6426900
198	Depot Flat	LIMESTONE	778644	6426855
199	Enorama	LITH ARENITE	279780	6536250
200	Winnitinny Creek	LIMESTONE	298090	6528300
201	Martins Well	LIMESTONE	327780	6522360

This is a listing of all samples collected in the thesis area with the prefix 819-. The heirarchy for ordering is rock type first, then area, followed by sample number.

ROCK TYPE	AREA	NUMBER	EASTING	NORTHING
BASALT	Dedmans Bore	002	278590	6541420
BASALT	Willigon	053	273180	6565370
BASALT	Moolooloo	079	267000	6565450
BRECCIA	Willigon	045	272480	6565575
BRECCIA	Willigon	049	272520	6565565
BRECCIA	Willigon	051	272670	6565280
BRECCIA	Willigon	055	273120	6565700
BRECCIA	Willigon	070	273470	6567650
BRECCIA	Willigon	071	273470	6567650
BRECCIA	Charlies Camp	088	269970	6546100
BRECCIA	Kirbin Well	153	264580	6557450
BRECCIA	Kirbin Well	154	264580	6557450
BRECCIA	Enorama	164	279850	6537000
CALC ARENITE	Pine Creek	010	277920	6544730
CALC ARENITE	Mount Emily	087	279870	6547160
CALCITE	Dedmans Bore	038	278620	6541800
CONGLOMERATE	Little Werta	009	273100	6547220
CONGLOMERATE	Hostel	013	268150	6553100
CONGLOMERATE	Dedmans Bore	034	278140	6541260
CONGLOMERATE	Dedmans Bore	037	277760	6541130
CONGLOMERATE	Dedmans Bore	041	277940	6541400
CONGLOMERATE	Willigon	044	269500	6564440
CONGLOMERATE	Willigon	050	272630	6565250
CONGLOMERATE	Enorama	092	283150	6533100
CONGLOMERATE	Puttapa Gap	095	252280	6598140
CONGLOMERATE	Trebilcock Gap	097	246100	6592360
CONGLOMERATE	Dedmans Bore	106	277550	6541800
CONGLOMERATE	Bulls Gap	108	275070	6540750
CONGLOMERATE	Bulls Gap	109	275070	6540750
CONGLOMERATE	Red Range	111	280100	6540770
CONGLOMERATE	Enorama	117	278380	6538900
CONGLOMERATE	Trezona Bore	118	275950	6535080
CONGLOMERATE	Bennett Springs	131	288760	6545190
CONGLOMERATE	Etina Creek	150	274540	6530650
CONGLOMERATE	Enorama	162	280540	6536080
CONGLOMERATE	Enorama	163	280540	6536080
CONGLOMERATE	Enorama	170	280552	6533850
CONGLOMERATE	Enorama	171	281830	6534850
CONGLOMERATE	Trezona Camp	172	274540	6530650
DIAMICTITE	Dedmans Bore	039	278250	6541350
DIAMICTITE	Dedmans Bore	042	277940	6541400
DIAMICTITE	Moolooloo	073	268080	6566420
DIAMICTITE	Bulls Gap	094	275000	6540425
DIAMICTITE	Trezona Bore	129	276400	6535470
DIAMICTITE	Bennett Springs	130	288760	6545190
DIAMICTITE	Horns Camp	181	275000	6554995
DIAMICTITE	Dedmans Bore	195	277890	6541400
DIAPIR ROCK	Willigon	066	273780	6565070
DIAPIR ROCK	Willigon	067	273780	6565070
DOLERITE	Willigon	052	273180	6565370
DOLERITE.	Dedmans Bore	001	278640	6541290
DOLOMITE	Dedmans Bore	030	277440	6541470
DOLOMITE	Dedmans Bore	031	277670	6541450
DOLOMITE	Dedmans Bore	035	277880	6541160
DOLOMITE	Dedmans Bore	036	277880	6541160
DOLOMITE	Willigon	056	273820	6565720

ROCK TYPE	AREA	NUMBER	EASTING	NORTHING
DOLOMITE	Moolooloo	074	268020	6566520
DOLOMITE	Moolooloo	078	267150	6565700
DOLOMITE	Puttapa Gap	098	251040	6599430
DOLOMITE	Puttapa Gap	099	251050	6599500
DOLOMITE	Puttapa Gap	100	251050	6599770
DOLOMITE	Puttapa Gap	101	251050	6599770
DOLOMITE	Dedmans Bore	103	277720	6541650
DOLOMITE	Dedmans Bore	104	277640	6541740
DOLOMITE	Nuccaleena	123		
DOLOMITE	Glasses Gorge	127	272700	6561780
DOLOMITE	Glasses Gorge	128	272700	6561780
DOLOMITE	Dedmans Bore	139	277430	6541470
DOLOMITE	Depot Flat	147	778765	6426890
DOLOMITE	Enorama	161	280540	6536080
DOLOMITE	Enorama	165	279630	6537110
DOLOMITE	Enorama	166	279600	6537120
DOLOMITE	Enorama	169	279750	6537000
DOLOMITE	Trezona Camp	173	274630	6531000
DOLOMITE	Pumpa Bore	177	284300	6535330
DOLOMITE	Mallee Water	187	281450	6538370
DOLOMITE	White Cutting	188	279175	6551370
FELDS ARENITE	Willigon	072	271360	6566900
FELDS ARENITE	Moolooloo	076	267920	6566580
FELDS ARENITE	Glasses Gorge	086	273320	6560390
FELDS ARENITE	Bulls Gap	112	274050	6541670
FELDS ARENITE	Glasses Gorge	126	273345	6560300
FELDS ARENITE	Pumpa Bore	179	284900	6536560
FELDS ARENITE	Winna	184	275200	6552450
GNEISS	Oratunga	060	277050	6558225
GOSSAN	Willigon	061	272130	6566280
GOSSAN	Willigon	062	273040	6564750
GOSSAN	Willigon	063	273060	6564750
GOSSAN	Willigon	064	272890	6565000
GOSSAN	Willigon	065	272760	6564060
GOSSAN	Willigon	069	274160	6567640
GOSSAN	Moolooloo	077	267430	6566170
LIMESTONE	Mogs Hut	003	274670	6546850
LIMESTONE	Mogs Hut	004	274670	6546850
LIMESTONE	Mogs Hut	005	274670	6546850
LIMESTONE	Mogs Hut	006	274670	6546850
LIMESTONE	Hostel	011	268150	6553100
LIMESTONE	Hostel	012	268150	6553100
LIMESTONE	Dedmans Bore	040	278070	6541420
LIMESTONE	Charlies Camp	089	272270	6544050
LIMESTONE	Enorama	093	283150	6533100
LIMESTONE	Dedmans Bore	105	277680	6541700
LIMESTONE	Dedmans Bore	110	278390	6541150
LIMESTONE	Dedmans Bore	134	277620	6541730
LIMESTONE	Dedmans Bore	135	277620	6541730
LIMESTONE	Dedmans Bore	136	277620	6541730
LIMESTONE	Doodney's Well	137	286650	6546620
LIMESTONE	Bulls Gap	141	275550	6540950
LIMESTONE	Depot Flat	142	778680	6426890
LIMESTONE	Depot Flat	143	778710	6426890
LIMESTONE	Depot Flat	144	778740	6426890
LIMESTONE	Depot Flat	145	778750	6426890
LIMESTONE	Depot Flat	146	778760	6426890
LIMESTONE	Pichi Richi Pass	148	779900	6410300
LIMESTONE	Loop Road	152	265810	6563000
LIMESTONE	Kirbin Well	155	264670	6557360
LIMESTONE	Brachina Turnoff	156	280130	6531650

ROCK TYPE	AREA	NUMBER	EASTING	NORTHING
LIMESTONE	Brachina Turnoff	157	280070	6531700
LIMESTONE	Pumpa Bore	178	284680	6536010
LIMESTONE	Winna	186	275100	6550150
LIMESTONE	Racecourse	194	280890	6554020
LIMESTONE	Depot Flat	197	778620	6426900
LIMESTONE	Depot Flat	198	778644	6426855
LIMESTONE	Winnitinny Creek	200	298090	6528300
LIMESTONE	Martins Well	201	327780	6522360
LITH ARENITE	Guide Hut	043	284000	6539700
LITH ARENITE	Willigon	048	272515	6565572
LITH ARENITE	Oratunga	059	274270	6559820
LITH ARENITE	Charlies Camp	090	271960	6544020
LITH ARENITE	Charlies Camp	091	271960	6544020
LITH ARENITE	Charlies Camp	124	271900	6543980
LITH ARENITE	Dedmans Bore	132	277850	6542340
LITH ARENITE	Brachina Turnoff	158	279780	6532070
LITH ARENITE	Enorama	167	279610	6537100
LITH ARENITE	Enorama	168	279630	6537050
LITH ARENITE	Trezona Camp	174	274500	6530240
LITH ARENITE	Enorama	175	280540	6536010
LITH ARENITE	Horns Camp	182	274810	6554550
LITH ARENITE	Winna	185	275580	6552230
LITH ARENITE	Enorama	199	279780	6536250
MUDSTONE	Willigon	047	272514	6565573
MUDSTONE	Charlies Camp	125	271900	6543980
QTZ ARENITE	Little Werta	008	273010	6547010
QTZ ARENITE	Dedmans Bore	029	277500	6541530
QTZ ARENITE	Willigon	046	272513	6565574
QTZ ARENITE	Willigon	054	273120	6565310
QTZ ARENITE	Willigon	057	275000	6567000
QTZ ARENITE	Moolooloo	084	268720	6568440
QTZ ARENITE	Trebilcock Gap	096	245190	6590700
QTZ ARENITE	Bulls Gap	113	274050	6541670
QTZ ARENITE	Doodneys Well	114	288200	6544900
QTZ ARENITE	Doodneys Well	115	288200	6544900
QTZ ARENITE	Nildottie Gap	119	288720	6561170
QTZ ARENITE	Nildottie Gap	120	288705	6561080
QTZ ARENITE	Careys	121	288070	6556130
QTZ ARENITE	Careys	122	286000	6556675
QTZ ARENITE	Asbestos Mine	138	283270	6533600
QTZ ARENITE	Bulls Gap	140	275070	6540750
SHALE	Moolooloo	075	267990	6566575
SHALE	Moolooloo	080	267710	6564300
SHALE	Puttapa Gap	102	250910	6599800
SHALE	Brachina Turnoff	159	279320	6532280
SHALE	Yuonconna	160	277600	6530380
SHALE	Horns Camp	183	275025	6553730
SILTSTONE	Mogs Hut	007	274670	6546850
SILTSTONE	White Cutting	014	279340	6551460
SILTSTONE	Gum Creek	015	276420	6546160
SILTSTONE	Gum Creek	016	276430	6546125
SILTSTONE	Gum Creek	017	276250	6546060
SILTSTONE	Gum Creek	018	276400	6545740
SILTSTONE	Gum Creek	019	276370	6545600
SILTSTONE	Gum Creek	020	276300	6545500
SILTSTONE	Gum Creek	021	276250	6545450
SILTSTONE	Gum Creek	022	276230	6545400
SILTSTONE	Gum Creek	023	276100	6545180
SILTSTONE	Gum Creek	024	276120	6545000
SILTSTONE	Mount Emily	025	279080	6547400
SILTSTONE	Mount Emily	026	279100	6547370

ROCK TYPE	AREA	NUMBER	EASTING	NORTHING
SILTSTONE	Mount Emily	027	279620	6547360
SILTSTONE	Mount Emily	028	279080	6547460
SILTSTONE	Dedmans Bore	032	277490	6542490
SILTSTONE	Dedmans Bore	033	276880	6542960
SILTSTONE	Oratunga	058	274270	6559820
SILTSTONE	Willigon	068	273920	6565500
SILTSTONE	Moolooloo	081	268120	6564140
SILTSTONE	Moolooloo	082	268370	6564300
SILTSTONE	Moolooloo	083	268000	6565000
SILTSTONE	Moolooloo	085	268730	6568120
SILTSTONE	Dedmans Bore	107	277420	6541830
SILTSTONE	Doodneys Well	116	288200	6544900
SILTSTONE	Dedmans Bore	133	277380	6542520
SILTSTONE	Loop Road	151	266290	6462740
SILTSTONE	Enorama	176	280300	6535950
SILTSTONE	Elatina Hut	180	275530	6528450
SILTSTONE	White Cutting	189	279130	6551420
SILTSTONE	Racecourse	190	280700	6554095
SILTSTONE	Racecourse	191	280740	6554075
SILTSTONE	Racecourse	192	280770	6554050
SILTSTONE	Racecourse	193	280830	6554035
SILTSTONE	Depot Flat	196	778615	6426895
TUFF	Depot Flat	149	778280	6427000

This is a cross reference listing of all the samples with the prefix 819 collected for this thesis.

AREA	ROCK TYPE	NUMBER	EASTING	NORTHING
Asbestos Mine	QTZ ARENITE	138	283270	6533600
Bennett Springs	CONGLOMERATE	131	288760	6545190
Bennett Springs	DIAMICTITE	130	288760	6545190
Brachina Turnoff	LIMESTONE	156	280130	6531650
Brachina Turnoff	LIMESTONE	157	280070	6531700
Brachina Turnoff	LITH ARENITE	158	279780	6532070
Brachina Turnoff	SHALE	159	279320	6532280
Bulls Gap	CONGLOMERATE	109	275070	6540750
Bulls Gap	CONGLOMERATE	108	275070	6540750
Bulls Gap	DIAMICTITE	094	275000	6540425
Bulls Gap	FELDS ARENITE	112	274050	6541670
Bulls Gap	LIMESTONE	141	275550	6540950
Bulls Gap	QTZ ARENITE	140	275070	6540750
Bulls Gap	QTZ ARENITE	113	274050	6541670
Careys	QTZ ARENITE	122	286000	6556675
Careys	QTZ ARENITE	121	288070	6556130
Charlies Camp	BRECCIA	088	269970	6546100
Charlies Camp	LIMESTONE	089	272270	6544050
Charlies Camp	LITH ARENITE	091	271960	6544020
Charlies Camp	LITH ARENITE	090	271960	6544020
Charlies Camp	LITH ARENITE	124	271900	6543980
Charlies Camp	MUDSTONE	125	271900	6543980
Dedmans Bore	BASALT	002	278590	6541420
Dedmans Bore	CALCITE	038	278620	6541800
Dedmans Bore	CONGLOMERATE	034	278140	6541260
Dedmans Bore	CONGLOMERATE	041	277940	6541400
Dedmans Bore	CONGLOMERATE	106	277550	6541800
Dedmans Bore	CONGLOMERATE	037	277760	6541130
Dedmans Bore	DIAMICTITE	195	277890	6541400
Dedmans Bore	DIAMICTITE	039	278250	6541350
Dedmans Bore	DIAMICTITE	042	277940	6541400
Dedmans Bore	DOLERITE.	001	278640	6541290
Dedmans Bore	DOLOMITE	035	277880	6541160
Dedmans Bore	DOLOMITE	036	277880	6541160
Dedmans Bore	DOLOMITE	030	277440	6541470
Dedmans Bore	DOLOMITE	031	277670	6541450
Dedmans Bore	DOLOMITE	139	277430	6541470
Dedmans Bore	DOLOMITE	103	277720	6541650
Dedmans Bore	DOLOMITE	104	277640	6541740
Dedmans Bore	LIMESTONE	110	278390	6541150
Dedmans Bore	LIMESTONE	105	277680	6541700
Dedmans Bore	LIMESTONE	136	277620	6541730
Dedmans Bore	LIMESTONE	134	277620	6541730
Dedmans Bore	LIMESTONE	040	278070	6541420
Dedmans Bore	LIMESTONE	135	277620	6541730
Dedmans Bore	LITH ARENITE	132	277850	6542340
Dedmans Bore	QTZ ARENITE	029	277500	6541530
Dedmans Bore	SILTSTONE	032	277490	6542490
Dedmans Bore	SILTSTONE	033	276880	6542960
Dedmans Bore	SILTSTONE	133	277380	6542520
Dedmans Bore	SILTSTONE	107	277420	6541830
Depot Flat	DOLOMITE	147	778765	6426890
Depot Flat	LIMESTONE	146	778760	6426890
Depot Flat	LIMESTONE	145	778750	6426890
Depot Flat	LIMESTONE	144	778740	6426890
Depot Flat	LIMESTONE	143	778710	6426890
Depot Flat	LIMESTONE	142	778680	6426890
Depot Flat	LIMESTONE	198	778644	6426855

AREA	ROCK TYPE	NUMBER	EASTING	NORTHING
Depot Flat	LIMESTONE	197	778620	6426900
Depot Flat	SILTSTONE	196	778615	6426895
Depot Flat	TUFF	149	778280	6427000
Doodney's Well	LIMESTONE	137	286650	6546620
Doodneys Well	QTZ ARENITE	114	288200	6544900
Doodneys Well	QTZ ARENITE	115	288200	6544900
Doodneys Well	SILTSTONE	116	288200	6544900
Elatina Hut	SILTSTONE	180	275530	6528450
Enorama	BRECCIA	164	279850	6537000
Enorama	CONGLOMERATE	171	281830	6534850
Enorama	CONGLOMERATE	170	280552	6533850
Enorama	CONGLOMERATE	163	280540	6536080
Enorama	CONGLOMERATE	162	280540	6536080
Enorama	CONGLOMERATE	092	283150	6533100
Enorama	CONGLOMERATE	117	278380	6538900
Enorama	DOLOMITE	169	279750	6537000
Enorama	DOLOMITE	166	279600	6537120
Enorama	DOLOMITE	165	279630	6537110
Enorama	DOLOMITE	161	280540	6536080
Enorama	LIMESTONE	093	283150	6533100
Enorama	LITH ARENITE	199	279780	6536250
Enorama	LITH ARENITE	175	280540	6536010
Enorama	LITH ARENITE	168	279630	6537050
Enorama	LITH ARENITE	167	279610	6537100
Enorama	SILTSTONE	176	280300	6535950
Etina Creek	CONGLOMERATE	150	274540	6530650
Glasses Gorge	DOLOMITE	127	272700	6561780
Glasses Gorge	DOLOMITE	128	272700	6561780
Glasses Gorge	FELDS ARENITE	086	273320	6560390
Glasses Gorge	FELDS ARENITE	126	273345	6560300
Guide Hut	LITH ARENITE	043	284000	6539700
Gum Creek	SILTSTONE	015	276420	6546160
Gum Creek	SILTSTONE	019	276370	6545600
Gum Creek	SILTSTONE	020	276300	6545500
Gum Creek	SILTSTONE	018	276400	6545740
Gum Creek	SILTSTONE	023	276100	6545180
Gum Creek	SILTSTONE	024	276120	6545000
Gum Creek	SILTSTONE	021	276250	6545450
Gum Creek	SILTSTONE	022	276230	6545400
Gum Creek	SILTSTONE	017	276250	6546060
Gum Creek	SILTSTONE	016	276430	6546125
Horns Camp	DIAMICTITE	181	275000	6554995
Horns Camp	LITH ARENITE	182	274810	6554550
Horns Camp	SHALE	183	275025	6553730
Hostel	CONGLOMERATE	013	268150	6553100
Hostel	LIMESTONE	011	268150	6553100
Hostel	LIMESTONE	012	268150	6553100
Kirbin Well	BRECCIA	153	264580	6557450
Kirbin Well	BRECCIA	154	264580	6557450
Kirbin Well	LIMESTONE	155	264670	6557360
Little Werta	CONGLOMERATE	009	273100	6547220
Little Werta	QTZ ARENITE	008	273010	6547010
Loop Road	LIMESTONE	152	265810	6563000
Loop Road	SILTSTONE	151	266290	6462740
Mallee Water	DOLOMITE	187	281450	6538370
Martins Well	LIMESTONE	201	327780	6522360
Mogs Hut	LIMESTONE	004	274670	6546850
Mogs Hut	LIMESTONE	005	274670	6546850
Mogs Hut	LIMESTONE	006	274670	6546850
Mogs Hut	LIMESTONE	003	274670	6546850
Mogs Hut	SILTSTONE	007	274670	6546850

AREA	ROCK TYPE	NUMBER	EASTING	NORTHING
Moolooloo	BASALT	079	267000	6565450
Moolooloo	DIAMICTITE	073	268080	6566420
Moolooloo	DOLOMITE	078	267150	6565700
Moolooloo	DOLOMITE	074	268020	6566520
Moolooloo	FELDS ARENITE	076	267920	6566580
Moolooloo	GOSSAN	077	267430	6566170
Moolooloo	QTZ ARENITE	084	268720	6568440
Moolooloo	SHALE	075	267990	6566575
Moolooloo	SHALE	080	267710	6564300
Moolooloo	SILTSTONE	085	268730	6568120
Moolooloo	SILTSTONE	081	268120	6564140
Moolooloo	SILTSTONE	082	268370	6564300
Moolooloo	SILTSTONE	083	268000	6565000
Mount Emily	CALC ARENITE	087	279870	6547160
Mount Emily	SILTSTONE	028	279080	6547460
Mount Emily	SILTSTONE	027	279620	6547360
Mount Emily	SILTSTONE	025	279080	6547400
Mount Emily	SILTSTONE	026	279100	6547370
Nildottie Gap	QTZ ARENITE	119	288720	6561170
Nildottie Gap	QTZ ARENITE	120	288705	6561080
Nuccaleena	DOLOMITE	123		
Oratunga	GNEISS	060	277050	6558225
Oratunga	LITH ARENITE	059	274270	6559820
Oratunga	SILTSTONE	058	274270	6559820
Pichi Richi Pass	LIMESTONE	148	779900	6410300
Pine Creek	CALC ARENITE	010	277920	6544730
Pumpa Bore	DOLOMITE	177	284300	6535330
Pumpa Bore	FELDS ARENITE	179	284900	6536560
Pumpa Bore	LIMESTONE	178	284680	6536010
Puttapa Gap	CONGLOMERATE	095	252280	6598140
Puttapa Gap	DOLOMITE	099	251050	6599500
Puttapa Gap	DOLOMITE	101	251050	6599770
Puttapa Gap	DOLOMITE	100	251050	6599770
Puttapa Gap	DOLOMITE	098	251040	6599430
Puttapa Gap	SHALE	102	250910	6599800
Racecourse	LIMESTONE	194	280890	6554020
Racecourse	SILTSTONE	192	280770	6554050
Racecourse	SILTSTONE	193	280830	6554035
Racecourse	SILTSTONE	191	280740	6554075
Racecourse	SILTSTONE	190	280700	6554095
Red Range	CONGLOMERATE	111	280100	6540770
Trebilcock Gap	CONGLOMERATE	097	246100	6592360
Trebilcock Gap	QTZ ARENITE	096	245190	6590700
Trezona Bore	CONGLOMERATE	118	275950	6535080
Trezona Bore	DIAMICTITE	129	276400	6535470
Trezona Camp	CONGLOMERATE	172	274540	6530650
Trezona Camp	DOLOMITE	173	274630	6531000
Trezona Camp	LITH ARENITE	174	274500	6530240
White Cutting	DOLOMITE	188	279175	6551370
White Cutting	SILTSTONE	189	279130	6551420
White Cutting	SILTSTONE	014	279340	6551460
Willigon	BASALT	053	273180	6565370
Willigon	BRECCIA	055	273120	6565700
Willigon	BRECCIA	051	272670	6565280
Willigon	BRECCIA	070	273470	6567650
Willigon	BRECCIA	045	272480	6565575
Willigon	BRECCIA	071	273470	6567650
Willigon	BRECCIA	049	272520	6565565
Willigon	CONGLOMERATE	050	272630	6565250
Willigon	CONGLOMERATE	044	269500	6564440
Willigon	DIAPIR ROCK	067	273780	6565070

AREA	ROCK TYPE	NUMBER	EASTING	NORTHING
Willigon	DIAPIR ROCK	066	273780	6565070
Willigon	DOLERITE	052	273180	6565370
Willigon	DOLOMITE	056	273820	6565720
Willigon	FELDS ARENITE	072	271360	6566900
Willigon	GOSSAN	063	273060	6564750
Willigon	GOSSAN	065	272760	6564060
Willigon	GOSSAN	062	273040	6564750
Willigon	GOSSAN	064	272890	6565000
Willigon	GOSSAN	069	274160	6567640
Willigon	GOSSAN	061	272130	6566280
Willigon	LITH ARENITE	048	272515	6565572
Willigon	MUDSTONE	047	272514	6565573
Willigon	QTZ ARENITE	057	275000	6567000
Willigon	QTZ ARENITE	054	273120	6565310
Willigon	QTZ ARENITE	046	272513	6565574
Willigon	SILTSTONE	068	273920	6565500
Winna	FELDS ARENITE	184	275200	6552450
Winna	LIMESTONE	186	275100	6550150
Winna	LITH ARENITE	185	275580	6552230
Winnitinny Creek	LIMESTONE	200	298090	6528300
Yuonconna	SHALE	160	277600	6530380

Sample Number: 819 - 171 Area Location: Enorama

Location, AMG Coords. 281830E, 6534850N. R.L.: 550 metres

Macro Description: CONGLOMERATE Angular, granule to small pebble conglomerate composed almost entirely of heavy mineral banded, very fine to fine grained sandstone in a matrix/cement which has been totally replaced by sparry dolomite.

Micro Description: Lithic clasts of micaceous heavy mineral banded, very fine grained feldsarenite and some sandy matrix in a cement of dolomite and later stage calcite and common large crystals of authigenic quartz. The quartz appears to have replaced gypsum and the grains have poikilitic inclusions and deeply embayed dissolution edges. There are a few (5%) lithic clasts of devtrified glassy volcanics. here are some authigenic o/growths on qtz & felds in the matrix.

Composition: Quartz 15% Feldspar % Rock Fragments/Lithic 30%
Opaques % Calcite 4% Dolomite 46% as cement
Cement Type & % as above plus authigenic qtz & felds 15%
Matrix Type & %
Carbonate Form & % Dolomite is Ca(1.0)Mg(.88)Fe(.12)(CO3)2

Peel Description:

X.R.D.Results: Calcite d spacing: 3.0261 Dolomite d spacing: 2.8904

Sample Number: 819 - 172 Area Location: Trezona Camp

Location, AMG Coords. 274540E, 6530650N. R.L.: 370 metres

Macro Description: CONGLOMERATE Well bedded, small - large pebble conglomerate in a matrix of very coarse sand with a carbonate cement. This is a resampling of 819-150. 50% of the clasts are recessively weathered Trezona limestones.

Micro Description:

Composition: Quartz % Feldspar % Rock Fragments/Lithic %
Opaques % Calcite % Dolomite %
Cement Type & %
Matrix Type & %
Carbonate Form & %

Peel Description: Large rounded clasts of Trezona limestone types, red violet lake stained stromatolitic, intraclastic and ooid limestones together with dolo siltstones and sandstones, dolerite and cherty dolomite in a mx of mature sands, calcite spar cement One zS clast has voids after halite, now spar filled.

X.R.D.Results: Calcite d spacing: Dolomite d spacing:

APPENDIX IV

MEASURED SECTION SUMMARIES

This appendix contains a listing of all measured sections complete with AMG Co-ordinates of the start and finish of each traverse, thicknesses of the units measured and the scale and technique followed for each section.

This is a list of all sections measured in the thesis area together with the the local name and AMG co-ordinates of the start and finish of each section.

SECTION No.	AREA	Co-ordinates start		co-ordinates finish	
		Easting	Northing	Easting	Northing
001	Gum Creek Homestead	276400	6546150	276050	6545200
002	Mogs Bore	274700	6546900	274250	6546050
003	Mog's Bore / Little Werta	274250	6547250	272850	6547000
004	Werta	272280	6548030	271480	6544560
005	Gum Creek / Pine Creek	278000	6544860	277670	6544280
006	Mount Emily	279560	6546270	282830	6544690
007	Crown Hill	279870	6543810	279640	6543130
008	Angorichina Hostel	268320	6553120	268090	6553000
009	Pine Creek	278400	6542850	278220	6542840
010	Dedmans Hut to Bull's Gap	278400	6541200	274410	6540700
011	Aldoona	279800	6541710	279480	6542120
012	Aldoona - McFarlane's Gap	282000	6543100	282770	6543240
013	Aldoona - Park boundary, Guide Hut	282880	6539890	284260	6540350
014	Loop Road, 2nd and 3rd springs	269670	6564050	269500	6464620
015	Moolooloo, on the road in.	268130	6566460	267890	6566700
016	Charlie's Camp. just south of gate.	272000	6544040	271760	6543910
017	Six Springs Water	269960	6546100	269730	6546040
018	Mount Emily - northern end	279090	6547470	279840	6547150
019	Brachina Road, Trezona turnoff.	274710	6530000	274420	6530270
020	Red Range, on the Park boundary.	280050	6540380	279780	6541500
021	Mallee Water	278520	6539030	278330	6538880
022	Rocks Well to Blackfellow's Gap.	282120	6548830	283320	6548820
023	Trezona Bore	277900	6535060	276850	6535060
024	Blinman Racecourse, just south.	282780	6553970	283250	6554050
025	Glen View Homestead	282650	6551500	283410	6551400
026	Mallee Water	278180	6538790	278000	6538710
027	Dedmans Bore	278150	6542300	277170	6542500
028	Parachilna Gorge .	264050	6553380	263958	6553380
029	Parachilna Gorge - Oratunga Creek	265000	6554580	264400	6554630
030	Doodney's Well to Bennett Springs	286000	6544590	289480	6545200
031	Loop Road, S of Moolooloo turnoff	267650	6562150	265620	6563100
032	Kirbin Well, on the Loop Road	265700	6557300	264430	6557550
033	Brachina Turnoff, Enorama Creek	280500	6531150	277560	6533270
034	Younconna Creek	278400	6529270	267730	6531600
035	Enorama Creek	281950	6533630	280230	6533380
036	Middlesight Water	274300	6529300	274070	6529520
037	Enorama Diapir Margin (north)	280620	6536090	280400	6535940
038	Enorama Diapir Margin (south)	281000	6535950	280400	6535700
039	Guide Hut (south)	285050	6537830	285970	6538660
040	Pantapinna (north)	288500	6534380	289820	6535260
041	Elatina Hut	276330	6527620	274350	6529500
042	Yanyanna Trail	274100	6525620	273040	6526560
043	Whitford Well	279460	6561330	280910	6563840
044	Bilpigna Well	280700	6559370	282000	6560300
045	Angorigina	282590	6558000	283870	6558540
046	Depot Flat, N of Quorn.	778620	6426900	778800	6426850
047	Pichi Richi Pass, W side.	780080	6410750	779290	6411380
048	Pichi Richi Pass, E side.	780210	6410700	780600	6410500
049	Pantapinna (south)	290900	6532900	291420	6534050
050	Winnitinny Creek	297630	6528250	301000	6528610
051	Martins Well	327750	6520320	327750	6522600
052	Asbestos Mine	282500	6532770	284900	6533500
053	Pantapinna Track	283640	6534200	285575	6537340
054	Nungawurtina	275135	6555180	276290	6547170
055	White Cutting	278845	6551695	281570	6549925
056	Rocky Waterhole	279960	6554455	280835	6554435
057	Glasses Gorge	273430	6560140	270740	6564710
058	Oratunga	277430	6559900	279000	6561770

SECTION No. 001

GEOGRAPHIC LOCATION: Gum Creek Homestead

POSITION AT START OF TRAVERSE, AMG Coordinates: 276400 mE / 6546150 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 276050 mE / 6545200 mN

TOTAL LENGTH: 249 metres STATUS: Staffed yes , Taped – , Calculated – .

DIP AT START: 15 DIP AT END: 13 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		249.0	
Enorama Shale			
		244.2	
Etina Formation	Dedmans Band		17.2
		227.0	
	shale		63.0
		160.0	
	Aldoona Band		9.5
		151.5	
	shale		117.0
		36.0	
	Idandanoo Band		26.5
		8.0	
	Patterton Shale		

COMMENTS: This is the reference section for the Wundowie equivalent in the area. Thickness of Wundowie is 236.2 metres. Ls/Sh ratio = 0.296

SECTION No. 002

GEOGRAPHIC LOCATION: Mogs Bore

POSITION AT START OF TRAVERSE, AMG Coordinates: 274700 mE / 6546900 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 274250 mE / 6546050 mN

TOTAL LENGTH: 256 metres STATUS: Staffed yes , Taped yes , Calculated – .

DIP AT START: 15 DIP AT END: 16 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		66.0	
Enorama Shale			
		29.0	
Etina Formation	Dedmans Band		15.0
		14.0	
	shale		64.0
		10.0/0	
	Aldoona Band		6.0
		4.0	
	shale		105.0
		35.0/0	
	Idandanoo Band		28.5
		6.5	
	Patterton Shale		
		0.0	

COMMENTS: Wundowie Equivalent 218.5 metres. Ls/Sh ratio = 0.293

SECTION No. 003

GEOGRAPHIC LOCATION: Mog´s Bore / Little Werta

POSITION AT START OF TRAVERSE, AMG Coordinates: 274250 mE / 6547250 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 272850 mE / 6547000 mN

TOTAL LENGTH: 193 metres STATUS: Staffed yes , Taped yes , Calculated - .

DIP AT START: 16 DIP AT END: 17 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		42.0	
Enorama Shale			
		40.3	
Etina Formation	Dedmans Band		16.8
		23.5/6	
	shale		56.0
		5.0 /0	
	Aldoona Band		4.0
		1.0/30	
	shale		109.0
		28.0	
	Idandanoo Band		27.0
		1.0	
	Patterton Shale		
		0.0	

COMMENTS: Wundowie equivalent is 212.8 metres. Ls/Sh ratio = 0.290

SECTION No. 004

GEOGRAPHIC LOCATION: Werta

POSITION AT START OF TRAVERSE, AMG Coordinates: 272280 mE / 6548030 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 271480 mE / 6544560 mN

TOTAL LENGTH: 893 metres STATUS: Staffed yes , Taped yes , Calculated yes.

DIP AT START: 13 DIP AT END: 12 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		684.0	
Elatina Formation			
		681.0	
Trezona Formation			299.0
		382.0	
Enorama Shale			380.0
		2/28.0	
Etina Formation	Dedmans Band		8.5
		19.5/0	
	shale		58.0
		13.0/	
	Aldoona Band		3.0
		10.0/0	
	shale		110.0
		26.0	
	Idandanoo Band		22.6
		3.4	
	Patterton Shale		224.0
		0.0	

COMMENTS: Wundowie equivalent is 202.1 metres. Ls/Sh ratio = 0.203
Thickness of the Trezona from the base to the big band is 66.5 m.
Patterton Shale measured by trig calculation
Section 4 up to top of Etina, section 4A from Etina to base Elatina.
Yaltipena starts to appear 500m S from the end of the section.

SECTION No. 005

GEOGRAPHIC LOCATION: Gum Creek / Pine Creek

POSITION AT START OF TRAVERSE, AMG Coordinates: 278000 mE / 6544860 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 277670 mE / 6544280 mN

TOTAL LENGTH: 150 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 12 DIP AT END: 10 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		31.0	
Enorama Shale			
		29.0	
Etina Formation	Dedmans Band		27.0
		2.0/43	
	shale		82.0
		0/41.0	
	Aldoona Band		25.0
		16.0	
	shale		
		0.0	

COMMENTS: Wundowie equivalent is 277.5 mteres if Idandanoo and shale are included from Section 1. Ls/Sh ratio = 0.460, missing interval from section 6. Dramatic change in thickness in Aldoona Band across a N-S fault between Sections 5 and 1.
Dramatic tidal sequences mapped in Aldoona sandstones, 17 day lunar fortnight?

SECTION No. 006

GEOGRAPHIC LOCATION: Mount Emily

POSITION AT START OF TRAVERSE, AMG Coordinates: 279560 mE / 6546270 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 282830 mE / 6544690 mN

TOTAL LENGTH: 250 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 6 DIP AT END: 6 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		96.0	
Enorama Shale			
		93.0	
Etina Formation	Dedmans Band		19.0
		74.0	
	shale		74.0
		0/23.0	
	Aldoona Band		9.4
		13.6 /	
	shale		110 ?
		41.0	
	Idandanoo Band		36.0
		5.0	
	Patteron Shale		
		0.0	

COMMENTS: Wundowie equivalent is 248.4 metres. Ls/Sh ratio = 0.350
I-A shale measured by a trig construction across a fault zone.

SECTION No. 007

GEOGRAPHIC LOCATION: Crown Hill

POSITION AT START OF TRAVERSE, AMG Coordinates: 279870 mE / 6543810 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 279640 mE / 6543130 mN

TOTAL LENGTH: 96 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 1 DIP AT END: 1 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		96.0	
Etina Formation	Dedmans Band		10 +
		86.0	
	shale		58.0
		28.0	
	Aldoona Band		20.3
		7.7	
	shale		
		0.0	

COMMENTS: Wundowie equivalent is 245.4 metres if Idandanoo and I-A shale from Section 1 and Dedmans the average of Sections 9 and 10
Ls/Sh ratio = 0.518. I and I-A shale from an average of sections 6 and 20.

SECTION No. 008

GEOGRAPHIC LOCATION: Angorichina Hostel

POSITION AT START OF TRAVERSE, AMG Coordinates: 268320 mE / 6553120 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 268090 mE / 6553000 mN

TOTAL LENGTH: 132 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 37 DIP AT END: 38 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		132.0	
Enorama Shale			
		130.4	
Etina Formation	Dedmans Band		12.4
		118.0	
	shale		28.4
		89.6	
	Aldoona Band		7.6
		82.0	
	shale		62.5
		19.5	
	Idandanoo Band		13.5
		6.0	
	Patterton Shale		
		0.0	

COMMENTS: Wundowie equivalent is 124.4 metres. Ls/Sh ratio = 0.369

SECTION No. 009

GEOGRAPHIC LOCATION: Pine Creek

POSITION AT START OF TRAVERSE, AMG Coordinates: 278400 mE / 6542850 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 278220 mE / 6542840 mN

TOTAL LENGTH: 33 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 10 DIP AT END: 10 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		33.0	
Enorama Shale			
		31.0	
Etina Formation	Dedmans Band		22.0
		9.0	
	shale		
		0.0	

COMMENTS: This unit seems too thin here. The base may be faulted out.

SECTION No. 010

GEOGRAPHIC LOCATION: Dedmans Hut to Bull's Gap

POSITION AT START OF TRAVERSE, AMG Coordinates: 278400 mE / 6541200 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 274410 mE / 6540700 mN

TOTAL LENGTH: 1842 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 65 DIP AT END: 10 SCALE OF MEASURED SECTION: 1cm:1m &2m

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		190.0	
Brachina Formation			
		186.5	
Nuccaleena Formation			8.0
		178.5	
Elatina Formation			87.0
		91.5	
Trezona Formation	Yaltipena Member		86.7
		4.5	
			396.8
Enorama Shale			481.0
		138.0	
Etina Formation	Dedmans Band		38.0
		100.0	
	shale		69.5
		30.5	
	Aldoona Band		30.5
		0/243.	
	shale		117.0
		126.5	
	Idandanoo Band		47.5
		79.0	
	Patterton Shale		304.4
		255/0	
	Winna limestone		
		0.0	

COMMENTS: Wundowie equivalent is 302.5m. Trezona base to big band is 77.5m. Section 10 measured in 7 stages, 10 (137m), 10A (313.5m), 10B (226m), 10C 395.5 10D (190m), 10E (325m), 10F (255m). From the base, 255 on F = 0 on A, 243.5 on A = 0 on 10, 137 on 10 = 11.2 on B, 224 on B = 49 on C, 395.5 on C = 0 on E, 319.3 on E = 4.8 on D. Rapid facies changes in Enorama. Wundowie Ls/Sh = 0.622

SECTION No. 011

GEOGRAPHIC LOCATION: Aldoona

POSITION AT START OF TRAVERSE, AMG Coordinates: 279800 mE / 6541710 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 279480 mE / 6542120 mN

TOTAL LENGTH: 49 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 6 DIP AT END: 6 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		49.0	
Etina Formation	shale		
		47.4	
	Aldoona Band		42.4
		5.0	
	shale		
		0.0	

COMMENTS: Thick Aldoona section of wave rippled flaser bedded sands. Large scale slumps commence the band.

SECTION No. 012

GEOGRAPHIC LOCATION: Aldoona - McFarlane's Gap

POSITION AT START OF TRAVERSE, AMG Coordinates: 282000 mE / 6543100 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 282770 mE / 6543240 mN

TOTAL LENGTH: 24 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 6 DIP AT END: 6 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		24.0	
Enorama Shale			
		21.6	
Etina Formation	Dedmans Band		20.6
		1.0	
	shale		
		0.0	

COMMENTS: Slumps at the base of the band. 1.5m deep intraclast filled channels between large mounds of stromatolites which consist of small tuberous columns (Tungussia Etina).

SECTION No. 013

GEOGRAPHIC LOCATION: Aldoona - Park boundary, Guide Hut

POSITION AT START OF TRAVERSE, AMG Coordinates: 282880 mE / 6539890 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 284260 mE / 6540350 mN

TOTAL LENGTH: 463 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 17 DIP AT END: 12 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		24.0	
Enorama Shale			
		20.5	
Etina Formation	Dedmans Band		18.5
		2/111	
	shale		73.0
		38.0	
	Aldoona Band		27.8
		147/10	
	shale		91.5
		55.7	
	Idandanoo Band		37.2
		18.5	
	Patterton Shale		180 ?

COMMENTS: Wundowie equivalent is 248 metres. Ls/Sh ratio = 0.508
This is a composite section, from the base 13B (147.2m), 13 (111.0), 13A (24.0m). Patterton thickness by trig construction.

SECTION No. 014

GEOGRAPHIC LOCATION: Loop Road, 2nd and 3rd springs

POSITION AT START OF TRAVERSE, AMG Coordinates: 269670 mE / 6564050 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 269500 mE / 6464620 mN

TOTAL LENGTH: 152 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 20 DIP AT END: 20 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		147.0	
Enorama Shale			
		145.1	
Etina Formation	Dedmans Band		10.6
		134.5	
	shale		38.2
		96.3	
	Aldoona Band		9.0
		87.3	
	shale(+5m)		66.1
		26.2	
	Idandanoo Band		16.2
		10.0	
	Patterton Shale		
		0.0	

COMMENTS: 5m added to the section in the I-A shale to account for a fault.
Wundowie equivalent is 140.1 metres. Ls/Sh ratio = 0.343
Note the very coarse grain size of the Aldoona band.

SECTION No. 015

GEOGRAPHIC LOCATION: Moolooloo, on the road in.

POSITION AT START OF TRAVERSE, AMG Coordinates: 268130 mE / 6566460 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 267890 mE / 6566700 mN

TOTAL LENGTH: 129 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 18 DIP AT END: 18 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		129.0	
Brachina Formation			
		67.0	
Nuccaleena Formation			7.0
		60.0	
Elatina Formation			56.7
		3.3	
Trezona Formation			
		0.0	

SUPPLEMENTARY SECTION	15A, JUST TO THE SOUTH		
		17.0	
Brachina Formation			
		14.5	
Nuccaleena Formation			7.0
		7.5	
Elatina Formation			
		0.0	

COMMENTS: 15A is a composite section compiled near the Oratunga Mine and further south near the Nuccaleena turnoff to show the dolomite facies variation - shaly dolomite grading to red shales with dolomite concretions to the north i.e. into deeper water. Also, 15A shows dropstones in the Elatina in a zone of poor outcrop along 15.

SECTION No. 016

GEOGRAPHIC LOCATION: Charlie´s Camp. just south of gate.

POSITION AT START OF TRAVERSE, AMG Coordinates: 272000 mE / 6544040 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 271760 mE / 6543910 mN

TOTAL LENGTH: 72 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 14 DIP AT END: 14 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		72.0	
Brachina Formation			
		67.0	
Nuccaleena Formation			10.0
		57.0	
Elatina Formation			43.6
		13.4	
Trezona Formation	Yaltipena Member		6.9
		6.5	
" "			
		0.0	

COMMENTS: This section was re-measured with Vic as part of the Elatina study. Yaltipena Mbr was only recognized after the cross section was drafted. It was originally designated as Elatina.

SECTION No. 017

GEOGRAPHIC LOCATION: Six Springs Water

POSITION AT START OF TRAVERSE, AMG Coordinates: 269960 mE / 6546100 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 269730 mE / 6546040 mN

TOTAL LENGTH: 69 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 16 DIP AT END: 16 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		69.0	
Brachina Formation			
		58.5	
Nuccaleena Formation			14.5
		44.0	
Elatina Formation			41.0
		3.0	
Trezona Formation			
		0.0	

COMMENTS: Yaltipena Member is absent. There is a solution collapse breccia bleaching and limonitization on the contact between the Trezona and the Elatina. This section was re- measured with Vic and the glacials assigned lithofacies codes as per Eyles et al.

SECTION No. 018

GEOGRAPHIC LOCATION: Mount Emily - northern end

POSITION AT START OF TRAVERSE, AMG Coordinates: 279090 mE / 6547470 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 279840 mE / 6547150 mN

TOTAL LENGTH: 239 metres STATUS: Staffed tes , Taped - , Calculated - .

DIP AT START: 8 DIP AT END: 7 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		239.0	
Etina Formation	Idandanoo Band		
		236.8	
	Patterton Shale		233.8
		3.0	
	Winna limestone		
		0.0	

COMMENTS: This is the reference section for the Patterton Shale, named after Patterton Creek and Spring which are 2km west of this section.

SECTION No. 019

GEOGRAPHIC LOCATION: Brachina Road, Trezona turnoff.

POSITION AT START OF TRAVERSE, AMG Coordinates: 274710 mE / 6530000 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 274420 mE / 6530270 mN

TOTAL LENGTH: 116 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 17 DIP AT END: 15 SCALE OF MEASURED SECTION: 1cm:2metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		116.0	
Brachina Formation			
		106.0	
Nuccaleena Formation			8.6
		97.4	
Elatina Formation			84.4
		13.0	
Trezona Formation			
		0.0	
REPEAT SECTION			
		92.0	
Nuccaleena Formation			
		83.0	
Elatina Formation			83.0
		0.0	
Trezona Formation			
		-2.0	

COMMENTS: This is the Type Section for the Elatina in Elatina Creek and was re-measured with Vic to give a new assessment of the formation in terms of lithofacies codes. This was checked again when faulting discovered to have repeated the basal 14m of section. Yaltipena absent and the glacials sit unconformably on karsted stromatolitic limestones of the Trezona.

SECTION No. 020

GEOGRAPHIC LOCATION: Red Range, on the Park boundary.

POSITION AT START OF TRAVERSE, AMG Coordinates: 280050 mE / 6540380 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 279780 mE / 6541500 mN

TOTAL LENGTH: 304 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 27 DIP AT END: 10 SCALE OF MEASURED SECTION: 1cm:2m

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		304.0	
Etina Formation	shale		
		299.6	
	Idandanoo Band		56.6
		243.0	
	Patterton Shale		224.0
		19.0	
	Winna limestone		
		0.0	

COMMENTS: There is possibly a minor fault at the base of the Patterton Shale
There is also a fault in the I-A shale which prevents calculation of its thickness. Ls/Sh ratio = 0.701 using the assumptions below.
Wundowie equivalent is 288.4 metres. This uses the following assumptions:
I-A shale average of sections 10 & 6, Aldoona from 11, A-D shale average 7,9&12

SECTION No. 021

GEOGRAPHIC LOCATION: Mallee Water

POSITION AT START OF TRAVERSE, AMG Coordinates: 278520 mE / 6539030 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 278330 mE / 6538880 mN

TOTAL LENGTH: 149 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 90 DIP AT END: 0 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		149.0	
Enorama Shale			135 +
		14.0	
Enorama Diapir			
		0.0	

COMMENTS: 112 - 149m was added on 26/5/85 when it became clear how important this section is. Dolomitic conglomerates swept off the rising diapir have themselves been upturned to vertical by continued diapir movement. Turbidites in the Enorama Shale have flutes to 180 and 000, bidirectional along the axis of the syndepositional sink next to the diapir. The syncline is preserved.

SECTION No. 022

GEOGRAPHIC LOCATION: Rocks Well to Blackfellow's Gap.

POSITION AT START OF TRAVERSE, AMG Coordinates: 282120 mE / 6548830 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 283320 mE / 6548820 mN

TOTAL LENGTH: 445 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 13 DIP AT END: 11 SCALE OF MEASURED SECTION: 1cm:1meter

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		235.0	
Enorama Shale			
		32.4	
Etina Formation	Dedmans Band		23.4
		209.0	
	shale		60.0
		149.0	
	Aldoona Band		11.0
		138.0	
	shale		105.0
		33.0	
	Idandanoo Band		30.0
		3.0	
	Patterton Shale		210 ?
		0.0	

COMMENTS: Wundowie equivalent is 229.4 metres. Patterton Shale calculated by trigonometry.
Ls/Sh ratio = 0.390

SECTION No. 023

GEOGRAPHIC LOCATION: Trezona Bore

POSITION AT START OF TRAVERSE, AMG Coordinates: 277900 mE / 6535060 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 276850 mE / 6535060 mN

TOTAL LENGTH: 182 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 11 DIP AT END: 12 SCALE OF MEASURED SECTION: 1cm : 2m

FORMATION NAME	MEMBER / BAND		BOUNDARY POSITION	THICKNESS (M)
			182.0	
Brachina Formation				
			180.0	
Nuccaleena Formation				4.0
			176.0	
Elatina Formation				80.0
			96.0	
Trezona Formation	Yaltipena Member	(+10m)		104.0
			2.0	
" "				
			0.0	

COMMENTS: Base of Yaltipena is faulted out - outcrop to the north suggests that 10m is missing.
Elatina section was re-measured with Vic on 22/5/85 to assign lithofacies codes
The corrected thickness is now 85.2 metres.

SECTION No. 024

GEOGRAPHIC LOCATION: Blinman Racecourse, just south.

POSITION AT START OF TRAVERSE, AMG Coordinates: 282780 mE / 6553970 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 283250 mE / 6554050 mN

TOTAL LENGTH: 180 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 24 DIP AT END: 24 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		180.0	
Enorama Shale			
		176.5	
Etina Formation	Dedmans Band		12.0
		164.5	
	shale		40.4
		124.0	
	Aldoona Band		18.0
		106.0	
	shale		76.0
		30.0	
	Idandanoo Band		27.0
		3.0	
	Patterton Shale		
		0.0	

COMMENTS: Wundowie equivalent is 173.5 metres. Ls/Sh ratio = 0.489

SECTION No. 025

GEOGRAPHIC LOCATION: Glen View Homestead

POSITION AT START OF TRAVERSE, AMG Coordinates: 282650 mE / 6551500 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 283410 mE / 6551400 mN

TOTAL LENGTH: 363 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 15 DIP AT END: 17 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		195.0	
Enorama Shale			
		192.3	
Etina Formation	Dedmans Band		18.3
		174.0	
	shale		50.4
		123.6	
	Aldoona Band		14.6
		109.0	
	shale		82.5
		26.5	
	Idandanoo Band		23.5
		3.0	
	Patterton Shale		168 ?
		0.0	

COMMENTS: Wundowie equivalent is 189.3 metres. Ls/Sh ratio = 0.424
Trigonometry on Patterton Shale x = sin 0 (a + ^h/tan0)
where a = 610m, 0 = 15, ^h = +10m.

SECTION No. 026

GEOGRAPHIC LOCATION: Mallee Water

POSITION AT START OF TRAVERSE, AMG Coordinates: 278180 mE / 6538790 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 278000 mE / 6538710 mN

TOTAL LENGTH: 115 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 25 DIP AT END: 20 SCALE OF MEASURED SECTION: 1cm:1metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		114.6	
Trezona Formation			76.4 +
		38.2	
Enorama Shale			38.2 +
		0.0	

COMMENTS: Thickness of Trezona to the top of the big band is 76.4 metres.

SECTION No. 027

GEOGRAPHIC LOCATION: Dedmans Bore

POSITION AT START OF TRAVERSE, AMG Coordinates: 278150 mE / 6542300 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 277170 mE / 6542500 mN

TOTAL LENGTH: 264 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 25 DIP AT END: 15 SCALE OF MEASURED SECTION: 1cm : 2m

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		264.0	
Enorama Shale			264 +
		0.0	
Etina Formation	Dedmans Band		
		-2.0	

COMMENTS: Correlation by bed tracing, 264m on section 27 = 217m on 10B = 27m on 10C.
This section was measured through the deepest part of the syndepositional sink, just to the north of the Enorama Diapir

SECTION No. 028

GEOGRAPHIC LOCATION: Parachilna Gorge .

POSITION AT START OF TRAVERSE, AMG Coordinates: 264050 mE / 6553380 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 263958 mE / 6553380 mN

TOTAL LENGTH: 92 metres STATUS: Staffed - , Taped yes , Calculated - .

DIP AT START: 90 DIP AT END: 90 SCALE OF MEASURED SECTION: 1cm : 2m

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		92.0	
Brachina Formation			
		66.0	
Nuccaleena Formation			15.2
		50.8	
Elatina Formation			50.8
		0.0	
Trezona Formation			

COMMENTS: Trezona is deeply eroded, weathered, sideritized and limonitized but the contact with the Elatina is sharp.
The top of the Nuccaleena is defined by the last dolomite nodules. If the first sand in the sequence is used, then the Nuccaleena ends at 84m i.e. is 33.2m thick. The last dolomite nodule is used as the end in all other sections.

SECTION No. 029

GEOGRAPHIC LOCATION: Parachilna Gorge - Oratunga Creek

POSITION AT START OF TRAVERSE, AMG Coordinates: 265000 mE / 6554580 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 264400 mE / 6554630 mN

TOTAL LENGTH: 595 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 62 DIP AT END: 65 SCALE OF MEASURED SECTION: 1cm : 2m

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Trezona Formation			118 ?
Enorama Shale			332
		120.2	
Etina formation	Dedmans Band		11.8
		108.4	
	shale		26.2
		82.2	
	Aldoona Band		2.2
		80.0	
	shale		65.6
		14.4	
	Idandanoo Band		14.4
		0.0	
	Patterton Shale		143

COMMENTS: Very good correlation with section 8, even across the major fault. Trezona is much reduced. The top is removed by erosion and at least 50m of the remainder is sideritized and limonitized with some karsting evident along the contact with the Elatina Formation. Wundowie equivalent is 120.2 metres. Trig calculation on the Trezona, Enorama and Patterton. Ls/Sh ratio = 0.309

SECTION No. 030

GEOGRAPHIC LOCATION: Doodney's Well to Bennett Springs

POSITION AT START OF TRAVERSE, AMG Coordinates: 286000 mE / 6544590 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 289480 mE / 6545200 mN

TOTAL LENGTH: 641 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 10 DIP AT END: 15 SCALE OF MEASURED SECTION: 1cm : 2m

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		130.0	
Brachina Formation			
		129.0	
Nuccaleena Formation			14.6
		114.4	
Elatina Formation			114.4
		0/511.	
Trezona Formation	Yaltipena Member		104.0
		407.0	
" "			357.8
		49.2	
Enorama Shale			
		0	

COMMENTS: Trezona base to top of the big band is 104.8 metres. This is the suggested type section for the Yaltipena Member.

SECTION No. 031

GEOGRAPHIC LOCATION: Loop Road, S of Moolooloo turnoff

POSITION AT START OF TRAVERSE, AMG Coordinates: 267650 mE / 6562150 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 265620 mE / 6563100 mN

TOTAL LENGTH: 843 metres STATUS: Staffed yes , Taped , Calculated yes.

DIP AT START: 21 DIP AT END: 21 SCALE OF MEASURED SECTION: 1cm:2metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Nuccaleena Formation	(estimate only)		10.0
Elatina Formation			43.0
Trezona Formation			170.0
Enorama Shale			317.0
		132.6	
Etina Formation	Dedmans Band		7.6
		125.0	
	shale		34.0
		91.0	
	Aldoona Band		4.0
		87.0	
	shale		70.4
		14.6	
	Idandanoo Band		14.6
		0.0	
	Patterton Shale		170

COMMENTS: Wundowie equivalent = 132.6m Ls/Sh ratio = 0.251
Elatina, Trezona, Enorama and Patterton by trig construction.
Although A. Gaal measured 150m for the Trezona, a check on trig construction in the area shows he may have been out. (132m by trig across the Wundowie)

SECTION No. 32

GEOGRAPHIC LOCATION: Kirbin Well, on the Loop Road

POSITION AT START OF TRAVERSE, AMG Coordinates: 265700 mE / 6557300 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 264430 mE / 6557550 mN

TOTAL LENGTH: 772 metres STATUS: Staffed yes , Taped , Calculated yes.

DIP AT START: 37 DIP AT END: 37 SCALE OF MEASURED SECTION: 1cm:5metre

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Brachina Formation			
		265.0	
Nuccaleena Formation			13.0
		252.0	
Elatina Formation			43.0
		189.0	
Trezona Formation			134.0
		55.0	
Enorama Shale			310
		0.0	
Etina Formation	Wundowie equivalent		122
	Patterton Shale		150

COMMENTS: Trig construction on Wundowie and Patterton.
Top of Trezona eroded to below the stromatolite unit, 1-2m breccia developed on the contact. The Nuccaleena shows well developed tepoids.

SECTION No. 33

GEOGRAPHIC LOCATION: Brachina Turnoff, Enorama Creek

POSITION AT START OF TRAVERSE, AMG Coordinates: 280500 mE / 6531150 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 277560 mE / 6533270 mN

TOTAL LENGTH: 844 metres STATUS: Staffed yes , Taped , Calculated yes.

DIP AT START: 15 DIP AT END: 13 SCALE OF MEASURED SECTION: 1cm:2m

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		448.0	
Enorama Shale			460
		389.0	
Etina Formation	Dedmans Band		20.0
		369.0	
	shale		35.2
		338.8	
	Aldoona Band		21.4
		312.4	
	shale		98.4
		214.0	
	Idandanoo Band		22.0
		192.0	
	Patterton Shale		187.0
		4.4	
	Winna Limestone		
		0.0	

COMMENTS: Wundowie equivalent = 197.0m. Ls/Sh ratio = 0.475

SECTION No. 034

GEOGRAPHIC LOCATION: Younconna Creek

POSITION AT START OF TRAVERSE, AMG Coordinates: 278400 mE / 6529270 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 267730 mE / 6531600 mN

TOTAL LENGTH: 774 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 18 DIP AT END: 17 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		362.0	
Enorama Shale			416.0
		358.0	
Etina Formation	Dedmans Band		15.0
		343.0	
	shale		43.0
		300.0	
	Aldoona Band		18.0
		282.0	
	shale		92.0
		190.0	
	Idandanoo Band		16.0
		174.0	
	Patterton Shale		174.0

COMMENTS: Wundowie equivalent = 184.0m. Ls/Sh ratio = 0.363

SECTION No. 035

GEOGRAPHIC LOCATION: Enorama Creek

POSITION AT START OF TRAVERSE, AMG Coordinates: 281950 mE / 6533630 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 280230 mE / 6533380 mN

TOTAL LENGTH: 903 metres STATUS: Staffed yes , Taped – , Calculated yes.

DIP AT START: 16 DIP AT END: 13 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		442.0	
Enorama Shale			475
		439.4	
Etina Formation	Dedmans Band		14.8
		424.6	
	shale		51.2
		373.4	
	Aldoona Band		20.4
		353.0	
	shale		109.0
		244.0	
	Idandanoo Band		22.0
		222.0	
	Patterton Shale		211.0
		11.0	
	Winna Limestone		
		0.0	

COMMENTS: Wundowie equivalent = 217.4m. Ls/Sh ratio = 0.357.

SECTION No. 036

GEOGRAPHIC LOCATION: Middlesight Water

POSITION AT START OF TRAVERSE, AMG Coordinates: 274300 mE / 6529300 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 274070 mE / 6529520 mN

TOTAL LENGTH: 70 metres STATUS: Staffed yes , Taped – , Calculated – .

DIP AT START: 20 DIP AT END: 20 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		70.0	
Brachina Formation			
		69.0	
Nuccaleena Formation			6.6
		11.0	
Elatina Formation			51.4
		0.0	
Trezona Formation			

COMMENTS: This section was measured to get away from the faults that cut through the type section just to the north at section 19.

SECTION No. 037

GEOGRAPHIC LOCATION: Enorama Diapir Margin (north)

POSITION AT START OF TRAVERSE, AMG Coordinates: 280620 mE / 6536090 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 280400 mE / 6535940 mN

TOTAL LENGTH: 214 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 90 DIP AT END: 28 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		214.0	
Enorama Shale			
		214.0	
Etina Formation	Dedmans Band		15.0
		199.0	
	shale		69.5
		129.5	
	Aldoona Band		20.5
		109.0	
	shale		29.0
		80.0	
	Idandanoo Band		45.6
		34.4	
	Patterton Shale		32.4
		2.0	
Diapiric breccia			

COMMENTS: Wundowie equivalent = 179.6m. Ls/Sh ratio = 0.823. Section cuts Wundowie just before the base butts onto the Enorama Diapir. A thick conglomerate section in the Patterton Shale and the carbonates near the diapir contact are all dolomitic and shallow water with laminated stromatolitic mats with fenestral texture indicative of a sabkha environment.

SECTION No. 038

GEOGRAPHIC LOCATION: Enorama Diapir Margin (south)

POSITION AT START OF TRAVERSE, AMG Coordinates: 281000 mE / 6535950 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 280400 mE / 6535700 mN

TOTAL LENGTH: 718 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: -45 DIP AT END: 21 SCALE OF MEASURED SECTION: 1cm:5m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		290.0	
Enorama Shale			437
		281.0	
Etina Formation	Dedmans Band		11.0
		270.0	
	shale		50.5
		219.5	
	Aldoona Band		41.0
		178.5	
	shale		75.5
		103.0	
	Idandanoo Band		28.0
		75.0	
	Patterton Shale		75.0
		0.0	
Diapiric breccia			

COMMENTS: Wundowie equivalent = 206.0m. Ls/Sh ratio = 0.635.

SECTION No. 039

GEOGRAPHIC LOCATION: Guide Hut (south)

POSITION AT START OF TRAVERSE, AMG Coordinates: 285050 mE / 6537830 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 285970 mE / 6538660 mN

TOTAL LENGTH: 435 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 25 DIP AT END: 22 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		260.0	
Enorama Shale			
		255.4	
Etina Formation	Dedmans Band		11.4
		244.0	
	shale		68.0
		176.0	
	Aldoona Band		12.5
		163.5	
	shale		114.5
		49.0	
	Idandanoo Band		38.0
		11.0	
	Patterton Shale		187

COMMENTS: Wundowie equivalent = 244.4m. Ls/Sh ratio = 0.339.

SECTION No. 040

GEOGRAPHIC LOCATION: Pantapinna (north)

POSITION AT START OF TRAVERSE, AMG Coordinates: 288500 mE / 6534380 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 289820 mE / 6535260 mN

TOTAL LENGTH: 449 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 19 DIP AT END: 15 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		262.0	
Enorama Shale			
		260.0	
Etina Formation	Dedmans Band		25.0
		235.0	
	shale		52.0
		183.0	
	Aldoona Band		28.4
		154.6	
	shale		99.1
		55.6	
	Idandanoo Band		42.5
		0.0	
	Patterton Shale		200

COMMENTS: Wundowie equivalent = 247.0m. Ls/Sh ratio = 0.635.

SECTION No. 041

GEOGRAPHIC LOCATION: Elatina Hut

POSITION AT START OF TRAVERSE, AMG Coordinates: 276330 mE / 6527620 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 274350 mE / 6529500 mN

TOTAL LENGTH: 947 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 25 DIP AT END: 20 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Trezona Formation			228
		70.0	
Enorama Shale			371
		68.0	
Etina Formation	Dedmans Band		15.0
		53.0	
	shale		44.0
		9.0	
	Aldoona Band		8.0
		1.0	
	shale		90.0
		0/19.2	
	Idandanoo Band		14.0
		5.2	
	Patterton Shale		177
		0.0	

COMMENTS: Wundowie equivalent = 171.0m. Ls/Sh ratio = 0.276. Patterton, I-A shale, Enorama and Trezona thicknesses calculated by trig construction.

SECTION No. 042

GEOGRAPHIC LOCATION: Yanyanna Trail

POSITION AT START OF TRAVERSE, AMG Coordinates: 274100 mE / 6525620 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 273040 mE / 6526560 mN

TOTAL LENGTH: 643 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 28 DIP AT END: 28 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		150.0	
Enorama Shale			339
		146.0	
Etina Formation	Dedmans Band		9.5
		136.5	
	shale		33.5
		103.0	
	Aldoona Band		5.0
		98.0	
	shale		77.6
		20.4	
	Idandanoo Band		14.4
		6.0	
	Patterton Shale		164
		0.0	

COMMENTS: Wundowie equivalent = 140.0m. Ls/Sh ratio = 0.259. Patterton, and Enorama thicknesses calculated by trig construction.

SECTION No. 043

GEOGRAPHIC LOCATION: Whitford Well

POSITION AT START OF TRAVERSE, AMG Coordinates: 279460 mE / 6561330 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 280910 mE / 6563840 mN

TOTAL LENGTH: 1111 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 25 DIP AT END: 22 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Elatina Formation			67
Trezona Formaton			308
Enorama Shale			349
		197.0	
Etina Formation	Dedmans Band		13.0
		184.0	
	shale		48.4
		135.6	
	Aldoona Band		10.6
		125.0	
	shale		78.0
		47.0	
	Idandanoo Band		41.0
		6.0	
	Patterton Shale		196
		0.0	

COMMENTS: Wundowie equivalent = 191.0m. Ls/Sh ratio = 0.510.
Patterton, Enorama, Trezona and Elatina thicknesses calculated by trig construction. Trezona cuts out just into the main domal stromatolite band. Elatina has Smd basal 1/4, then ripple cross laminated very fine to fine red sand then red siltstone top 1/4.

SECTION No. 044

GEOGRAPHIC LOCATION: Bilpigna Well

POSITION AT START OF TRAVERSE, AMG Coordinates: 280700 mE / 6559370 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 282000 mE / 6560300 mN

TOTAL LENGTH: 291 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 11 DIP AT END: 12 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		71.0	
Enorama Shale			
		69.0	
Etina Formation	Dedmans Band		18.0
		51.0	
	shale		34.0
		~17.0	
	Aldoona Band		14.0
		0/3.0	
	shale		60.0
		22.0	
	Idandanoo Band		27.0
		0.0	
	Patterton Shale		138.0

COMMENTS: Wundowie equivalent = 153.0m. Ls/Sh ratio = 0.628
Base of Idandanoo missing from the measured section. Top of Aldoona could not be placed accurately due to lack of outcrop.
The entire section is much reduced across this block.

SECTION No. 045

GEOGRAPHIC LOCATION: Angorigina

POSITION AT START OF TRAVERSE, AMG Coordinates: 282590 mE / 6558000 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 283870 mE / 6558540 mN

TOTAL LENGTH: 376 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 17 DIP AT END: 17 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Enorama Shale			
Etina Formation	Dedmans Band		23
	shale		42
	Aldoona Band		20
	shale		69
	Idandanoo Band		35
	Patterton Shale		187

COMMENTS: Wundowie equivalent = 189.0m. Ls/Sh ratio = 0.703
Although the Wundowie bands were staffed, the dip used was incorrect, and all measurements were corected using trig construction on a dip calculated from topographic contours on the big hill just W of Angorigina H.S.

SECTION No. 046

GEOGRAPHIC LOCATION: Depot Flat, N of Quorn.

POSITION AT START OF TRAVERSE, AMG Coordinates: 778620 mE / 6426900 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 778800 mE / 6426850 mN

TOTAL LENGTH: 132 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 31 DIP AT END: 31 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		132.0	
Willochra Sub-group			
		127.4	
Brighton Limestone	(equivalent)		126.4
		1.0	
Tapley Hill Formation			
		0.0	

COMMENTS: One of the best examples in the Flinders of a shallowing upward carbonate sequence.

SECTION No. 047

GEOGRAPHIC LOCATION: Pichi Richi Pass, W side.

POSITION AT START OF TRAVERSE, AMG Coordinates: 780080 mE / 6410750 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 779290 mE / 6411380 mN

TOTAL LENGTH: 335 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 15 DIP AT END: 32 SCALE OF MEASURED SECTION: 1cm:5m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		335.0	
Brachina Formation			
		330.0	
Nuccaleena Formation			5.0
		325.0	
Elatina Formation			71.0
		244.0	
Willochra Sub-group			244+m
		0.0	

COMMENTS: Section was measured to define the Elatina. The lower boundary was uncertain as the Willochra and the Elatina both contain grit and pebble trains. the discovery of algal limestone, similar to the Trezona made the boundary much easier to define.

SECTION No. 048

GEOGRAPHIC LOCATION: Pichi Richi Pass, E side.

POSITION AT START OF TRAVERSE, AMG Coordinates: 780210 mE / 6410700 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 780600 mE / 6410500 mN

TOTAL LENGTH: 345 metres STATUS: Staffed yes , Taped - , Calculated - .

DIP AT START: 25 DIP AT END: 65 SCALE OF MEASURED SECTION: 1cm:5m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		345.0	
Brachina Formation			
		338.0	
Nuccaleena Formation			8.0
		330.0	
Elatina Formation			87.0
		243.0	
Willochra Sub-group			243+m

COMMENTS: This was a good check on the thicknesses measured in section 047. The section was measured on the other side of the anticline.

SECTION No. 049

GEOGRAPHIC LOCATION: Pantapinna (south)

POSITION AT START OF TRAVERSE, AMG Coordinates: 290900 mE / 6532900 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 291420 mE / 6534050 mN

TOTAL LENGTH: 434 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 19 DIP AT END: 18 SCALE OF MEASURED SECTION: 1cm:2m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		270.0	
Enorama Shale			
		268.0	
Etina Formation	Dedmans Band		39.0
		229.0	
	shale		63.0
		166.0	
	Aldoona Band		27.0
		139.0	
	shale		68.6
		70.4	
	Idandanoo Band		49.4
		21.0	
	Patterton Shale		185
		0.0	

COMMENTS: Wundowie equivalent = 247.0m. Ls/Sh ratio = 0.877
Patterton calculated by trig.

SECTION No. 050

GEOGRAPHIC LOCATION: Winnitinny Creek

POSITION AT START OF TRAVERSE, AMG Coordinates: 297630 mE / 6528250 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 301000 mE / 6528610 mN

TOTAL LENGTH: 1445 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 28 DIP AT END: 28 SCALE OF MEASURED SECTION: 1cm:2 & 5m

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Brachina Formation			
		587.0	
Nuccaleena Formation			26.0
		561.0	
Elatina Formation			102.0
		459.0	
Trezona Formation	Yaltipena Member		105.0
		354.0	
Trezona Formation			338.0
		16/404	
Enorama Shale			470
		0/403.	
Etina Formation	Dedmans Band		39.4
		364.0	
	shale		36.0
		328.0	
	Aldoona Band		32.0
		296.0	
	shale		67.6
		228.4	
	Idandanoo Band		39.4
		189.0	
	Patterton Shale		187.0
		2.0	
	Winna Limestone		
		0.0	

COMMENTS: Wundowie equivalent = 214.4m. Ls/Sh ratio = 1.069
Enorama was measured by trig and shows two thin dolomite bands just prior to the incoming of the green shale at 174m. The green shale ends at 360m. Although there is a lot more limestone than shale than usual in the Etina, the rest of the sequence is very similar to that in section 30.

SECTION No. 051

GEOGRAPHIC LOCATION: Martins Well

POSITION AT START OF TRAVERSE, AMG Coordinates: 327750 mE / 6520320 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 327750 mE / 6522600 mN

TOTAL LENGTH: 982 metres STATUS: Staffed yes , Taped - , Calculated yes.

DIP AT START: 32 DIP AT END: 44 SCALE OF MEASURED SECTION: 1cm:2 & 5m

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		260.0	
Brachina Formation			
		255.0	
Nuccaleena Formation			12.5
		242.5	
Elatina Formation			40.5
		202.0	
Trezona Formation			136.5
		65.5	
Enorama Shale			461
		103.2	
Etina Formation	Dedmans Band		16.2
		87.0	
	shale		26.4
		60.6	
	Aldoona Band		38.6
		22.0	
	shale		67.0
		39.6	
	Idandanoo Band		35.2
		4.4	
	Patterton Shale		143

COMMENTS: Wundowie equivalent = 183.4m. Ls/Sh ratio = 0.964
Enorama and Patterton by trig construction. The Enorama shows the same two thin dolomite bands on the contact with the central green shale as seen in section 50. Small scale foldinf forced the bottom three units to be measured 2km to the west in another creek. The Wundowie shows definite signs of shallowing.

SECTION No. 052

GEOGRAPHIC LOCATION: Asbestos Mine

POSITION AT START OF TRAVERSE, AMG Coordinates: 282500 mE / 6532770 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 284900 mE / 6533500 mN

TOTAL LENGTH: 700 metres STATUS: Staffed - , Taped - , Calculated yes.

DIP AT START: 90 DIP AT END: 63 SCALE OF MEASURED SECTION: 1cm:20m

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
		700	
Tapley Hill Formation	Tindelpina Shale		
		695	
Merinjina/Pualco Tillite	Wilyerpa Formation		295
		400	
	Warcowie Dolomite		168
		232	
Yudnamutana Subgroup			42
		190	
	Holowilena Ironstone		144
		46	
	Braemar Tillite		46
		0	
Diapir			

COMMENTS: Details of the Holowilena Ironstone from the second gutter south of the Asbestos Mine at 283480mE, 6533520mN.

SECTION No. 053

GEOGRAPHIC LOCATION: Pantapinna Track

POSITION AT START OF TRAVERSE, AMG Coordinates: 283640 mE / 6534200 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 285575 mE / 6537340 mN

TOTAL LENGTH: 2138 metres STATUS: Staffed - , Taped - , Calculated yes.

DIP AT START: 63 DIP AT END: 25 SCALE OF MEASURED SECTION: 1cm:100m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Etina Formation	Patterton Shale		
	Winna Limestone		836
Tapley Hill Formation	shale		197
	Wockerawirra Dolomite		86
	shale		473
	Mt. Caernarvon Greywacke		241
	shale		285
	Tindelpina Shale		20

COMMENTS: Calculation from field traverse and trig.

SECTION No. 054

GEOGRAPHIC LOCATION: Nungawurtina

POSITION AT START OF TRAVERSE, AMG Coordinates: 275135 mE / 6555180 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 276290 mE / 6547170 mN

TOTAL LENGTH: 2273 metres STATUS: Staffed - , Taped - , Calculated yes.

DIP AT START: 90 DIP AT END: 14 SCALE OF MEASURED SECTION: 1cm:100m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Etina Formation	Patterton Shale		
	Winna Limestone		745
Tapley Hill Formation	shale		261
	Wockerawirra Dolomite		224
	shale		415
	Mt. Caernarvon Greywacke		158
	shale		370
Diapir			

COMMENTS: Calculation from field traverse and trig.

SECTION No. 055

GEOGRAPHIC LOCATION: White Cutting

POSITION AT START OF TRAVERSE, AMG Coordinates: 278845 mE / 6551695 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 281570 mE / 6549925 mN

TOTAL LENGTH: 1375 metres STATUS: Staffed - , Taped - , Calculated yes.

DIP AT START: 90 DIP AT END: 14 SCALE OF MEASURED SECTION: 1cm:100m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Etina Formation	Patterton Shale		
	Winna Limestone		772
Tapley Hill Formation	shale		126
	Wockerawirra Dolomite		84
	shale		145
	Mt. Caernarvon Greywacke		127
	shale		121
Diapir			

COMMENTS: Calculation from field traverse and trig.

SECTION No. 056

GEOGRAPHIC LOCATION: Rocky Waterhole

POSITION AT START OF TRAVERSE, AMG Coordinates: 279960 mE / 6554455 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 280835 mE / 6554435 mN

TOTAL LENGTH: 693 metres STATUS: Staffed - , Taped - , Calculated yes.

DIP AT START: 90 DIP AT END: 41 SCALE OF MEASURED SECTION: 1cm:100m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Etina Formation	Patterton Shale		
	Winna Limestone		118+
Tapley Hill Formation	shale		113
	Wockerawirra Dolomite		91
	shale		222
	Mt. Caernarvon Greywacke		81
	shale		68
Diapir			

COMMENTS: Calculation from field traverse and trig.

SECTION No. 057

GEOGRAPHIC LOCATION: Glasses Gorge

POSITION AT START OF TRAVERSE, AMG Coordinates: 273430 mE / 6560140 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 270740 mE / 6564710 mN

TOTAL LENGTH: 2350 metres STATUS: Staffed - , Taped - , Calculated yes.

DIP AT START: 90 DIP AT END: 20 SCALE OF MEASURED SECTION: 1cm:100m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Etina Formation	Patterton Shale		166
	Winna Limestone		649
Tapley Hill Formation	shale		275
	Wockerawirra Dolomite		82
	shale		590
	Mt. Caernarvon Greywacke		516
	shale		72

Diapir

COMMENTS: Calculation from field traverse and trig.

SECTION No. 058

GEOGRAPHIC LOCATION: Oratunga

POSITION AT START OF TRAVERSE, AMG Coordinates: 277430 mE / 6559900 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 279000 mE / 6561770 mN

TOTAL LENGTH: 1541 metres STATUS: Staffed - , Taped - , Calculated yes.

P AT START: 90 DIP AT END: 25 SCALE OF MEASURED SECTION: 1cm:100m.

SECTION No. 058

GEOGRAPHIC LOCATION: Oratunga

POSITION AT START OF TRAVERSE, AMG Coordinates: 277430 mE / 6559900 mN

POSITION AT END OF TRAVERSE, AMG Coordinates: 279000 mE / 6561770 mN

TOTAL LENGTH: 1541 metres STATUS: Staffed - , Taped - , Calculated yes.

DIP AT START: 90 DIP AT END: 25 SCALE OF MEASURED SECTION: 1cm:100m.

FORMATION NAME	MEMBER / BAND	BOUNDARY POSITION	THICKNESS (M)
Etina Formation	Patterton Shale		196
	Winna Limestone		751
Tapley Hill Formation	shale		110
	Wockerawirra Dolomite		32
	shale		320
	Mt. Caernarvon Greywacke		70
	shale		62

Diapir

COMMENTS: Calculated by trig with geology by photo interp and dips from Coat's map.

APPENDIX V

Reprint of the paper entitled

Blinman to Enorama - A one day excursion

which was included in the excursion guide,

Proterozoic to Cambrian sedimentary environments and resource potential, Flinders Ranges, South Australia,

compiled by C.R. Dalgarno

for the 8th. Australian Geolgical Convention, 1986.

Lemon, N.M. (1986). Blinman to Enorama – A one day excursion. In Dalgarno, C.R. (comp.), Proterozoic to Cambrian sedimentary environments and resource potential, Flinders Ranges, South Australia. For *The Eighth Australian Geological Convention, February 16-21, 1986,* Flinders University, Adelaide.

NOTE: This publication is included in the print copy of the thesis held in the University of Adelaide Library.

APPENDIX VI

A preprint of the paper entitled

Glacigenic sediments of the late Proterozoic Elatina Formation and equivalents, Adelaide Geosyncline, South Australia.

by N.M. Lemon and V.A. Gostin

for inclusion in the Brian Daily Memorial Volume
to be published by the Geological Society of Australia.

Lemon, N.M. and Gostin, V.A. (1990). Glacigenic sediments of the late Proterozoic Elatina Formation and equivalents, Adelaide Geosyncline, South Australia. In *The Brian Daily Memorial Volume* published by Geological Society of Australia.

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