The structural evolution of the western frontal margin of the Adelaide Fold Belt in South Australia.

by

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ABSTRACT

Sediments belonging to the western frontal margin of the Adelaide Fold Belt in the Southern Flinders Ranges have undergone deformation in the Delamerian Orogeny. Through continual E-W compression the, the sediments were folded and thrusted. A major decolloment was formed within the Callanna Beds at the base of the Adelaidean Sequence and a thin thrust sheet (approx. 5km) was produced. The decollement extends to the edge of the ranges, to the west of which are the relatively undeformed units of the Stuart Shelf.

Within the thrust sheet, a high degree of subsidiary thrusting occurred leading to the generation of three distinct geometrical subdomains. These are a series of back thrusts near the leading edge of the thrust sheet, a series of forward thrusts to the east of the sections and a triangle zone between the two. Localised high strain areas occur along, or in the vicinity of thrusts in an otherwise low strain area.

The amount of crustal shortening within this part of the fold belt is on average 4.4km. This has been largely accommodated by the thrust displacement and to a lesser extent fault bend folds, fault propagation folds and cleavage development.

1. INTRODUCTION

1.1 Regional Geology and previous investigations

Shallow foreland fold and thrust belts are found on the continental margins of virtually all present day fold mountain belts [Coney, 1973]. Typically formed in weakly or unmetamorphosed sedimentary sequences, these rocks are deformed at shallow depths by stratal shortening and uplift. Stratal shortening is accommodated by thrusting and associated folding of the sequences [Hobbs et. al. 1976]. The Flinders Ranges of South Australia are such a foreland fold and thrust belt. The Flinders Ranges belong to what is generally known as the Adelaide Geosyncline. This formed as a deeply subsiding basin of late Precambrian to Cambrian age, which extended over the Flinders Ranges, the Mount Lofty Ranges and the Olary Province. Thick layers of sediments were accumulated and subsequently underwent thrusting, folded, metamorphosed, intruded and uplifted during the Late Cambrian to Early Ordovician Delamerian Orogeny [Preiss, 1987]. The fold belt displays a sigmoidal structural trend with the regional strike of the Lower Flinders Ranges trending approximately North-South.

Structural evolution of foreland fold and thrust belts typically involves large scale crustal shortening. The folds and thrusts produced in such cases are commonly geometrically and kinematically linked [Tavernelli, 1996]. Two particular types of linked folds and faults are fault-propagation folds and fault-bend folds. Understanding the relationships behind these fault related folds can provide constraints on the evolution of foreland fold and thrust belts such as the Flinders Ranges.

Fault-propagation folds form contemporaneously with propagating fault tips. Anticlines develop over the blind thrust and a syncline at the fault tip. The fault tip lies on the same layer as the branching point of the anticlinal surfaces and the fault ramp is predominantly at a 30∞ angle to the footwall flat [Mosar & Suppe, 1992]. The principles in the conservation of the volume of a solid produces the requirement for geometric and kinematic relationships to apply. Two models of fault-propagation fold have been produced; *1)* constant thickness theory where there is a balanced forward model with constant layer thickness and bed length and *2)* fixed axial surface theory where there is a balanced forward model with thickness change in the beds of the front limb [Suppe & Medwedeff, 1990] (Fig.1). The fault-propagation fold models are appropriate to the sedimentary rocks of the Flinders Ranges, as they apply to regions of the upper crust where rocks undergo brittle deformation and suffer little internal deformation under low grade metamorphism. The shape of simple fault-propagation folds, whether it be constant thickness theory or fixed axial surface theory, is dependent on two variables; the angle between the bedding and the fault ramp, and the shear imposed on the layers in the fold core [Mosar & Suppe, 1992]. Using mathematical relationships of fault-propagation folds and applying them to the structural data obtained in the field, the geometrical evolution of the Flinders Ranges foreland fold thrust belt can be determined.

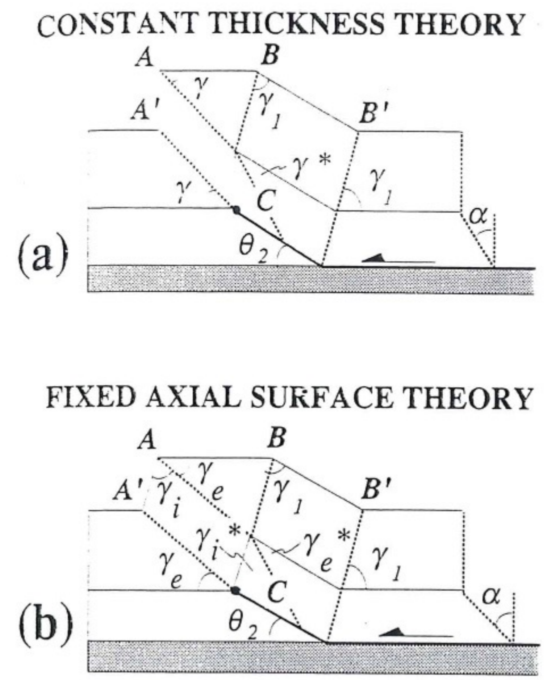


Fig. 1 [Fig. 3 from Mosar & Suppe 1992]

Thrust faults in orogenic zones tend to occur along preferred stratal planes such as beds of shale, salt or gypsum. They typically follow these beds for some distance then propagate through a more resistant layer to a stratigraphically higher, low strain-resistant bed. This produces a stair step-like geometry with an anticline formed over the top of the fault ramp (or 'step') and synclines between the hanging wall ramp and the hanging wall flats (Fig. 2) [Wibberley, 1996]. These are called fault-bend folds. Wibberley shows how models for this type of thrust sheet deformation can be used to estimate original ramp dip, ramp length, shear strains and extensional or shortening strains from field data. Applied to the field data collected from the Flinders Ranges, this could be useful in determining pre-deformational geometries of the stratigraphy and hence the extent of crustal shortening.

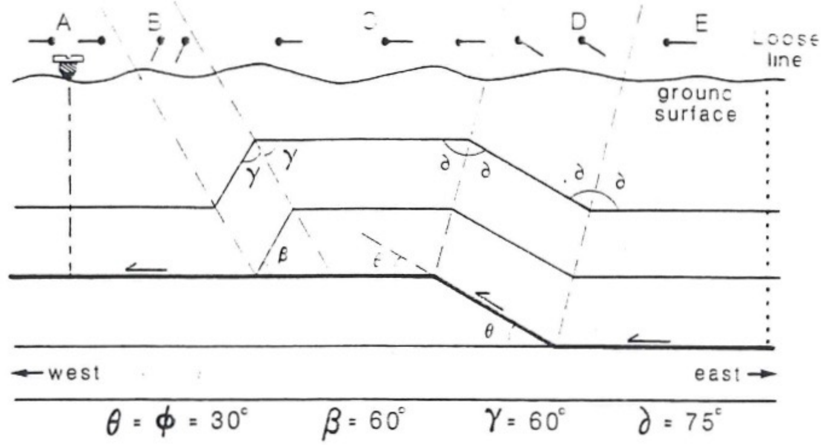


Fig. 2- A single step in a thrust fault and the associated anticline in the hanging wall thrust sheet illustrating the terminology used for describing cut-off angles and interlimb angles. [Fig. 14-5 from Marshak and Woodward, 1988]

Deformation mechanisms operating in the foreland thrust zone are dominated by cataclasic mechanisms due to the relatively low temperatures and confining pressures associated with these regions of orogenic belts [Wibberley, 1996]. Folds in such regions are characteristically large open structures and are typically angular (eg. kink folds, chevron folds), however this is not necessarily the case.

1.2 Location and physiography.

The main region of investigation is the western margin of the Flinders Ranges. Three areas, Nectar Brook, Pichi Richi Pass and Depot Creek were mapped in detail with all three being located on the frontal region of the Southern zone of the Flinders Ranges. Pichi Richi Pass is located approximately 21km E of Port Augusta, Nectar Brook approximately 33km SE of Port Augusta and Depot Creek approximately 38km NE of Port Augusta.

Access to the three areas varies from sealed roads to 4wd tracks to foot only. Pichi Richi Pass can be accessed through the main sealed road from Stirling North, just outside Port Augusta, to Quorn. Saltia Creek runs adjacent to this road and Waukarie Creek can be accessed on foot via this road and Richman Valley or by 4wd via a track through Woolshed Flat. Access to Depot Creek is via a dirt track through private property restricted to 4wd in winter and by foot through the main part of the creek itself. Nectar Brook is accessed through private property via 4wd tracks from either the National Highway One or through Hancocks Lookout. Access to Pichi Richi Pass and Depot Creek is generally unrestricted along the areas through which the Heysen Trail passes, however, Nectar Brook requires prior permission from the land holders.

The landforms of the Flinders Ranges are generally rugged with high relief. The more weathering resistant quartzites form large rocky ridges with relatively soft shales and carbonates forming valleys. Large creeks such as Depot Creek, Waukarie and Saltia Creeks and Nectar

Brook cut through the general trend of the rock strata producing excellent traverses along which to map. The plains to the west of the Ranges are very flat lying and are covered with Quaternary sediments with no unweathered outcrop visible.

Vegetation through the Lower Flinders Ranges predominantly consists of reasonably sparse spinifex, low shrubs, Mallee, Black Oak, Native Pine and River Red Gum. Rainfall in the lower Flinders Ranges is low as it is in an arid climate. Vegetation in the three main areas of investigation can be used to a certain extent to aid the interpretation of rock boundaries on aerial photographs. This is especially the case in the Pichi Richi Pass area where the Wonoka Formation with its high alkalinity predominantly supports spinifex and a few small trees. The ABC Range Quartzite however, supports many small shrubs and small trees. This difference in vegetation is generally easily distinguishable from the aerial photographs.

1.3 Aims and Methods of Investigation.

The aims of this project are to determine the geometrical, kinematic and dynamic evolution of the frontal region of the Adelaide foreland type fold and thrust belt by looking at the role of fault bend and fault propagation folds, fault slip and cleavage development in the areas described above. Outcomes include the production of detailed structural maps and cross-sections of the Depot Creek, Pichi Richi Pass and Nectar Brook areas and an understanding of the geometrical and kinematic evolution of these areas. This may better provide information applicable to other foreland fold and thrust belts and help in the understanding of their evolution.

The project involved a large component of field work lasting approximately six weeks. This included detailed mapping of the geological structures in my areas and accurate and detailed measurements were taken from observations in the field. This was integrated with published data on the local geology of the areas of investigation and structurally similar areas.

Analytical work involved the construction of balanced cross-sections in order to obtain an estimate for the extent of crustal shortening and were used to better constrain structural interpretations in areas of poor data quality. Analytical work also involved the analysis of thin sections of field samples with known orientation to gather information on strain variation across the area. All map and figure drafting work was carried out with programs such as Freehand 5 to produce a quality final draft of the geological map and cross sections, and a Stereographic plotting program to help obtain structural models of the field areas. Dip isogons were constructed to classify the various folds in the area.

2. LITHOLOGIES AND STRATIGRAPHY

2.1 General Stratigraphy in the Areas of Investigation.

The stratigraphy throughout the areas of investigation belong to the two super groups, the Warrina Supergroup and the Heysen Supergroup, of the Upper Proterozoic Adelaide System [Preiss, 1987]. The Warrina Supergroup consists of the Callanna and Burra Groups and the Heysen Supergroup consists of the Umberatana and Wilpena Groups.

The Callanna Beds are a lithologically varied sequence of Willourian units consisting of basic volcanics, sedimentary siltstones, sandstones and dolomites, and diapiric breccias. The Callanna Beds refers to that part of the lower Adelaidean Warrina Supergroup between the unconformably overlying Burra Group and the base of the Adelaide System.

The Burra Group ërefers to that part of the lower Adelaidean Warrina Supergroup between the base of the Rhynie Sandstone and the generally unconformable base of the Umberatana Groupí [Preiss, 1987]. The units of the Burra Group are the Rhynie Sandstone of the Emeroo Subgroup, the Skillogalee Dolomite and the unnamed dolomitic shales and quartzites of the Belair Subgroup [Preiss, 1987].

The Umberatana Group consists of tillites of the Adelaide Geosyncline, which were derived from two periods of glaciation called the Sturtian and Marinoan Glaciations, and the intervening interglacial sequence. The Umberatana Group occurs throughout the Adelaide Geosyncline and has an average thickness of about 4km [Preiss, 1987].

The Wilpena Group is described by Dalgaro and Johnson [Thomson et al. 1964] as the stratigraphic interval between the top of the 'upper glacial sequence' and the Pound Subgroup. The Wilpena Group is the youngest Precambrian unit in the Adelaide Geosyncline and is of Marinoan age. It is approximately 1-2km thick and the most widespread of all rocks in the geosyncline, although the Wonoka Formation is confined to the Flinders Ranges [Preiss 1987].

2.2 Depot Creek.

The Depot Creek stratigraphy belongs to the Callanna, Burra, Umberatana, and Wilpena Groups. Those units which are present in this area are the Roopena Volcanics, unnamed siltstone and sandstone beds and diapiric breccias of the Callanna Beds; the Rhynie Sandstone, Skillogalee Dolomite and unnamed dolomitic shales and quartzites of the Burra Group; Appila Tillite Equivalent, Tapley Hill Formation, Brighton Limestone Equivalent and Willochra Formation of the Umberatana Group; Brachina Formation and ABC Range Quartzite of the Wilpena Group.

The Roopena Volcanics are located at the western edge of the section. They consist of two units; a purple and a green-grey coloured amygdaloidal trachyte. The unnamed sedimentary unit within the Callanna Beds located at Depot Creek consist of interbedded purple coloured siltstones and silty sandstones with sedimentary structures such as ripple marks and cross-bedding showing the younging direction to the East.

The Rhynie Sandstone is a pink to buff coloured feldspathic quartzite with beds of reddish shales found near the base. Ripple marks were abundant showing facing to the East. The Rhynie Sandstone is approximately 600m thick.

The Skillogalee Dolomite conformably overlies the Rhynie Sandstone. It contains a very distinctive conglomerate with yellow and buff coloured clasts of magnesite in a very fine-grained matrix of grey coloured dolomite (plate 1 and plate 5A.). Large black chert pods were common throughout the base of the Skillogalee Dolomite. The thickness of this unit is approximately 500m.

The youngest member of the Burra Group in this section is the unnamed dolomitic shales and quartzites. Due to the low angle dip of the units in this area and the high topography, this unit does not outcrop in Depot Creek through which the section was mapped but up either side of the gully on the hills. This unit consisted of coarse grained buff coloured quartzite. The unnamed dolomitic quartzite is approximately 300m thick.

The basal unit of the Umberatana Group in Depot Creek is the Appila Tillite Equivalent. The contact between the Umberatana Group and the Burra Group usually occurs as a disconformity [Preiss, 1987] however, the contact in this section along Depot Creek is a fault contact. This is shown in cross-section 1. The Appila Tillite Equivalent contains unsorted angular clasts of various rock types, from boulder size to marble size, in a coarse grained quartzite and siltstone matrix. This unit is approximately 100m thick.

The Tapley Hill Formation is a calcareous, grey coloured, finely laminated shale with a good bedding parallel cleavage. Grain size is very fine and well sorted. This unit disconformably overlies the Appila Tillite Equivalent and has a thickness of approximately 180m.

The Brighton Limestone Equivalent conformably overlies and grades into the Tapley Hill Formation. It is a green-grey coloured dolomitic siltstone and has thick beds of stromatolites which are several metres thick and prominent in the lower Brighton Limestone Equivalent. The thickness of the Brighton Limestone Equivalent is approximately 370m.

The Willochra Formation overlies the Brighton Limestone Equivalent however, the nature of the contact was not determined as it is obscured by scree along the mapped section. According to Preiss and Sweet (1966), the boundary is conformable and the Brighton Limestone Equivalent grades into the Willochra Formation over an interval of approximately 50-100ft. The Willochra Formation can be divided into lower and upper units. The lower unit consists of calcareous purple-red siltstones with thin beds of orange-buff coloured quartzite. Ripple marks are present. The thickness of this lower unit is approximately 370m. The upper unit of the Willochra Formation predominantly consists of purple shales and quartzite, none of which are calcareous. Beds of quartzite increase in thickness near the top of the unit. The total thickness of the Willochra Formation is approximately 1km.

The contact between the Willochra Formation and Brachina Formation represents the conformable boundary between the Umberatana Group and the overlying Wilpena Group. The Nuccaleena Formation which is generally recognised as a thin marker bed for the base of the Wilpena Group [Preiss, 1987], was not present but may have been obscured by the scree of the Brachina Formation or was pinched out. The Brachina Formation is a very fine grained chocolate-brown shale with many fine pale green laminations. There are also fine grained sandstones present throughout the shale. The Brachina Formation contains small wavelength ripple marks. Pencil cleavages are common throughout the unit. The thickness is approximately 440†m. The thicknesses of the beds within this section may vary, however, for the sake of producing a restored and balanced cross-section, the thicknesses have been kept constant.

Conformably overlying the Brachina Formation is the ABC Range Quartzite. This unit represents the youngest unit within this Depot Creek section. The ABC Range Quartzite is easily distinguishable in the field as it forms large rocky ridges. The rock consists predominantly of very well sorted grains of fine to medium grained quartzite. It is generally buff or pink in colour with the occasional heavy mineral laminae. Sedimentary structures include ripple marks and cross-bedding.

2.3 Pichi Richi Pass.

The stratigraphy of the Pichi Richi Pass area is not unlike that of Depot Creek. It belongs to the Burra, Umberatana and Wilpena Groups. The units within these groups that are included in the section are the unnamed dolomitic shales and quartzites of the Burra Group; Appila Tillite Equivalent, Tapley Hill Formation, Brighton Limestone Equivalent and Willochra Formation of the Umberatana Group; Brachina Formation, ABC Range Quartzite, Bunyeroo Formation and Wonoka Formation of the Wilpena Group. The Skillogalee Dolomite and Rhynie Sandstone of the Burra Group and the Callanna Beds have been included in the extended cross-section but were not encountered in the field work.

The unnamed dolomitic shales and quartzites is the oldest unit that was mapped in the

Pichi Richi Pass section and is located on the western edge. This unit consisted of buff coloured coarse grained quartzite.

The Appila Tillite Equivalent consists of large angular clasts of various rock types in a matrix of quartzite interbedded with greenish coloured siltstone. Sizes of the clasts vary in layers, ranging from boulder size to very coarse grained. The clast size increases towards the top of the unit. The Appila Tillite Equivalent is approximately 220m thick.

The description of the Tapley Hill Formation located at the Pichi Richi Pass area is identical to that of Depot Creek. It contains green and white calcareous shales with very fine laminations, and a coarse grained sandstone. No sedimentary structures apart from bedding were observed. The thickness of this unit is approximately 150m.

The Brighton Limestone Equivalent is easily seen on the air photograph as a thin white bed. It is a green calcareous siltstone. The thickness of this unit is approximately 100m.

The Willochra Formation at this location consists of thick beds of medium-coarse grained quartzite sandstone, exhibiting ripplemarks which indicate a younging direction to the east. There are also thick beds of very fine grained siltstone. The boundary between Lower and Upper Willochra was not apparent and therefore it was mapped as a single unit approximately 1km thick.

The Brachina Formation conformably overlies the Willochra Formation and as with Depot Creek, the Nuccaleena Formation is not present. The Nuccaleena Formation can be found north of this section between the road and Devils Peak but is absent from this section. The Brachina Formation is comprised of interbedded purple to chocolate-brown shales and sandstones. Grain size ranges from fine to very fine. Sedimentary structures present are ripple cross laminae, ripple marks and mud drapes. This unit is approximately 180m thick.

The ABC Range Quartzite is fine to medium grained. It is pale pink to buff in colour. It contains sedimentary structures such as mud crack casts and cross-bedding. Slickensides are common throughout the section which give an indication on the vergence of the rock unit in some areas. This unit increases its thickness towards the east. In the west its thickness is approximately 140 m and in the east it is approximately 370m. The reasons for this are explained later in cross-section balancing.

The Bunyeroo Formation is a chocolate-brown shale with very fine grains with pale green and reddish fine laminae. It has a minimum thickness of approximately 260m and conformably overlies the ABC Range Quartzite with a relatively sharp boundary.

The Wonoka Formation consists of limestones, silty sandstones and dolomitic shales with a conglomerate at the base. The colours vary throughout the unit and include white, grey, green-grey, and pink-grey. The basal conglomerate includes large rounded clasts of Bunyeroo Formation and intraformational dolomite. The Wonoka Formation is conformable with the underlying Bunyeroo Formation except in areas where it has eroded through the lower formations. These areas where the Wonoka Formation has eroded into the lower units could be due to sub-marine canyon erosion or fluvial processes. This unit represent the top of the Wilpena Group and the youngest unit in this section.

2.4 Nectar Brook.

The units in this area belong to the Umberatana Group and the Wilpena Group.
The Umberatana Group unit within this area is the Willochra Formation. The other units of the Umberatana Group, such as the Brighton Limestone Equivalent, the Tapley Hill Formation,

Tindelpina Shale Member, and the Appila Tillite Equivalent, along with the units of the Burra Group and Callanna Beds, have been included in the cross-section but have not been mapped in the field work. The units of the Wilpena Group located in this area are the Brachina Formation, ABC Range Quartzite and the Bunyeroo Formation.

The Willochra Formation in the Nectar Brook area consists of red-brown quartzites and siltstones. As with the Willochra Formation at Pichi Richi Pass, the upper and lower units were indistinguishable and therefore treated as one thick unit. Ripple marks indicated that the younging direction west of the 'Sandy Knob Anticline' was to the west. The thickness of this unit was determined by extending the cross-section using data from the 1:250 000 scale maps produced by the Dept. of Mines and Energy SA. It is approximately 1.5km thick.

The Brachina Formation lithology is identical to that of the previous two areas but no sedimentary structures were found. The thickness of the unit is about 150m.

The ABC Range Quartzite varies from a very white to pink with some heavy mineral laminae. Cross-bedding was the only sedimentary structure observed. Grainsize is fine to medium grained. Slickensides were present in some outcrops giving a direction on slip movement. The thickness of this outcrop is 630m. The Bunyeroo Formation is the youngest unit of this section. Its lithology is the same as that of the other two areas.

3. STRUCTURAL GEOMETRY

3.1 Tectonic Subdomains

Each of the three areas of investigation have been divided into several tectonic subdomains, all of which are constrained by vergence direction and fault geometry. Each subdomain possesses its own characteristics in the way of fold geometry and cleavage orientations due to the imposition of differing stress regimes. All subdomains are orientated N-S due to the fault pattern. Each subdomain is numbered with a letter which refers to the first letter of the area (eg. D-Depot Creek, P-Pichi Richi Pass and N-Nectar Brook) and a number, beginning with one at the leading edge of the section (see Appendix 1). Stereonet plots of bedding and cleavage were produced (see Appendix 2) to illustrate the different characteristics between each subdomain. The cleavage plots however, seem rather ambiguous and should only be used as a guide.

3.1.1 Depot Creek

The thrust sheet in the Depot Creek section consists of three major subdomains. *Subdomain D1* is bounded by the leading edge of the section and the 'Rhynie Fault'. This subdomain exhibits east dipping beds due to an underlying fault ramp. This subdomain is verging to the west.

Subdomain D2 is a 'pop-up' structure. The large and small scale folds within this domain show vergence to the East. Beds predominantly dip uniformly to the east with a large scale fold at the eastern side. D2 is bounded by the 'Rhynie Fault' in the west and the 'Teeteetya Springs Fault' in the east.

Subdomain D3 is another westward verging block being thrusted up over a fault ramp in the decollement and under D3. Regional folds such as the 'Comstock Syncline' are included within this subdomain. D3 is bounded by the 'Teeteetya Springs Fault' in the west and 'Arden Fault' in the east.

3.1.2 Pichi Richi Pass

The Pichi Richi Pass section can be divided into three tectonic subdomains. *Subdomain P1* is located on the western edge of the section and is characterised by the series of back thrusts and its eastward vergence as the folds within it indicate. P1 is bounded in the west by the decollement and in the east by the 'Devils Peak Fault'.

Subdomain P2 is a triangle zone thrusted westwards but under both the East verging P1 and the West verging P3. P2 is bounded by the 'Devils Peak Fault' in the west and the 'Diagonal Fault' on the East side. Because the outcrop of P2 is only approximately 260m wide along this cross-section, information was taken from a wider section approximately 1.5km north of this section.

Subdomain P3 is located in the trailing edge of the section and is characterised by a series of forward thrusting faults. This subdomain is bounded by the 'Diagonal Fault' on the west side and the trailing edge of the section on the east side. The folds in P3 indicate westward vergence.

3.1.3 Nectar Brook

The Nectar Brook section can be divided into five tectonic subdomains. *Subdomain N1* is located at the leading edge of the section and is bounded by the decollement on the west side and the ‘ABC Fault’ on the east side. This block is characterised by its eastward vergence and its uniformly dipping beds.

Subdomain N2 is a small ‘pop-up’ structure bounded by the ‘ABC Fault’ in the west and the ‘Winninowie Fault’ in the east.

Subdomain N3 is an eastward verging block with easterly dipping beds. It is bounded by the ‘Winninowie Fault’ in the West and the ‘Reservoir Fault’ in the east. This subdomain is much the same as N4.

Subdomain N4 is also an eastward verging block with easterly dipping beds. N4 is bounded by the ‘Reservoir Fault’ on the west side and the ‘Hidden Fault’ on the east side. N4 could be included in the same subdomain as N3 as its characteristics are similar.

Subdomain N5 is the largest subdomain in this area. N5 is bounded by the ‘Hidden Fault’ on the west side and the trailing edge of the section in the east. This subdomain includes only 1.5km of data actually collected from the field with the rest obtained from the Orroroo 1:250 000 scale map produced by the Geological Survey of South Australia.

3.2 Fold Styles

3.2.1 Depot Creek

Mesoscopic folds within this section were not very prominent, however, those present display an open to close style. The mesoscopic fold found in the D2 subdomain is class 1B [after Ramsay, 1967]. It displays one moderately steep dipping east facing limb (52^{o}E) and two shallow dipping limbs (07^{o}N and 15^{o}NE). This fold is located within the hinge of a regional scale syncline. This fold geometry indicates eastward vergence. In the subdomain D3 there are a number of mesoscopic folds located near the ‘Teeteetya Springs Fault’. These all plunge approximately 20^{o}N. They exhibit the same style and class of folding as the previous mentioned fold. The short limbs of the fold faces east. This indicates eastward vergence even though the D3 block has moved to the west. This is acceptable however, because the folds are located on the western limb of a large fault bend anticline produced by a fault ramp in the decollement.

The regional scale folds within this section are all characteristically gentle folds and have wavelengths of several kilometres. All of the folds, both regional and mesoscopic, possess geometries which are related to the kinematics of the thrust sheet deformation.

3.2.2 Pichi Richi Pass

The folds in subdomain P1 typically possess a gentle to open style of class 1B [after Ramsays, 1967]. The mesoscopic anticline located within the Brachina Formation (Plate 2A.) tends not to show any direction of vergence as its axial plane is approximately vertical (88^{o}E). This could be due to the relative close proximity to the leading edge of the thrust sheet. Further East there are several small folds which possess the same geometry as that found in D2 at Depot Creek. The fold exhibits a short, steep dipping limb facing East with two long, shallow dipping limbs. These indicate that the vergence is to the East. Located just to the West of the ‘Pichi Richi Shear Zone’ are two folds with similar geometry to the previous mentioned fold but indicating vergence to the west (Plate 2B.). These folds plunge to the south and can be classed as 1B verging on 1C [after Ramsay, 1967]. These show west vergence due to being located on the east limb of a regional scale fold.

The regional scale folds within this subdomain all show vergence to the east. This is convincingly displayed by the ‘Holiday Camp Anticline’ with its axial plane dipping approximately 55°W.

The triangle zone P2 displays a fault bend fold at a depth of approximately 5.5km. The geometry of this fold and fault ramp does not comply with the geometry of a single step fault bend fold outlined by Marshak and Woodward (1988) (Fig 2). The angles within this fold do not quite adhere to the relationship described by the equation:

$$\phi = \theta = \tan^{-1}\{\sin 2\gamma / (2 \cos^2 (+ 1)\}$$

[Eq. 14-1, Marshak and Woodward, 1988]

This would almost certainly be due to the depth of this structure. The projection of data down to this depth is very ambiguous and effected by any thickness changes or any changes in fold geometry with depth.

Mesoscopic folds located in the Wonoka Formation between the 'Diagonal Fault' and the 'Babyís Bottom Fault' in subdomain P3, are ptygmatic. This is displayed by the calcite vein in Plate 3A. The Wonoka Formation is a very ductile rock which would explain why this is the only location that ptygmatic folds were located in this section. Further East, just over the 'Baby's Bottom Fault' in the ABC Range Quartzite, is an outcrop which exhibits large disharmonic chevron and open folds (Plate 3B.). These folds are typically class 1C, almost 1B, and show no particular vergence. These folds show a relatively intense strain compared to the rest of the area, which would be related to its close proximity to the 'Baby's Bottom Fault'.

The regional fold producing 'Richman Valley Syncline' has a fold axis dipping approximately 75°E which is a good indication of the westward vergence of the subdomain P3 and the net vergence of the thrust sheet in general.

3.2.3 Nectar Brook

The folds within this section are all of regional scale. There were no mesoscopic or microscopic folds found in the area. This may be due to the prevalence of quartzite, which is less ductile. The regional folds are all gentle and characteristic of relatively low strain. The asymmetry of the folds indicates vergence direction. The 'Sandy Knob Anticline' displays an eastward dipping axial plane which shows that the N5 block has a westward vergence. The only other significant fold within the section is the 'Alligator Gorge Syncline'. The data from this however, was obtained from the Orroroo 1: 250 000 scale map.

The use of folds in determining directions of vergence can be useful however, it seems that only the regional scale folds can be used to determine the overall vergence of large blocks within the thrust sheet. Small scale folds only show local vergence but can be used as indicators of the extent of strain. The intensity of folding is related to the proximity of the rocks to the fault. Every fold in all three sections could be classified as an F1 fold. S1 was parallel to the axial surface of the fold.

3.3 Faulting

3.3.1 Depot Creek

There are three major faults within the mapped area of Depot Creek, two of which trend approximately N-S (the 'Teeteetya Springs Fault' and the 'Arden Fault'), and the third fault trending approximately NW-SE (the 'Rhynie Fault').

The ‘Rhynie Fault’ is located to the west of the section. Air photograph interpretation showed up a linear feature trending approximately 315^o. Fault breccia was found and therefore confirmed as a fault. It displays a high angle reverse movement with the hanging wall on the east moving upwards relative to the west. The fault surface is interpreted to dip approximately 80^{o}E. The displacement is approximately 400m.

The ‘Teeteetya Springs Fault’ was located just west of Teeteetya Springs by air photograph interpretation. A small amount of fault breccia was found however, the main distinguishing feature which confirmed that it was a fault was the abrupt change in lithology which did not comply with expected stratigraphy. The linear trace of the fault along the ground surface indicates that the fault dips approximately 80^o to the west [W. Preiss, 1966]. Thus it is interpreted to be a high angle back thrust, joining to the ‘Rhynie Fault’ at a depth of 2km and producing a ‘pop-up’ structure, with the footwall to the east moving downwards with respect to the hanging wall on the west. The displacement of this fault is approximately 500m.

The ‘Arden Fault’ is located to the east of the section and is inferred. Slickensides were observed on the east side of ‘The Bluff’ in float, in the vicinity of the inferred fault however, there was no other evidence such as fault breccia found. These slickensides may be due to layer parallel slip related to folding rather than a thrust surface. This area is mostly covered with Quaternary sediments and the location of the fault is not observable on the air photograph. The trend of the fault, 010^o, was taken from the 1: 250 000 geological map of Orroroo produced by the Geological Survey of South Australia. The dip of the fault surface was interpreted to be towards the east in order to realistically comply with the cross-section model, thus producing another high angle forward thrusting fault.

Layers of fault breccia (approx. 5cm to 0.5m thick) located in the Skillogalee Dolomite, on the eastern side of subdomain D2, are parallel to the bedding indicating slip between beds which may explain the difficulty in producing an accurate calculation for depth to decollement outlined later.

The large anticline to the west of the ‘Comstock Syncline’ is associated with an interpreted ramp in the decollement and the beginning of a propagating thrust producing the convergence of several fold axes.

3.3.2 Pichi Richi Pass

There are six major faults located in the section investigated at Pichi Richi Pass. The direction of movement along the thrusts can be determined based on vergence directions obtained through the geometry of the folds in the area and stratigraphic relationships.

Beginning with the ‘Saltia Fault’, air photo interpretation shows an outcrop pattern which suggests that lateral movement (ie. sinistral movement) has occurred as well as vertical movement with the hanging wall on the west moving upwards relative to the east. This fault could be classed as an oblique slip fault. The lateral movement may cause some inaccuracy in cross-section balancing. The presence of fault breccia found at the top of ‘Saltia Hill’ provides evidence for the existence of this fault independent of the obvious stratigraphic relationships.

The next two faults east of the ‘Saltia Fault’, are back thrusts which bound the ‘Pichi Richi Pass Shear Zone’. This shear zone is located to the east of the main road through Pichi Richi Pass and is displayed by an intensely sheared segment of Wonoka Formation and ABC Range Quartzite (Plate 4a.). It is approximately 180m wide at the line of cross-section and is gradually pinched out to the North where the two faults meet. The faults can be seen clearly as lineations on the air photograph when the scale of the photo is reduced from 1: 40 000 to 1: 25

000. The dip of the beds of ABC Range Quartzite to the west of the road increase and the beds buckle as they dip down into the creek bed which suggests that this shear zone dips westward under the road and the 'Holiday Camp Anticline'. It would also suggest that this back thrusting shear is responsible for the geometry of the anticline. In the case of the 'Pichi Richi Pass Shear Zone', the western side is the hanging wall which has moved up over the footwall to the east. A small propagation fault may be the cause of the 'Saltia Syncline'.

The other three faults, 'Diagonal Fault', 'Baby's Bottom Fault' and 'Richman Fault', are located in subdomain P3, the eastern half of the section. All three faults dip to the east. Vergence is in a westerly direction, in reverse movement along each fault. With each of the eastern faults, the hanging wall is located to the east of the fault and is thrust at high angles over the footwall to the West of the faults. The steep dipping fault planes can be observed down the sides of large hills. From this, the dips of the fault planes are determined to be approximately 80ºE. The relatively straight fault traces observable on air photographs, despite the high relief topography, also suggests high dip angle faults. The 'Diagonal Fault' and the 'Baby's Bottom Fault' exhibit reverse displacements of approximately 74m and 440m respectively. The ABC Range Quartzite thickens considerably from the west side of 'Richman Fault' to the East side. Thus it is interpreted that 'Richman Fault' is a reactivated growth fault. It exhibits reverse displacement of approximately 280m.

3.3.3 Nectar Brook

The Nectar brook cross-section displays a westward vergent thrust sheet with four high angle forward thrusts and one back thrust located near the leading edge. This is illustrated in Cross-Section 3. The depth to the decollement, as explained later, was calculated to be approximately be 6-7km below the land surface. Vertical movement along each fault ranges from 250m to 750m. The evidence for the faults which bound subdomain N2 were brecciated ABC Range Quartzite and Brachina Fm. shale (Plate 4b. and 4c.). Fold geometries, stratigraphic relationships and slickenside measurements were then used to obtain fault orientations. There was no evidence to suggest any strike slip movement along these faults. Aerial photographs were not as useful in the interpretations of faults in the Nectar brook area because of the amount of float and vegetation covering the area.

The position of the intersection of the decollement with the ground surface at the leading edge of the section is inferred. Quaternary sediments obscure any fresh rock outcrops between the 'pop up' structure and the Spencer Gulf. Mt. Grainger, located on the shore of Spencer Gulf approximately 5.7km west of the beginning of the ranges, is a small hill of weathered quartzite rock. This could be interpreted as a weathered outcrop of ABC Range Quartzite or as the ABC Range Quartzite equivalent belonging to sequence of the Stuart Shelf. This was interpreted to be the latter of the two as the decollement in the two northern areas was interpreted to surface within close proximity to the ranges.

The 'Hidden Fault just west of the 'Sandy Knob Anticline' is an inferred fault. Scree sediments obscure all fresh rock outcrop where this fault is interpreted to surface, therefore providing no physical evidence of the fault. However, spatial problems in accommodating the 'Sandy Knob Anticline' which were discovered when producing the balanced cross-section, as explained later, have led to the interpretation of a fault through this location. Due to the geometries of the rocks surrounding the inferred fault, it is reasonable to suggest that it is an easterly dipping fault striking approximately North-South. The displacement of this fault is approximately 550m in a reverse direction.

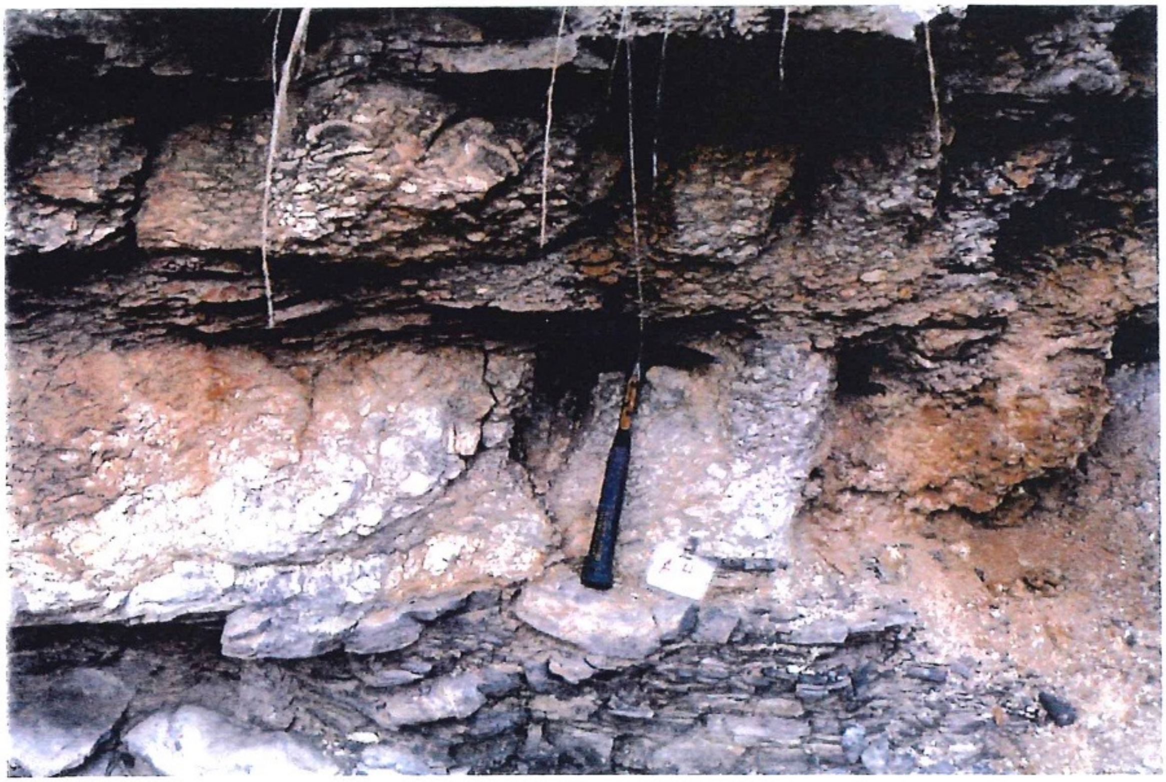


Plate 1
Magnesite Conglomerate in the Skillogalee Dolomite.

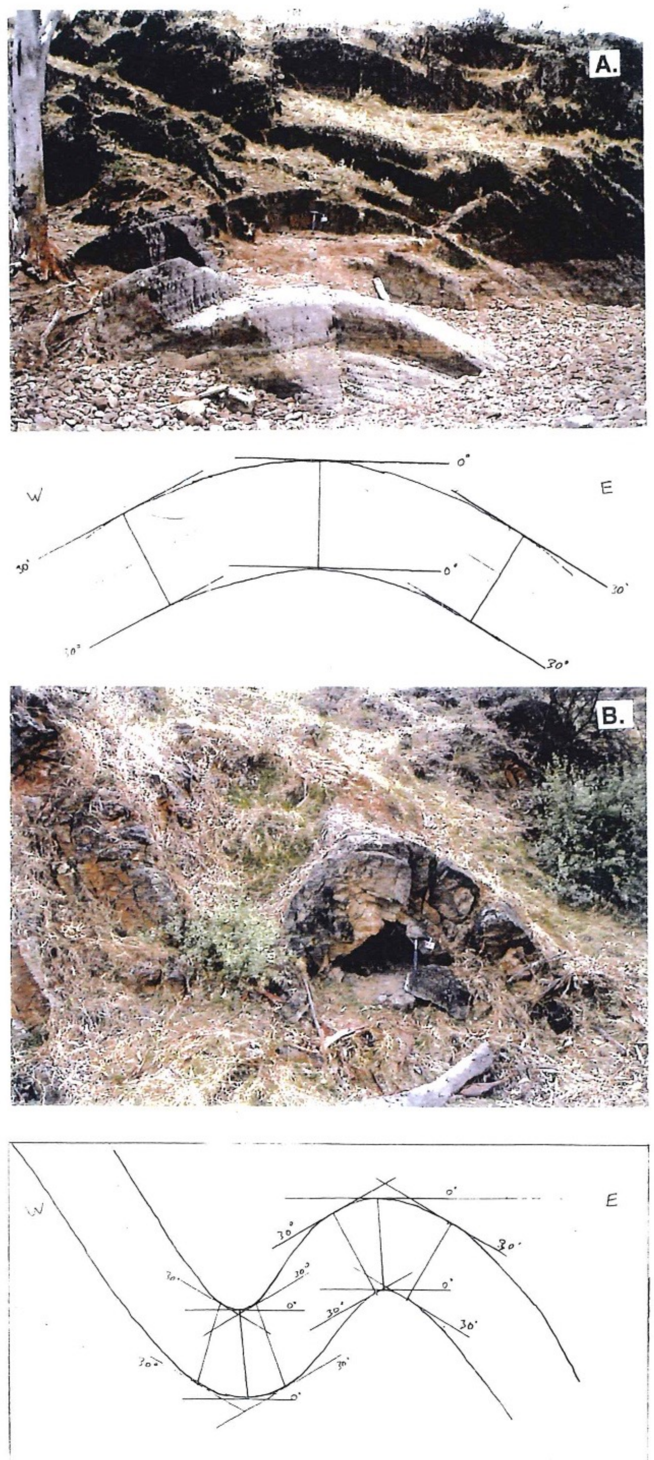
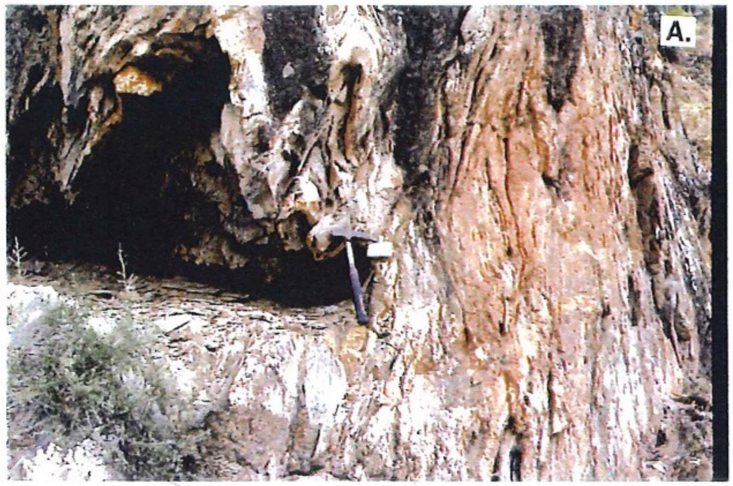


Plate 2

A. Fold in the Brachina Fm west of the 'Saltia Fault'. Shows S1 cleavage parallel to fold axis. Sketch of the fold shows that the fold is an open class 1B fold.

B. Assymetrical fold in the ABC Range Quartzite, west of the 'Pichi Richi Pass Shear Zone'. Sketch of fold shows that the fold is open class 1B verging on 1C.



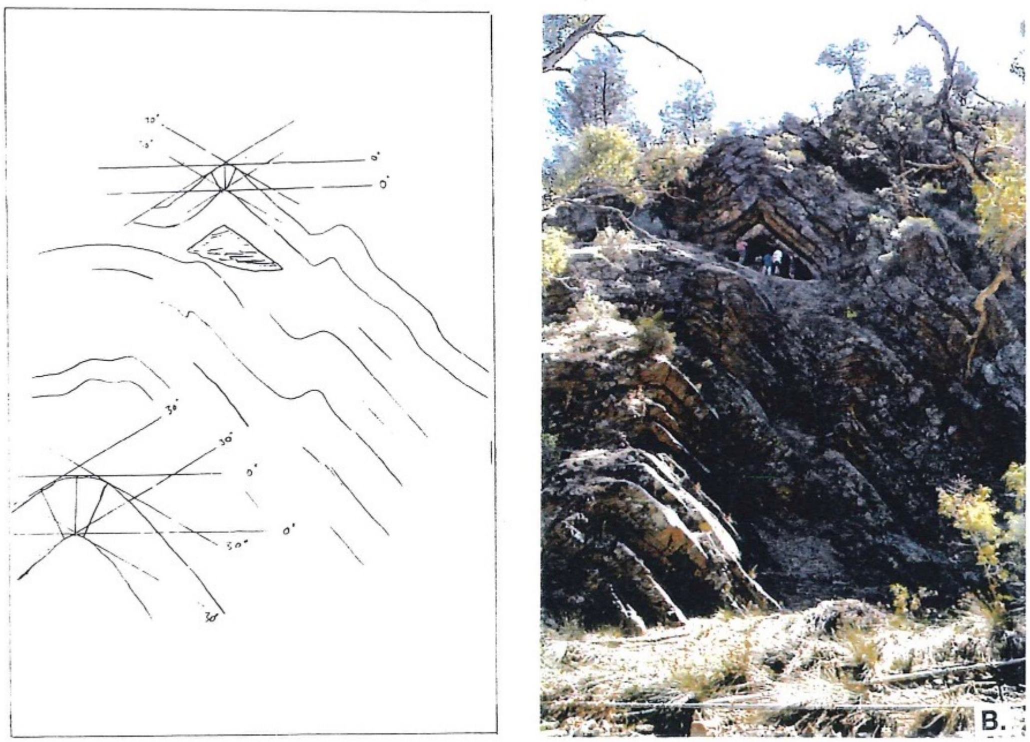


Plate 3

A. Ptygmatic fold of a calcite vein showing the intense deformation of the Wonoka Fm near the ‘Baby’s Bottom Fault’. A well developed cleavage is parallel to the axis of this fold. At Pichi Richi Pass.

B. Chevron folds in the ABC Range Quartzite, just east of the ‘Baby’s Bottom Faultí’at Pichi Richi Pass. Sketch of the folds show that they are chevron - open class 1C verging on 1B.

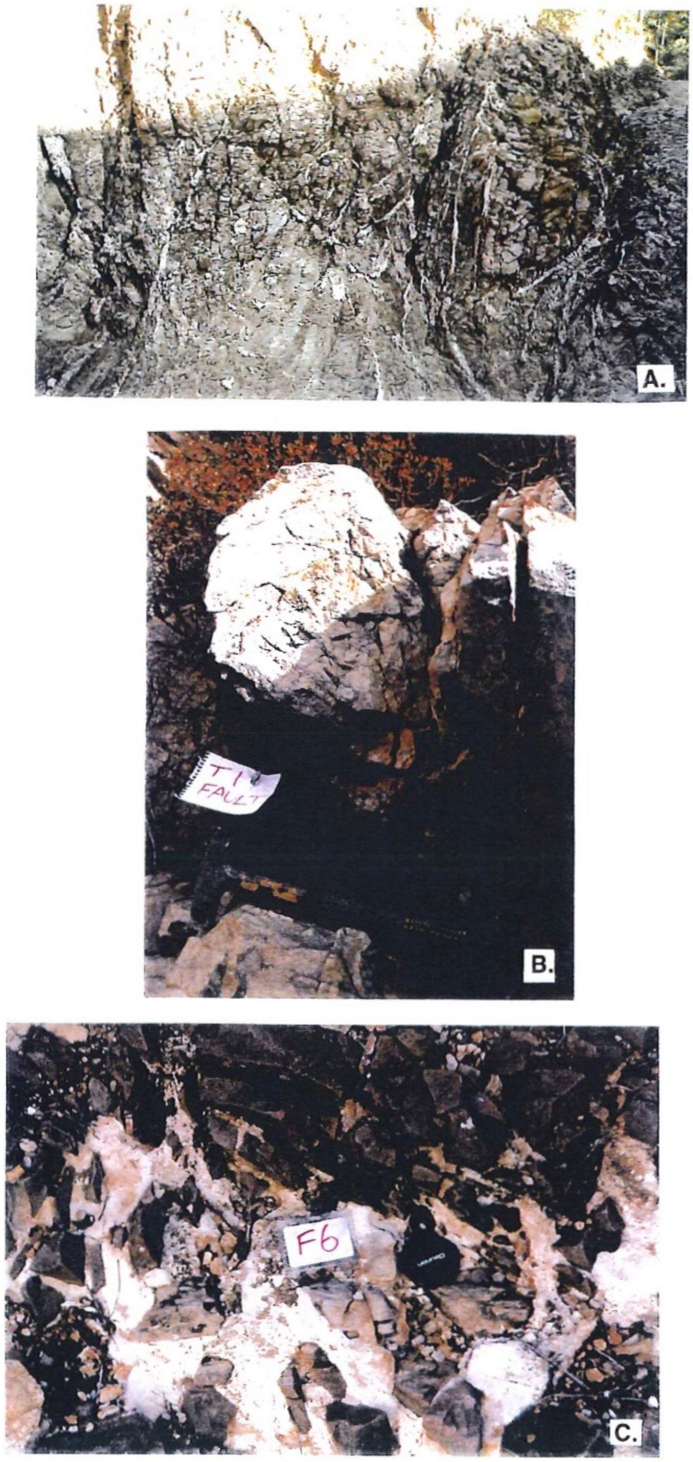


Plate 4

A. A very sheared outcrop of ABC Range Quartzite and Wonoka Fm from the Pichi Richi Pass shear zone.

B. Brecciated ABC Range Quartzite of the 'Winninowie Fault' at Nectar Brook.

C. Brecciated Brachina Fm of the 'ABC Fault. Nectar Brook.

4. STRAIN ANALYSIS

4.1 Section Balancing

4.1.1. Depot Creek

The fold limb at the base of the 'Comstock Syncline' seems to be the least deformed segment of the cross-section. This segment is interpreted to be a hanging wall flat juxtaposed over a footwall flat. This then gives a regional dip of approximately 13°east.

Depth to decollement calculations which have been outlined by Marshak and Woodward (1988), were unrealistic, most probably due to cleavage development and layer parallel slip. The calculations based on the amount of shortening of a section of rocks and the area of displaced rock produced a depth to decollement of 7.35km (see Appendix 1). This depth appeared to be too deep and it was therefore necessary to interpret a more realistic detachment and then test if it balanced.

The restoration method that was used for this section and the other two sections is outlined in Marshak and Mitra, 1988, and is based on bed-length balance. This method is used as the beds in the cross-section have been assumed to be of equal thickness. The fault displacement is assumed constant as well as the bed thickness in the restoration of the Depot Creek cross-section. A local pin line is drawn through the 'Comstock Syncline'. The decollement extends all the way to the eastern limits of the cross-section therefore no regional pin line could be applied. The hanging wall flat is the least deformed part of the section therefore the most likely place to draw the pin line. A loose line is fitted to the western edge of the section.

The restored cross-section exhibits a loose line which constantly dips to the west, a local pin line which remains perpendicular and in a fixed relative position to the beds above the decollement. All fault planes remain dipping to one direction and bed lengths and thicknesses are conserved. These properties of the restored cross-section show that the deformed state cross-section is balanced and the inferred depth to the decollement of 4.33km is feasible. The value given to the amount of shortening which has occurred within the section of rocks shown in the cross-section can only be the minimum value as the cross-section does not extend far enough to the west to show the leading edge of the hanging wall. Therefore the minimum amount of shortening is 7.38km.

4.1.2 Pichi Richi Pass

Depth to detachment calculations for the Pichi Richi Pass section have also been unrealistic. The thickening of the ABC Range Quartzite to the east has been accommodated by the interpretation of reactivated growth fault and together with layer parallel slip and cleavage development could be the reason for this. The Callanna Beds are the most likely horizon for the decollement as they are made up of siltstones, dolomites, and diapiric breccias which are an ideally low shear-resistant layer along which a decollement could propagate. The Callanna Beds are also located at a realistic depth of approximately 5-6km, at which one may expect to locate the decollement.

A local pin line was placed through the fold axis of the syncline just east of where the decollement intersects the land surface. Due to the difference in rock type and thicknesses of the rock units between the Stuart Shelf and the Adelaide Geosyncline a regional pin line through the relatively flat lying and undeformed units of the Stuart Shelf was not used. The trailing edge of the section (ie. the eastern edge) was extended approximately 3.7km in order to accommodate the full length of the fold axis of the 'Richman Valley Syncline' through which the loose line was fitted.

The presence of erosional canyons filled with the Wonoka Formation produced problems in the balancing of this section. The erosional unconformity made it difficult to determine the thicknesses of those units which underlie the Wonoka Formation such as the Bunyeroo Formation and the ABC Range Quartzite and the geometries of the structures beneath the canyons. Access to private property in the 'Saltia Syncline' was also a problem. Field data which was obtained from Saltia Creek was insufficient for determining the structures beneath the erosional unconformity with a great deal of accuracy. Thus, several possible models were tried and tested by cross-section balancing until the one was found which adhered to all the requirements of a balanced cross-section.

The process of balancing the cross-section produced an undeformed state cross-section which exhibits a zone of back thrusts, a triangle zone and a zone of forward thrusts which explain the two directions of vergence. The degree of shortening which was revealed by the restored cross-section was approximately 4.3km.

4.1.3 Nectar Brook

The methods used for the construction of a restored and balanced cross-section of Nectar Brook were the same as that of the previous two areas. A local pin line was used for the same reasons as Pichi Richi Pass and placed at the leading edge within the thrust sheet through subdomain N3. A loose line was placed at the trailing edge of the section through 'Alligator Gorge Syncline'. The section was extended by approximately 300m to the West and 13km to the East in order to include the 'Alligator Gorge Syncline' and the outcrop of the decollement. By including these, the depth to decollement could then be estimated to be at a realistic depth. Like the other two areas the decollement was placed along the Callanna Beds as these beds are located at a depth one might expect to locate the decollement and they are sufficiently ductile for detachment to occur. The depth to decollement was interpreted to be approximately 6-7km. The degree of shortening which has taken place is approximately 1.6km. This has been accommodated by folding (predominantly regional), high angle thrust faulting and to a lesser extent, cleavage development in all three areas.

The balancing of the Nectar Brook cross-section has produced a section which exhibits a predominantly forward thrusting regime (vergence to the west), with one back thrust located at the leading edge of the thrust sheet. A spatial problem in accommodating the 'Sandy Knob Anticline' arose from the balancing the cross-section. The location of the anticline was such that in order to account for the offset of the ABC Range Quartzite beds between sub-domains 4 and 5, it was reasonable to infer a fault through the area. Thus 'Hidden Fault' was inferred N-S, adjacent to a creek where there was very little outcrop and where evidence of the fault was most likely obscured.

4.2 Thin Sections

Several thin sections were produced from samples taken from the three areas and studied to determine the levels of strain imposed on the area by way of cleavage, crenulation and microscopic fold development. Refer to the appendix for the photographs of each thin section and their description.

The thin sections in general show very little strain. The rock units such as the ABC

Range Quartzite and Willochra Formation show no strain with the exception of fault breccia such as that shown by sample A2000/NBF8 (Plate 5f.) from the 'Reservoir Fault' at Nectar Brook. It is only the more ductile units such as the Brachina Formation and the Wonoka Formation which are located close to a fault that exhibit microscopic structures related to deformation. A sample of shale taken from the Brachina Formation, A2000/PRD8 (Plate 7a and 7b), exhibits small scale folds (scale in the order of size of a hand specimen) which at first appear to be crenulations along a very well developed S1 cleavage. Some of the folds however, exhibit small 'pop-up' structures at the top of the anticlines. This is not a characteristic of crenulation folds but fractures related to unequal zones of pressure squeezing out the top of the fold in the S0 at the same time that cleavage was forming. The cleavage is well developed and parallel to the axial surface of a larger mesoscopic fold (Plate 2a.) which has a strike and dip of 175°/88°E. This orientation is perpendicular to the net direction of displacement of the thrust sheet. Likewise, the samples taken from a very strained outcrop of Wonoka Formation, A2000/PRF13 (Plate 6e, 6f and Plate 8a; Plate 3a.), exhibit small deformational structures. The samples contain F1 folds and S1 solution cleavage. These structures indicate the high stress regimes imposed on the units of rock around the fault in an otherwise low strain region.

4.3 Other Strain Analyses

The relatively low strain of the three areas limits the strain analysis that can be conducted. The lack of strain ellipsoids within the thin sections rule out Rf/ϕ analysis (outlined by Dunnet, 1969) which would otherwise determine finite strain and strain variation. The Hudleston method is also of no use for the three areas. This method is used to determine relative variation in finite strain. It assumes that folds were initially class 1B and have been subjected to strain under homogeneous, pure shear conditions to develop class 1C (Hudleston, 1973). As the folds within the three areas are class 1B or only just class 1C, all this would achieve is to confirm that the area is low strain.

5. TECTONIC MODEL AND INTERPRETATIONS

The rock units of the Flinders Ranges and Adelaide Geosyncline were deposited during rifting. A large deep subsiding basin developed and thick layers of sediment were accumulated during the Late Precambrian to Cambrian.

The Late Cambrian to Early Ordovician brought about the Delamerian Orogeny and the thick layers of sediment underwent compression from the east. This compression produced thrusting, uplift, folding and metamorphism throughout the accumulated sediments, beginning with the units within the hinterland and gradually moving through to the foreland. Depot Creek, Pichi Richi Pass and Nectar Brook belong to the western margin of this foreland and therefore would not have experienced any great deformation until the end of the Delamerian Orogeny.

When compression was imposed on Depot Creek, Pichi Richi Pass and Nectar Brook, it produced thrusting and associated folding to accommodate the pressure. A decollement was formed at 4-7km depth along the Callanna Beds, a sufficiently weak unit along which the eastward vergence of the Adelaidean sequence could be accommodated. In some places the decollement stepped up through several units and continued on along a stratigraphically higher unit. In the Depot Creek and Pichi Richi Pass area this produced an associated fault bend fold. Similarly, small propagating faults and their associated folds are produced along with the forward thrusts.

The increase of thickness in the ABC Range Quartzite was interpreted to have been produced by a growth fault. Therefore to obtain the reverse displacement, the fault would have been reactivated in this time of thrusting. Also, thickening may have been produced by a series of small scale, intraformational fault bend folds, thrusting layers of ABC Range Quartzite between other layers of the same rock type. This can be seen in a railway cutting along the Pichi Richi Railway (Fig. 3)

When the westward vergence of the thrust sheet is interrupted by the steep incline of the end of the decollement, the rocks are rotated clockwise as they are pushed up the incline. This produces a spatial problem near the leading edge of the thrust sheet causing the series of back thrusts and 'pop-up' structures along the leading edge of the sections in each area.

Folds throughout the area are all F1 and are predominantly related to the thrust faulting, showing an increase in intensity towards the faults. Cleavage development also seems related to proximity of faults and rock type. The folds and cleavage development both indicate that the area is generally low strain which is expected for the western edge of this foreland fold and thrust belt.

Fig.3- Fault bend fold within the ABC Range Quartzite
along the railway at Pichi Richi Pass.

6. CONCLUSION

The structural features within the three areas have all developed during the Delamerian Orogeny in the Late Cambrian to Early Ordovician. These structures include a series of high angle east and west verging thrusts, and both macroscopic and mesoscopic, inclined F1 folds. Also located within the areas are fault bend folds and fault propagation folds associated with the thrust faults. S1 cleavage is present and well developed in the 'softer' units such as the Brachina and Wonoka Formations and is formed parallel to the axial planes of the folds in the area. Strain within the three areas is low overall with locally high areas of strain near the faults. The lack of strain fabric in the thin sections and the geometry of the folds also indicate low strain.

Crustal shortening has occurred during the Delamerian Orogeny, accommodated within a thin thrust sheet. Fault bend folds, fault propagation folds and cleavage development account for some of this shortening but fault displacement is the main medium through which crustal shortening has occurred.

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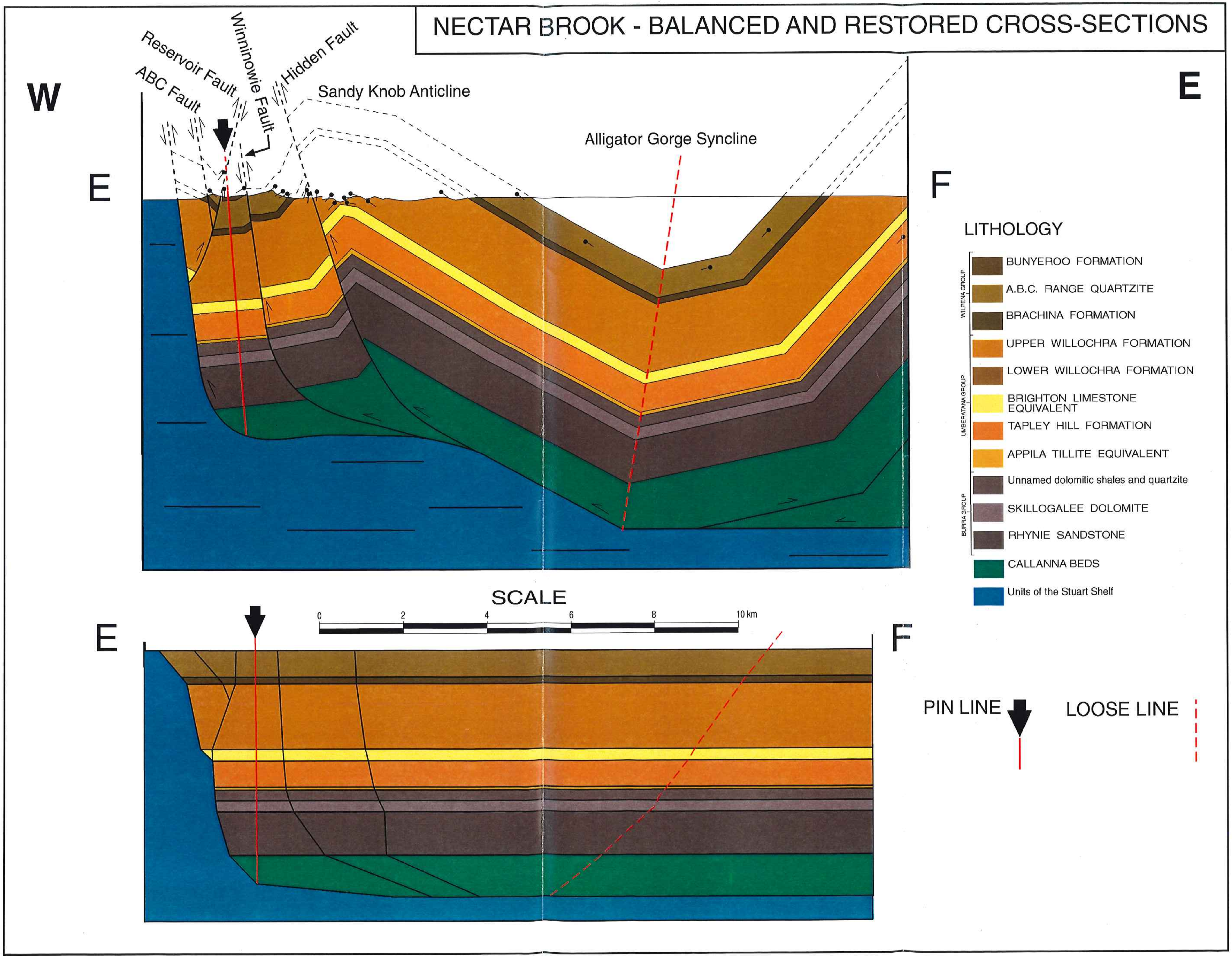
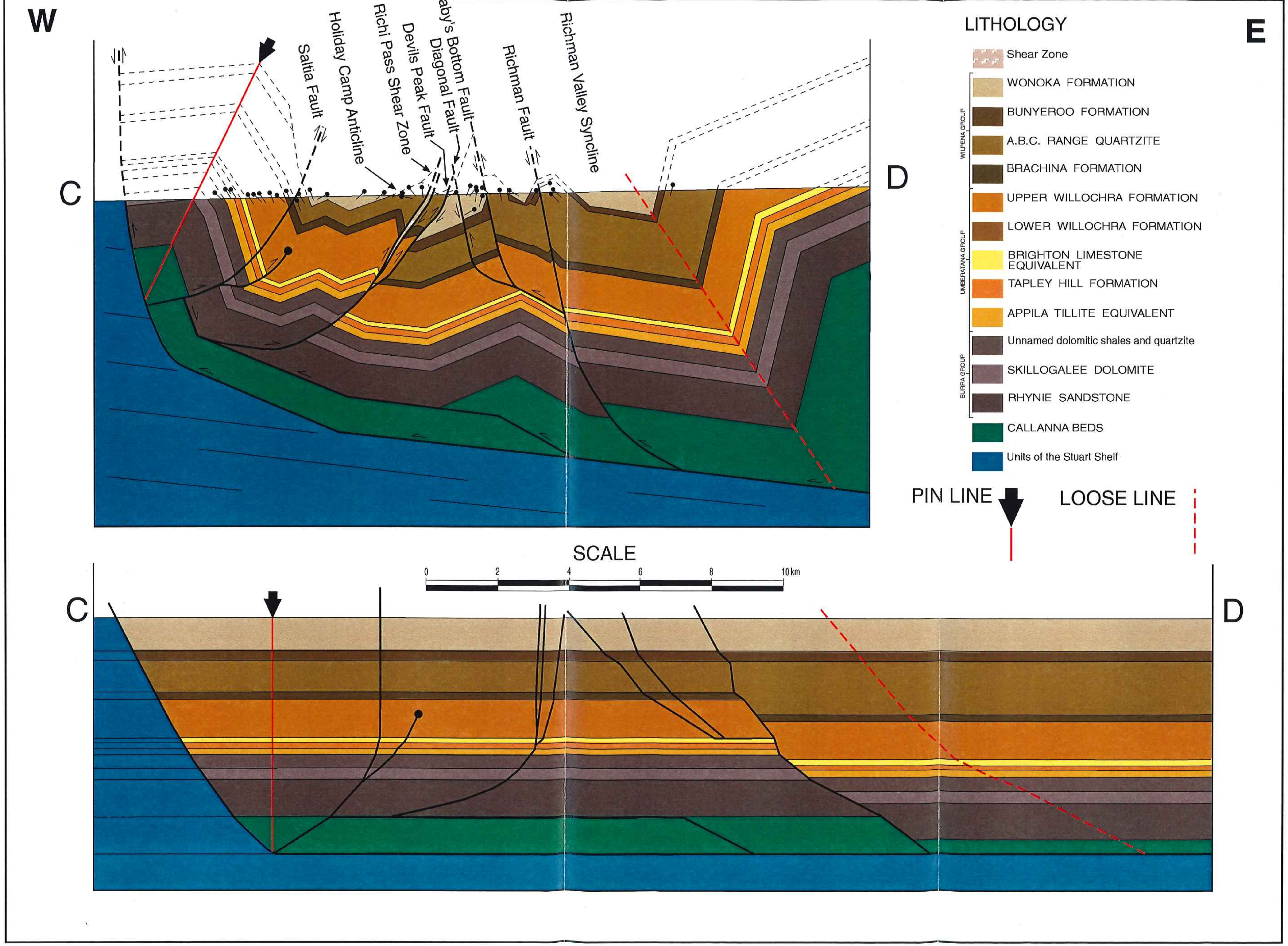
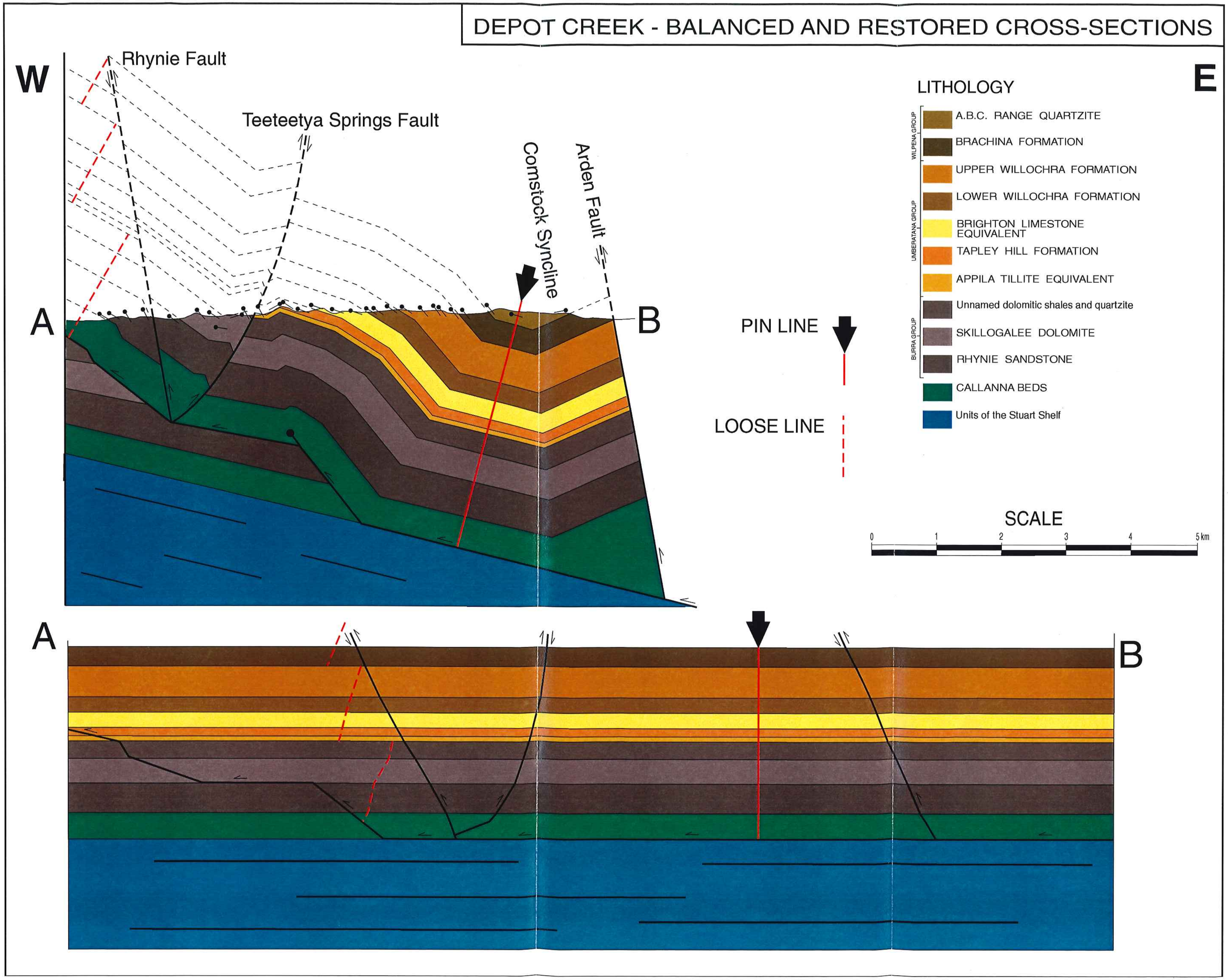
APPENDICES

Appendix 1 - Maps, cross-sections and cross-section calculations

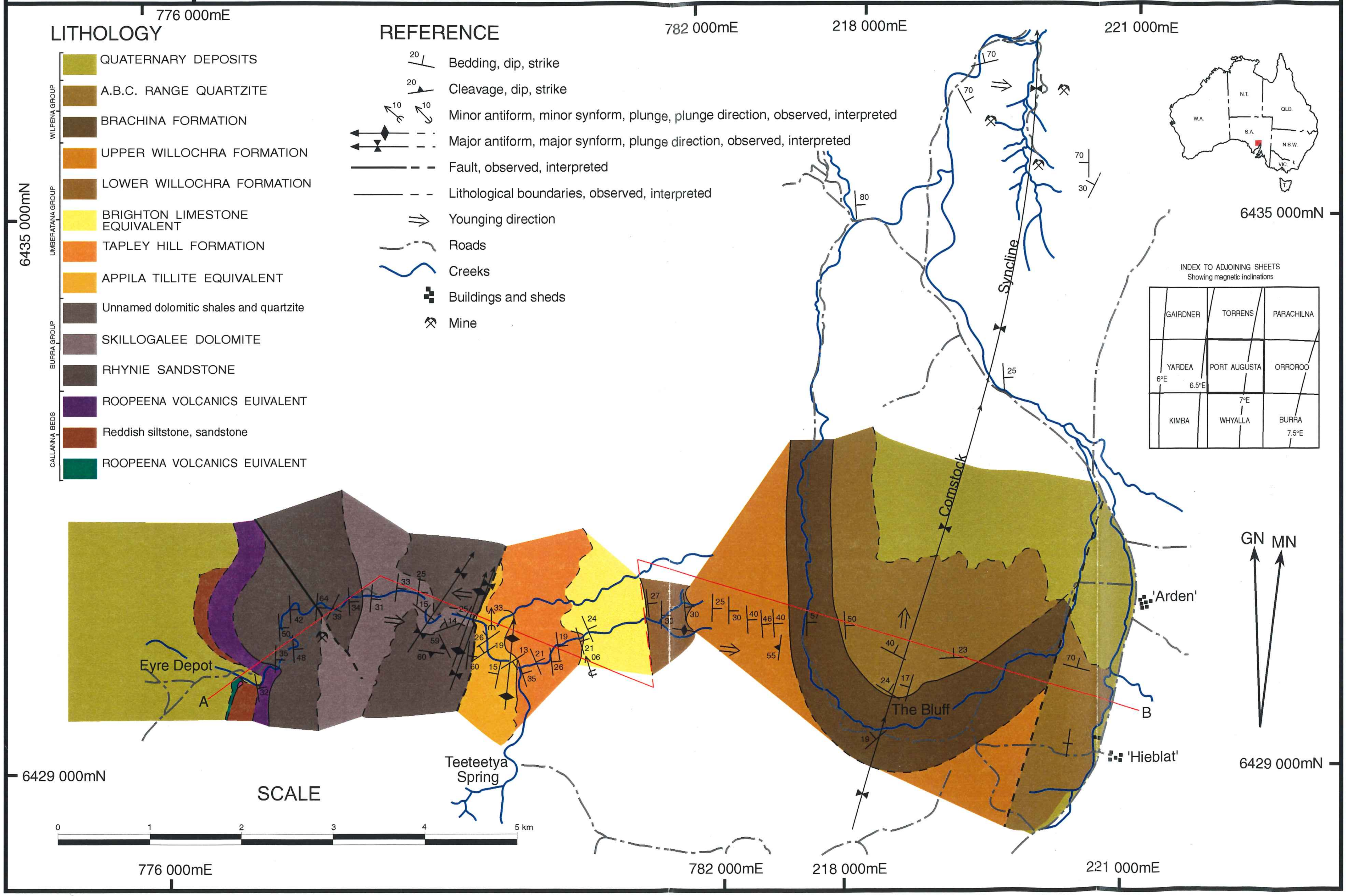

NECTAR BROOK - BALANCED AND RESTORED CROSS-SECTIONS
W
E
Reservoir Fault
ABC Fault
Winninowie Fault
Hidden Fault
Sandy Knob Anticline
Alligator Gorge Syncline
E
F
LITHOLOGY
WILPENA GROUP
BUNYEROO FORMATION
A.B.C. RANGE QUARTZITE
BRACHINA FORMATION
UMBERATANA GROUP
UPPER WILLOCHRA FORMATION
LOWER WILLOCHRA FORMATION
BRIGHTON LIMESTONE EQUIVALENT
TAPLEY HILL FORMATION
APPILA TILLITE EQUIVALENT
BURRA GROUP
Unnamed dolomitic shales and quartzite
SKILLOGALEE DOLOMITE
RHYNIE SANDSTONE
CALLANNA BEDS
Units of the Stuart Shelf
SCALE
0
2
4
6
8
10 km
E
F
PIN LINE
LOOSE LINE

PICHI RICHI PASS - BALANCED AND RESTORED CROSS-SECTIONS

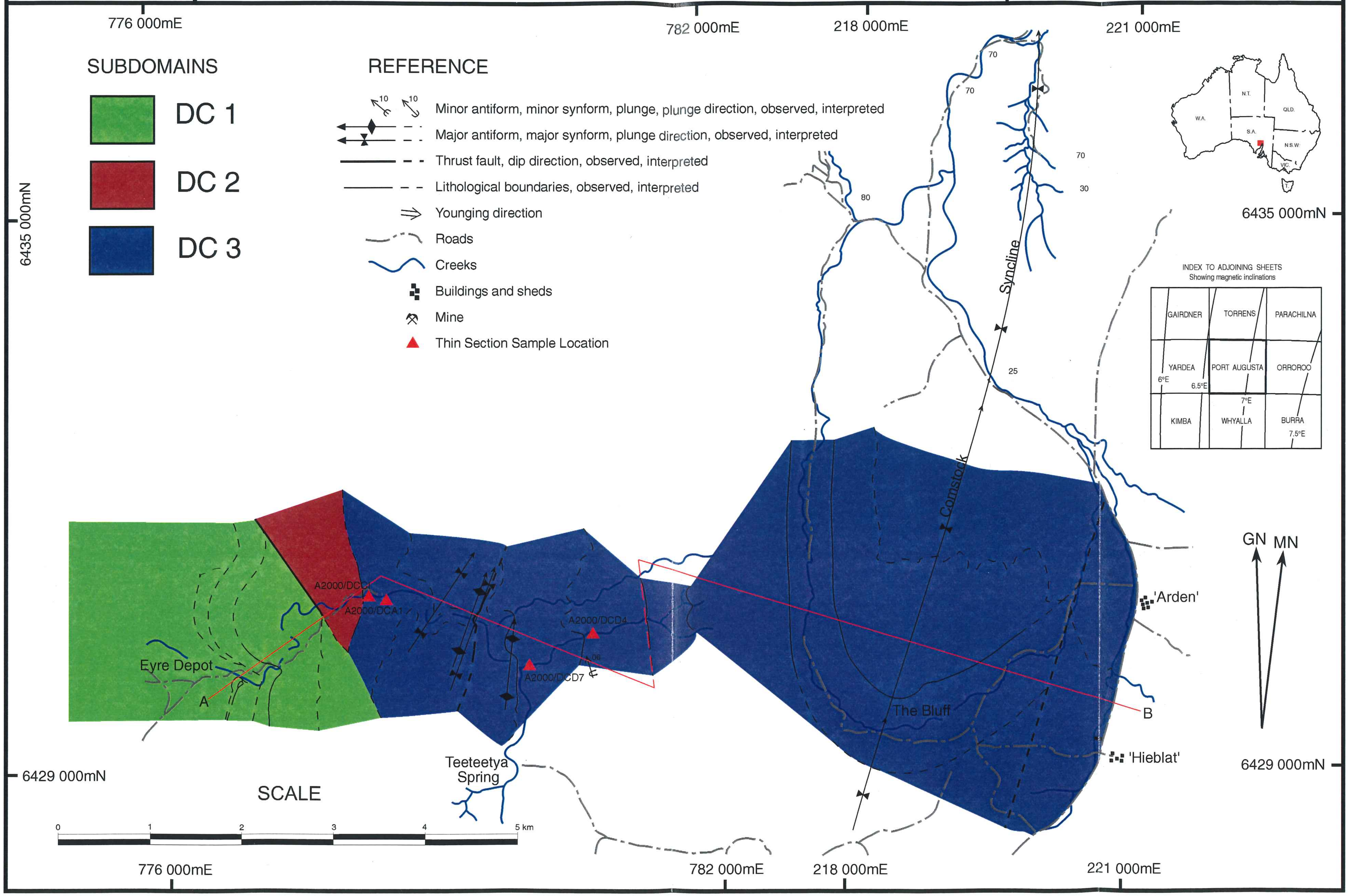



DEPOT CREEK - BALANCED AND RESTORED CROSS-SECTIONS
W
E
Rhynie Fault
Teeteetya Springs Fault
Comstock Syncline
Arden Fault
A
B
A
B
PIN LINE
LOOSE LINE
LITHOLOGY
WILPENA GROUP
A.B.C. RANGE QUARTZITE
BRACHINA FORMATION
UMBERATANA GROUP
UPPER WILLOCHRA FORMATION
LOWER WILLOCHRA FORMATION
BRIGHTON LIMESTONE EQUIVALENT
TAPLEY HILL FORMATION
APPILA TILLITE EQUIVALENT
BURRA GROUP
Unnamed dolomitic shales and quartzite
SKILLOGALEE DOLOMITE
RHYNIE SANDSTONE
CALLANNA BEDS
Units of the Stuart Shelf
SCALE
0
1
2
3
4
5 km

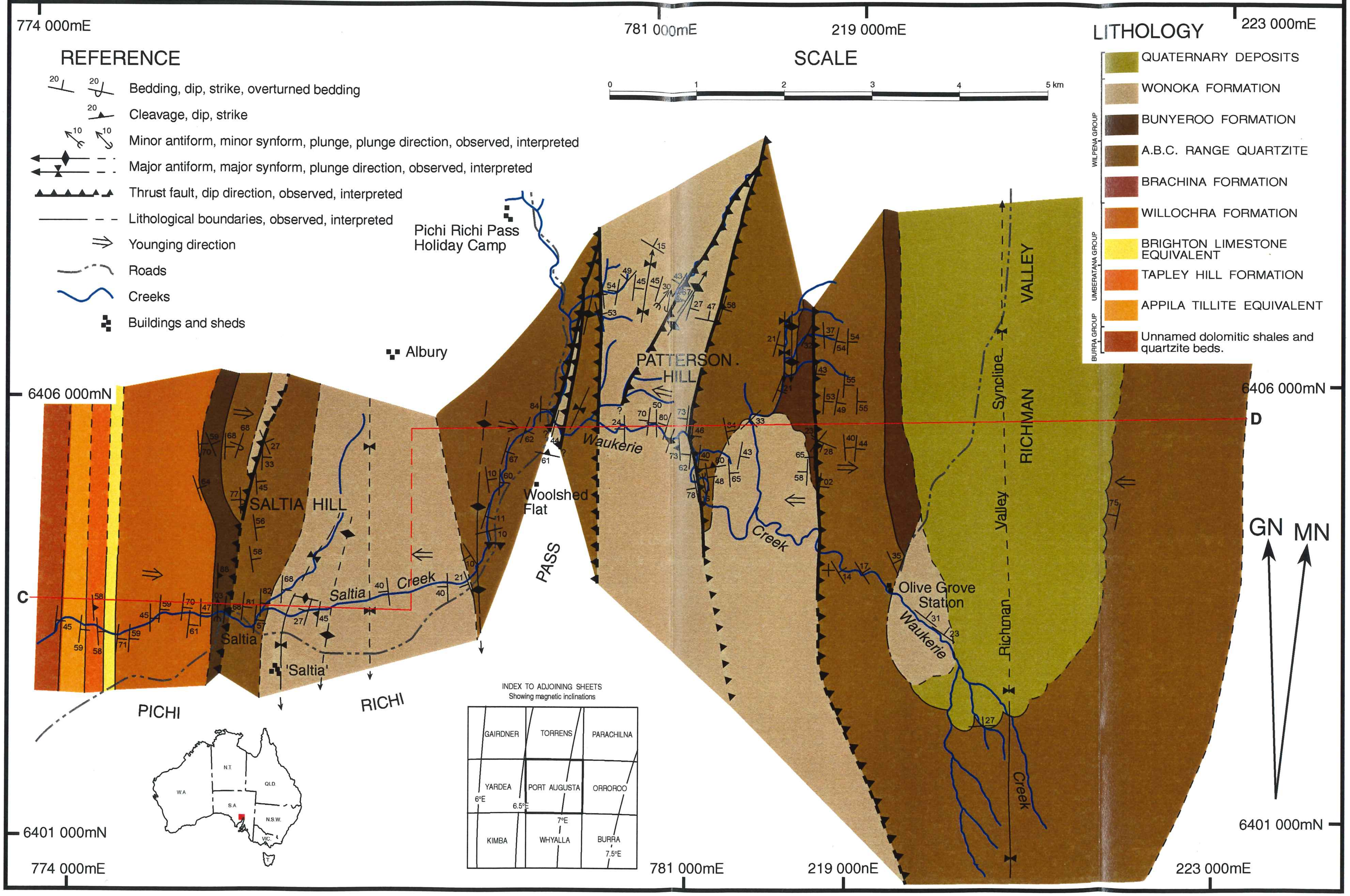
MAP 1a: DEPOT CREEK



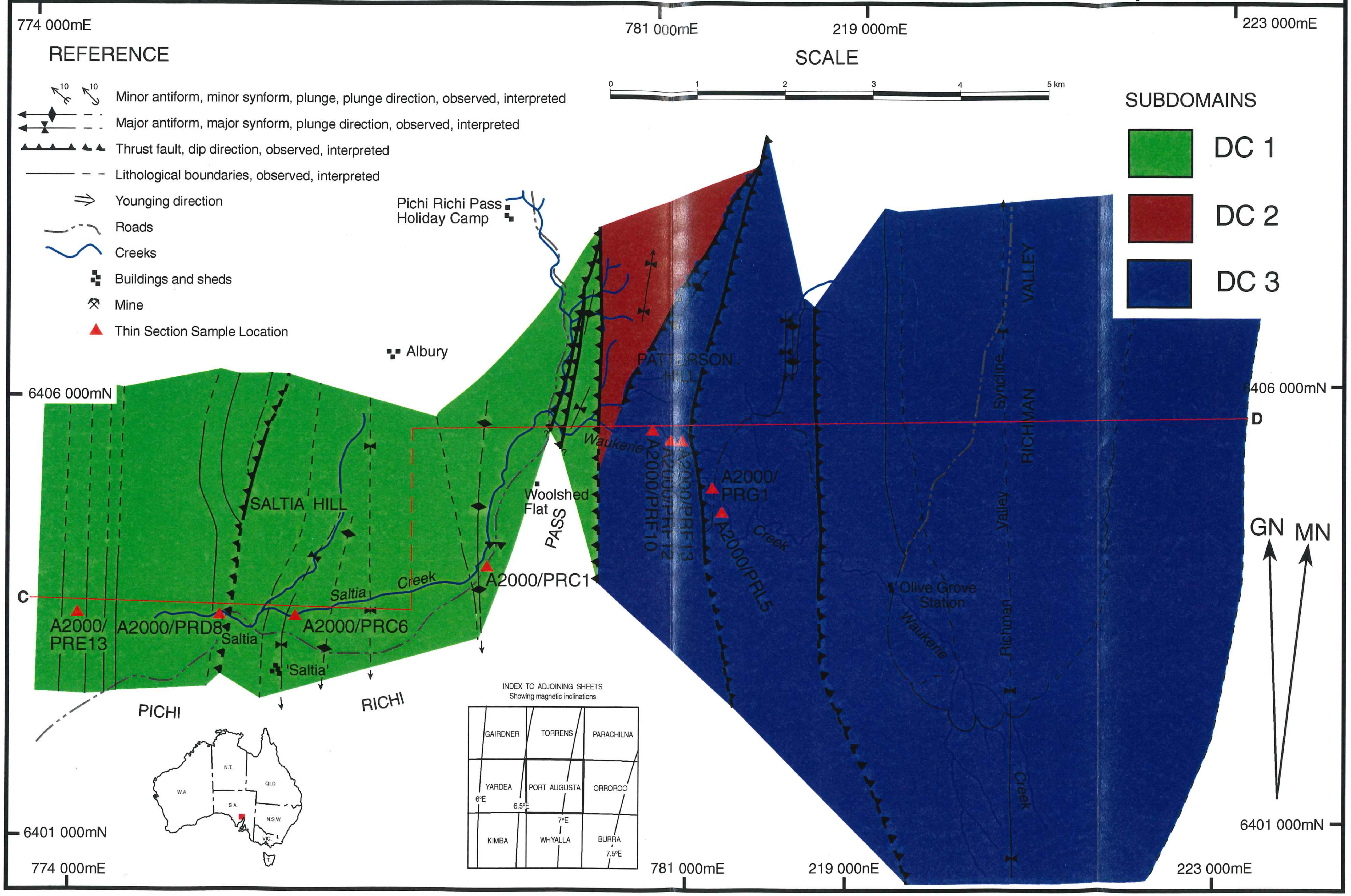
MAP 1b: DEPOT CREEK - Subdomains and Sample Locations



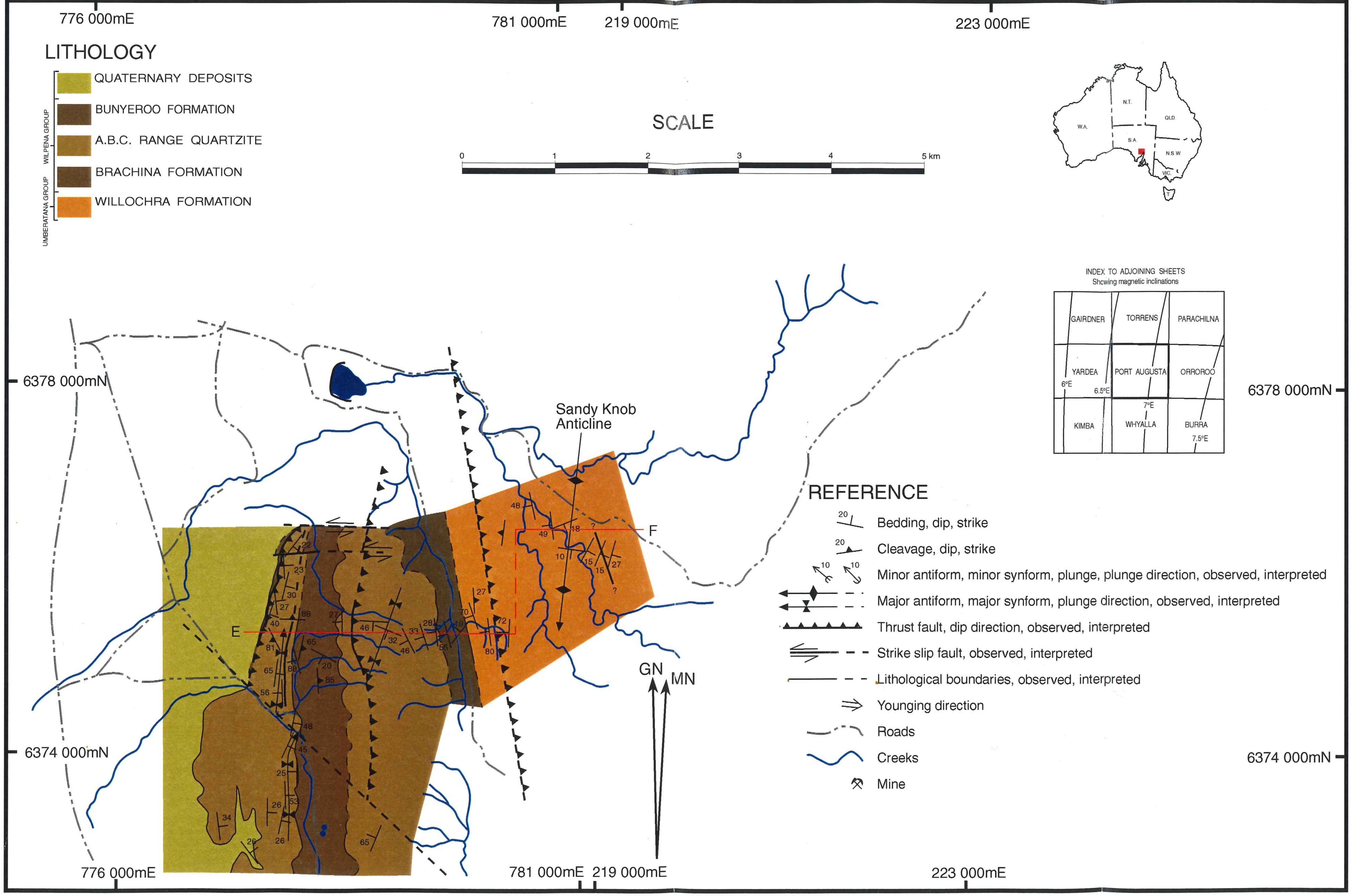
MAP 2a: WAUKARIE AND SALTIA CREEKS



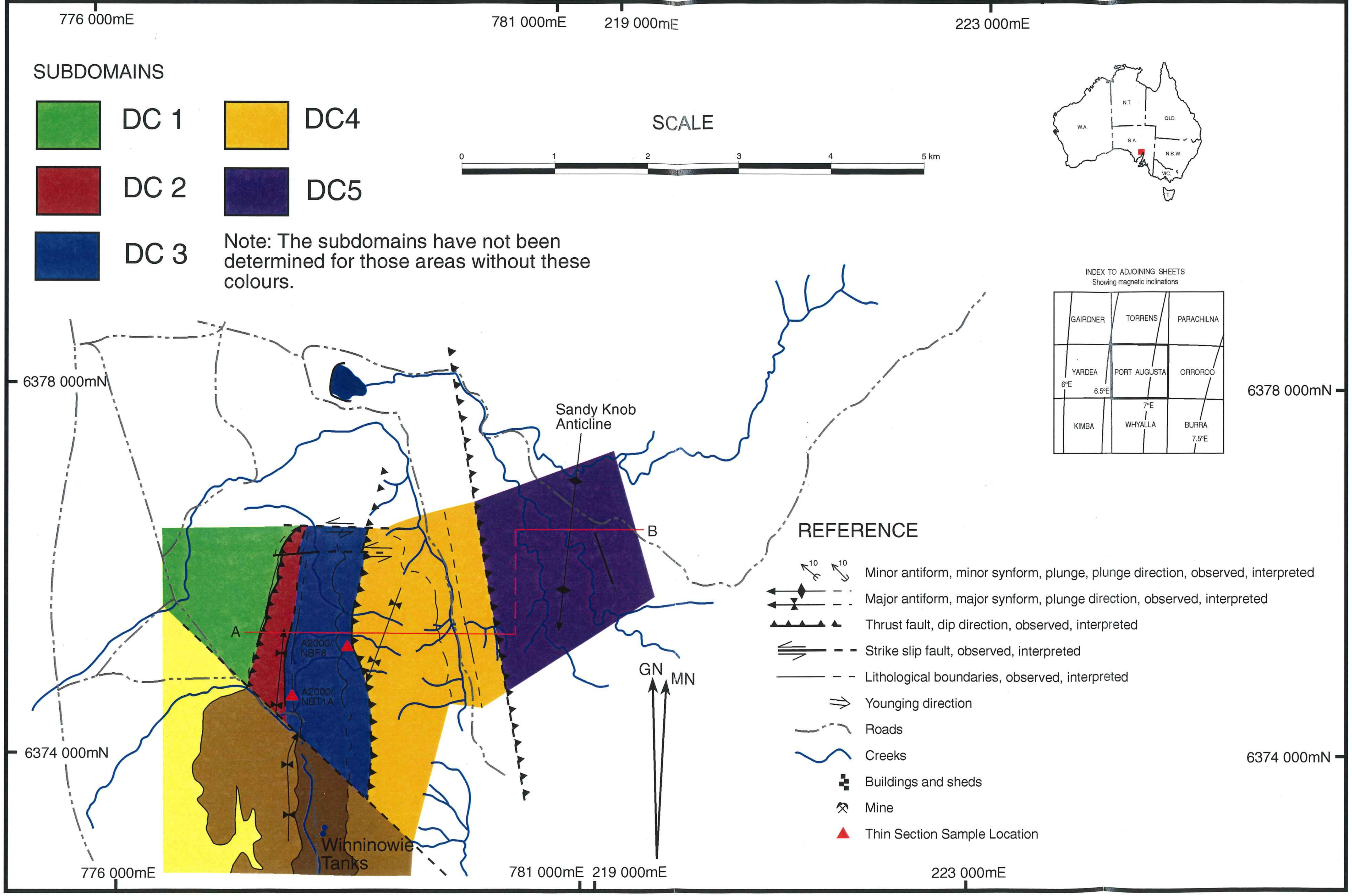
MAP 2b: WAUKARIE AND SALTIA CREEKS - Subdomains and Sample Locations



MAP 3a: NECTAR BROOK

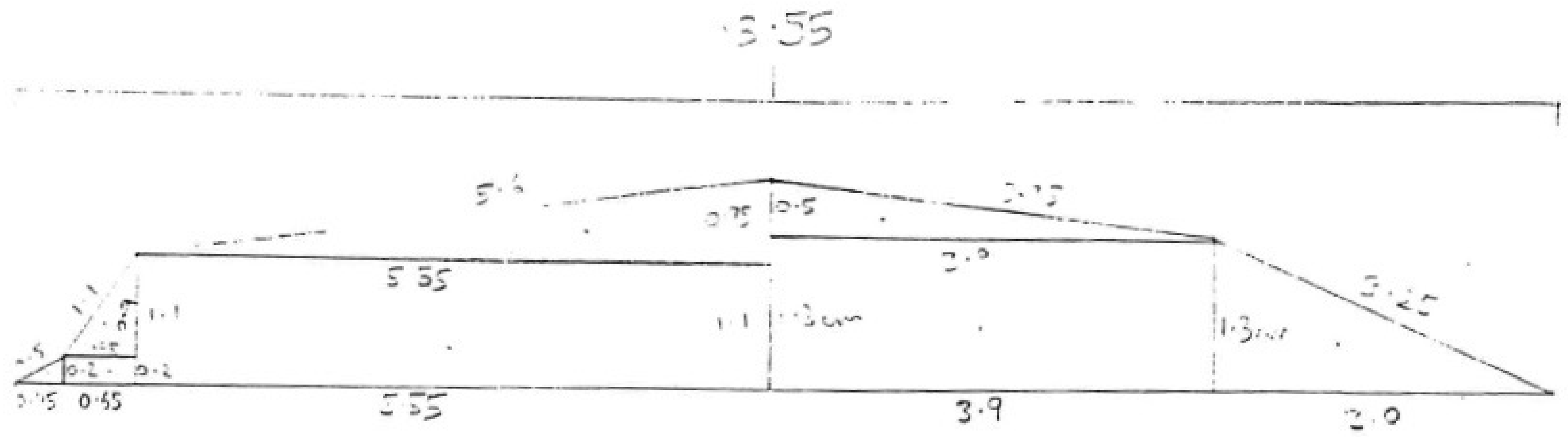


MAP 3b: NECTAR BROOK - Subdomains and Sample Locations



Scale 2.7cm : 1 km

Depth to Décollement Calculations
Depot Creek



Area = 0.05 + 0.13 + 0.29 + 6.11 + 2.02 + 5.07 + 0.98 + 1.95
= 16.66 cm²
= 2.28 km²

Bed Length = 14.4 cm
= 5.33 Km

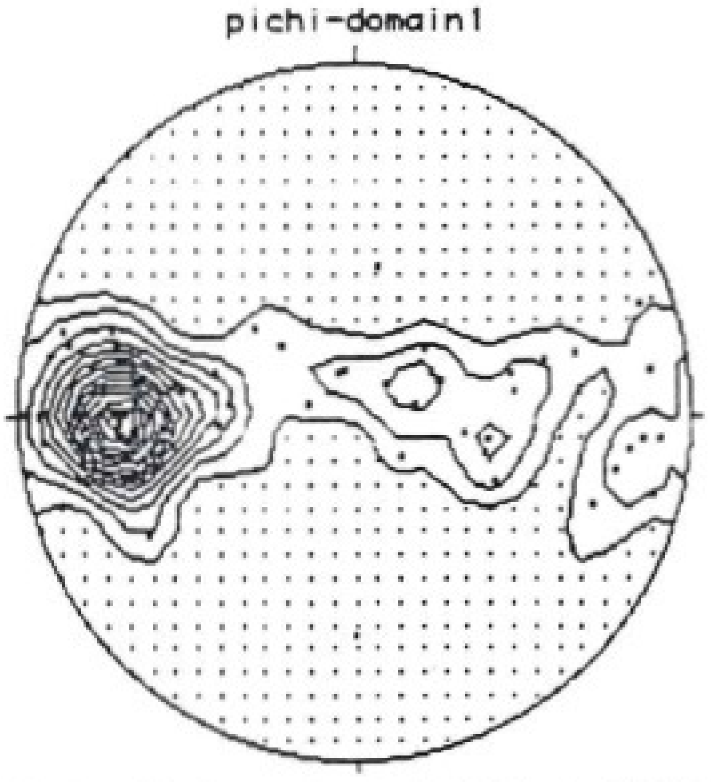
Length of Shortening = 0.85 cm
= 0.31 km

Depth to Décollement = Area / Length of Shortening
= 19.6 cm
= 7.35 km

Appendix 2 - Stereonet plots

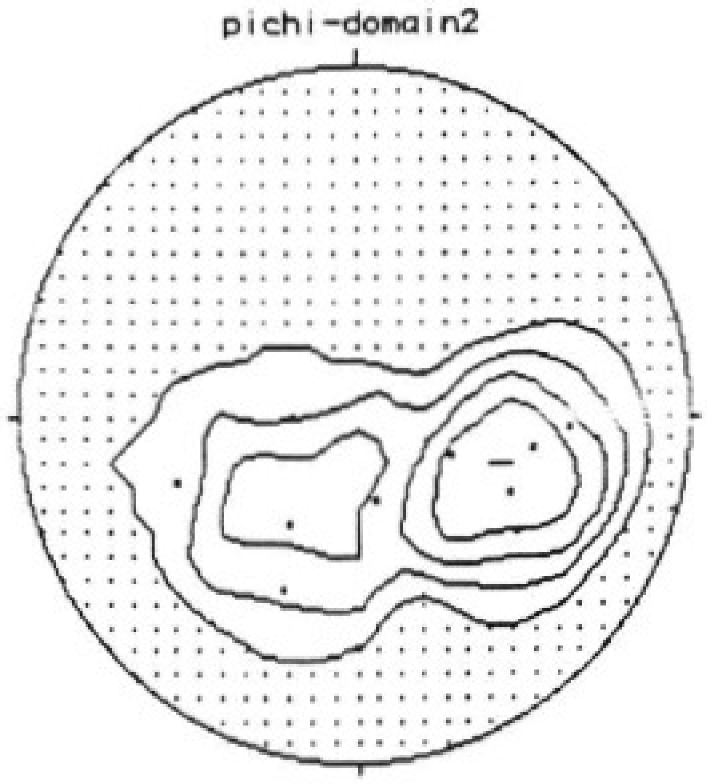
Pichi Richi Pass Bedding

pichi-domain1



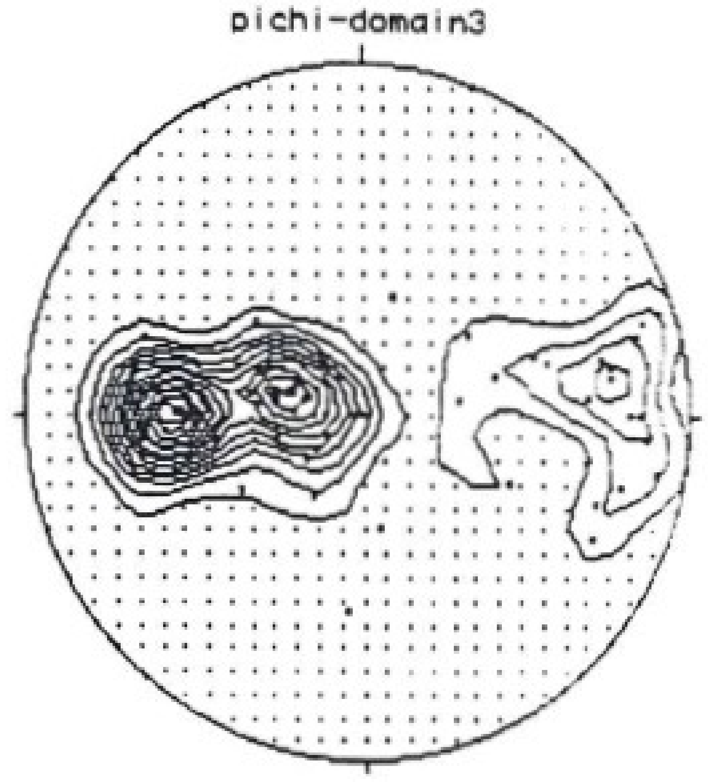
81 Data. Contoured at 1 2 3 4 5 6 7 8 9

pichi-domain2



10 Data. Contoured at 1 2 3 4 x uniform

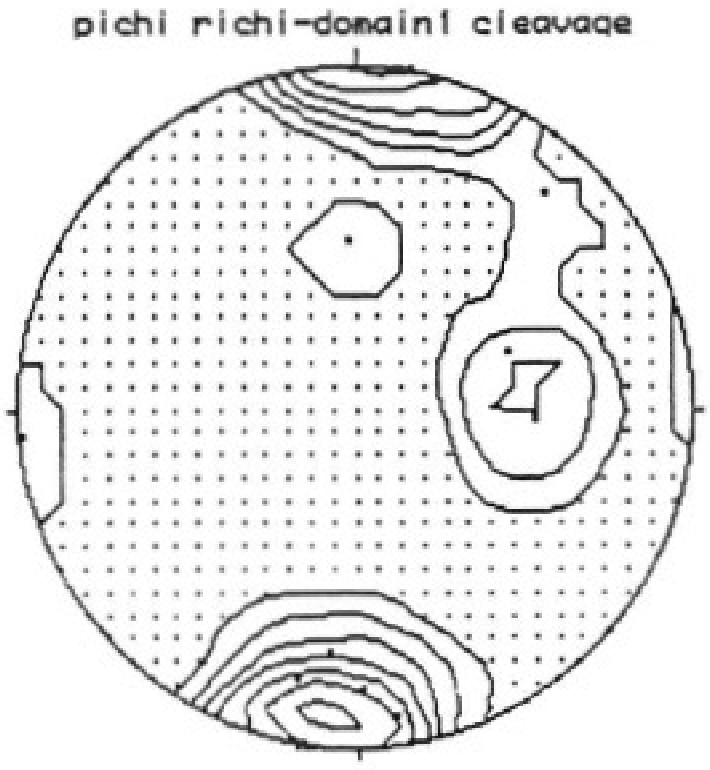
pichi-domain3



77 Data. Contoured at 1 2 3 4 5 6 7 8 9

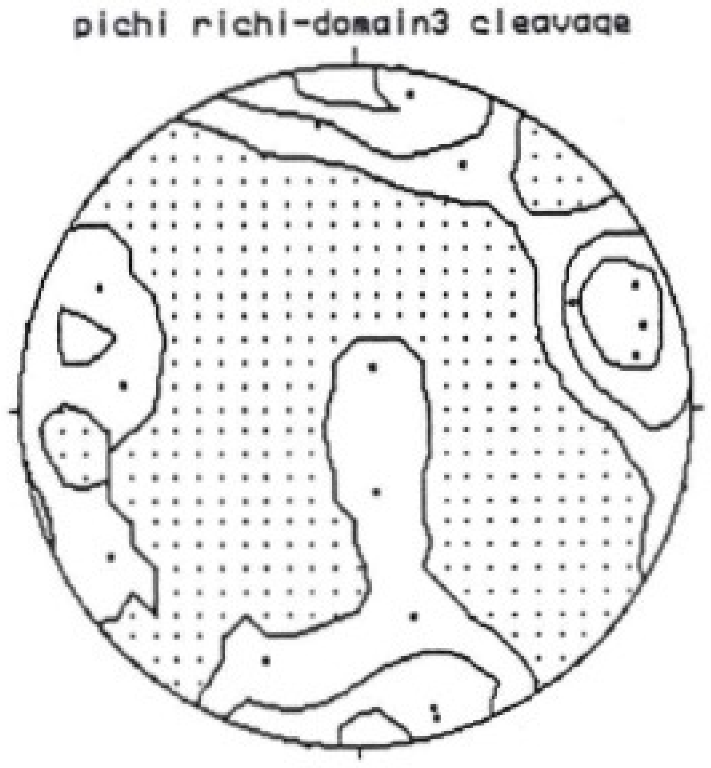
Pichi Richi Pass Cleavage

pichi richi-domain1 cleavage



14 Data. Contoured at 1 2 3 4 5 6 x

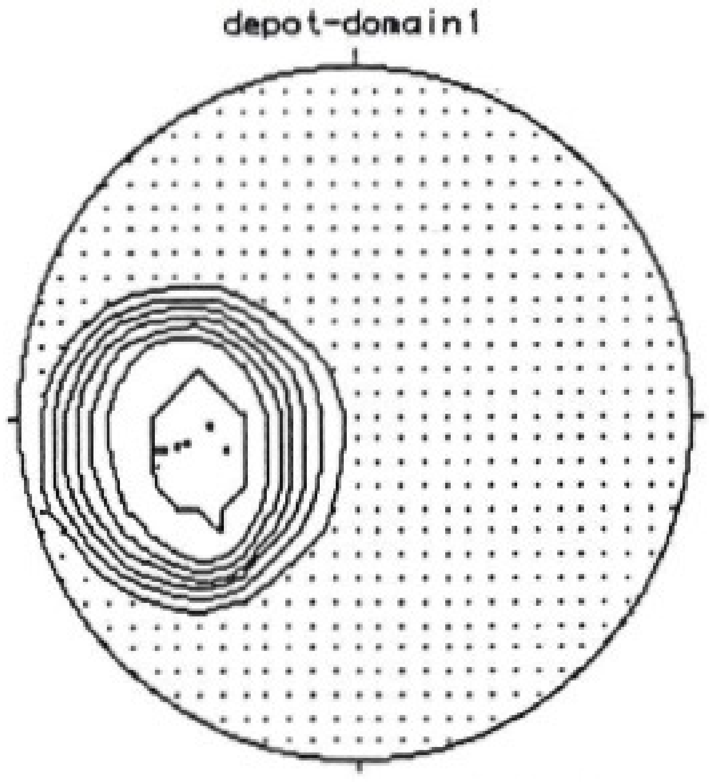
pichi richi-domain3 cleavage



18 Data. Contoured at 1 2 3 x uniform

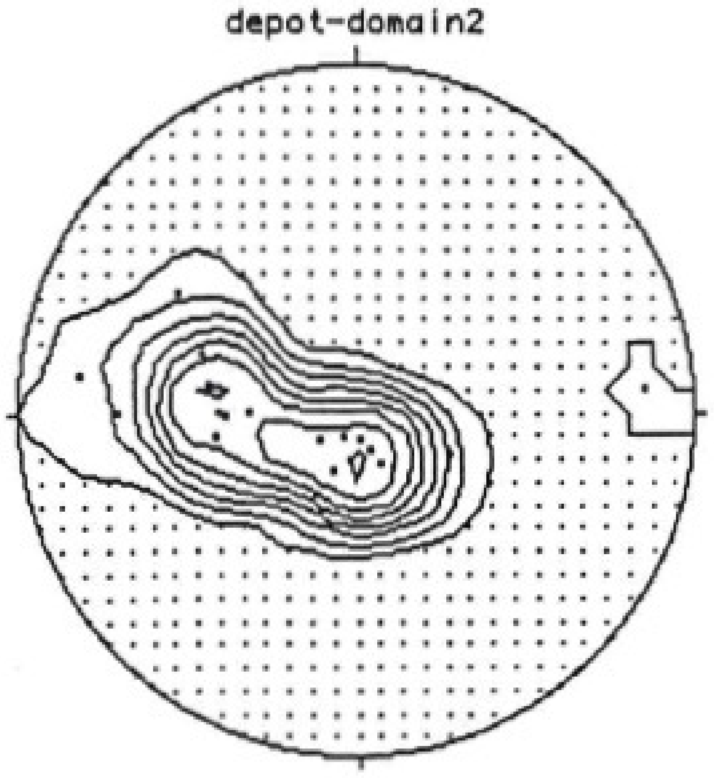
Depot Creek Bedding

depot-domain1



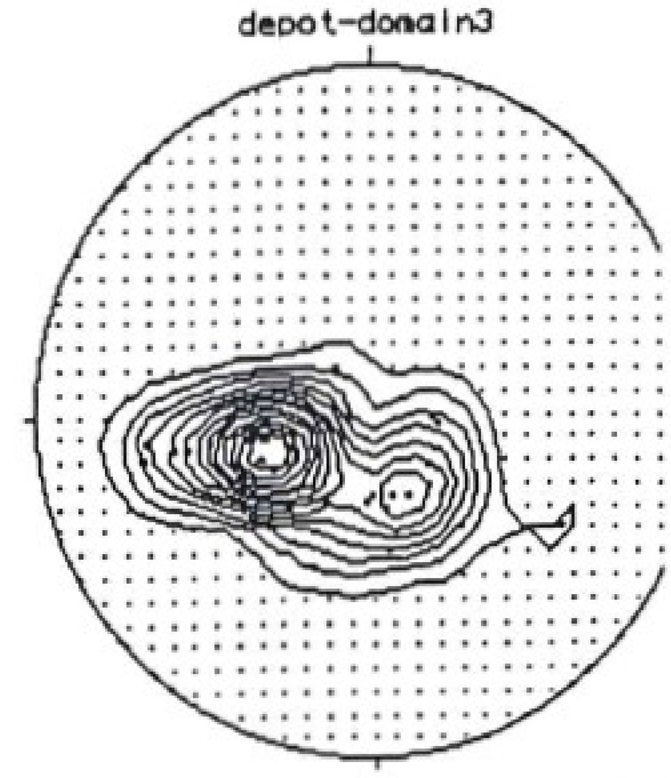
7 Data. Contoured at 1 2 3 4 5 6 x

depot-domain2



20 Data. Contoured at 1 2 3 4 5 6 x

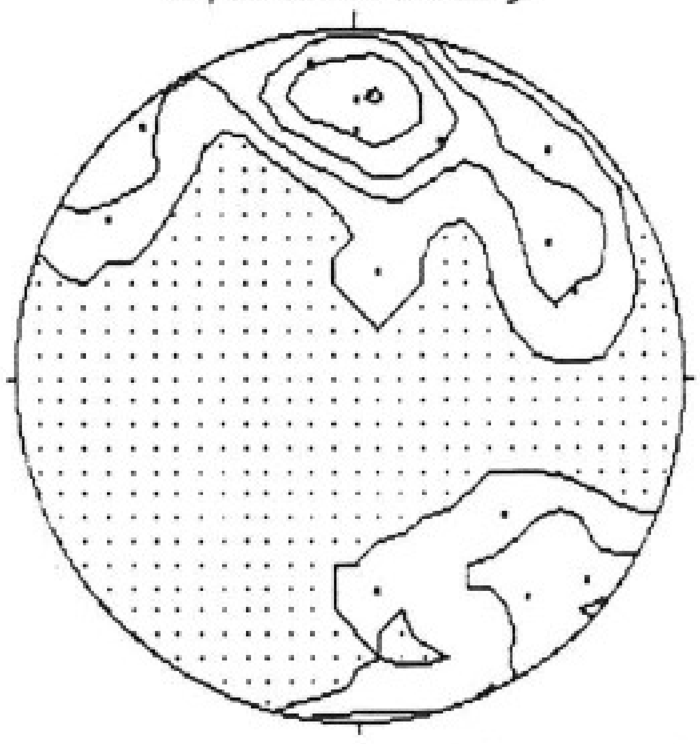
depot-domain3



39 Data. Contoured at 1 2 3 4 5 6 7

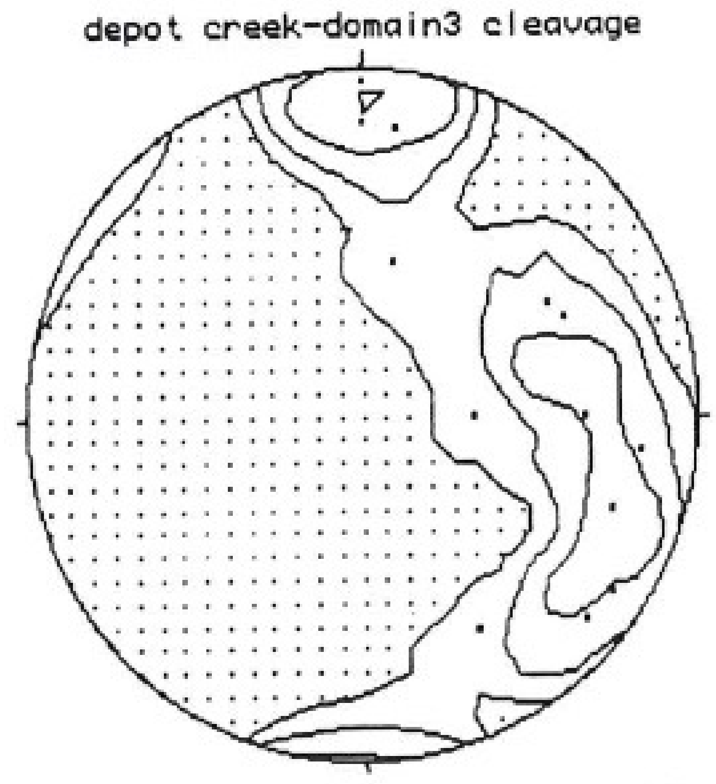
Depot Creek Cleavage

depot-dom.2cleavage



16 Data. Contoured at 1 2 3 4 x uniform

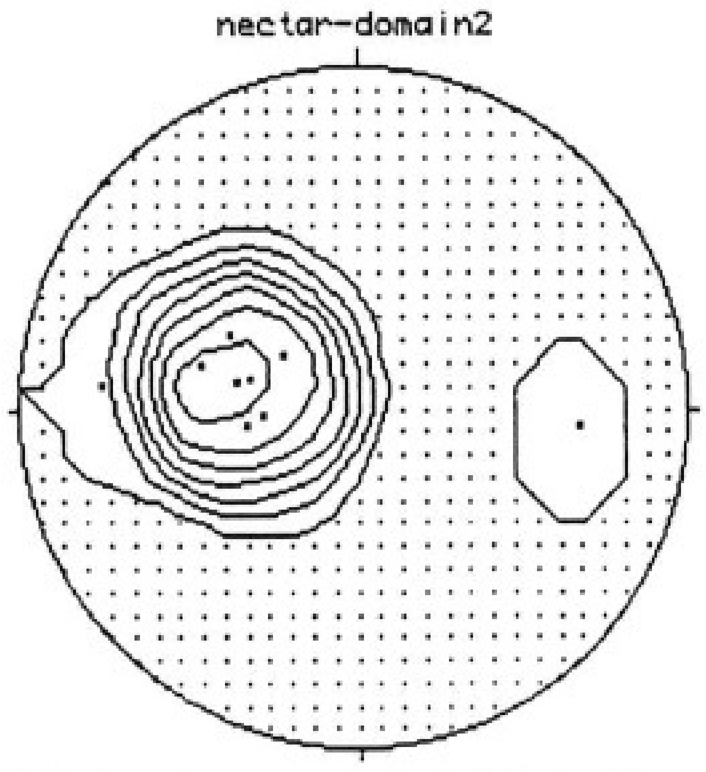
depot creek-domain3 cleavage



14 Data. Contoured at 1 2 3 x uniform

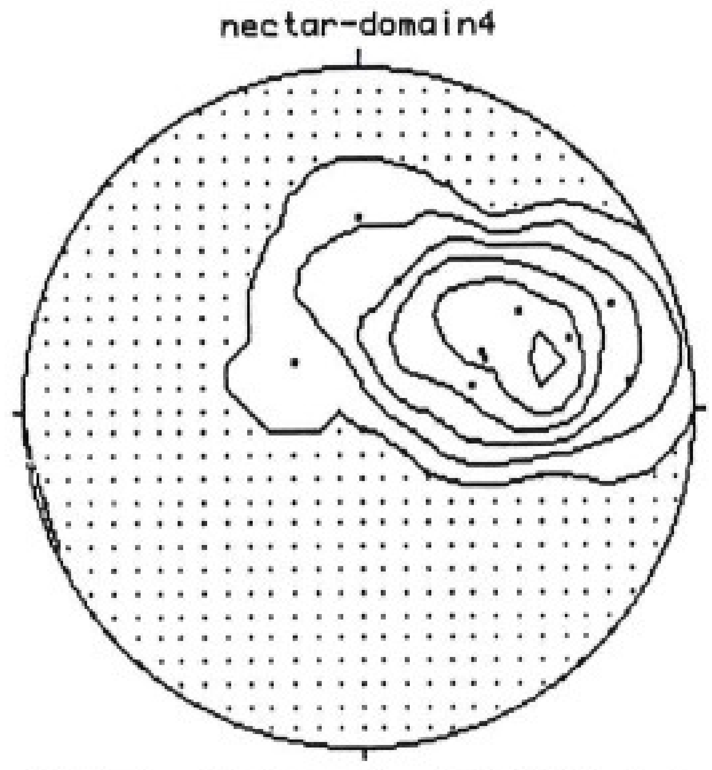
Nectar Brook Bedding

nectar-domain2



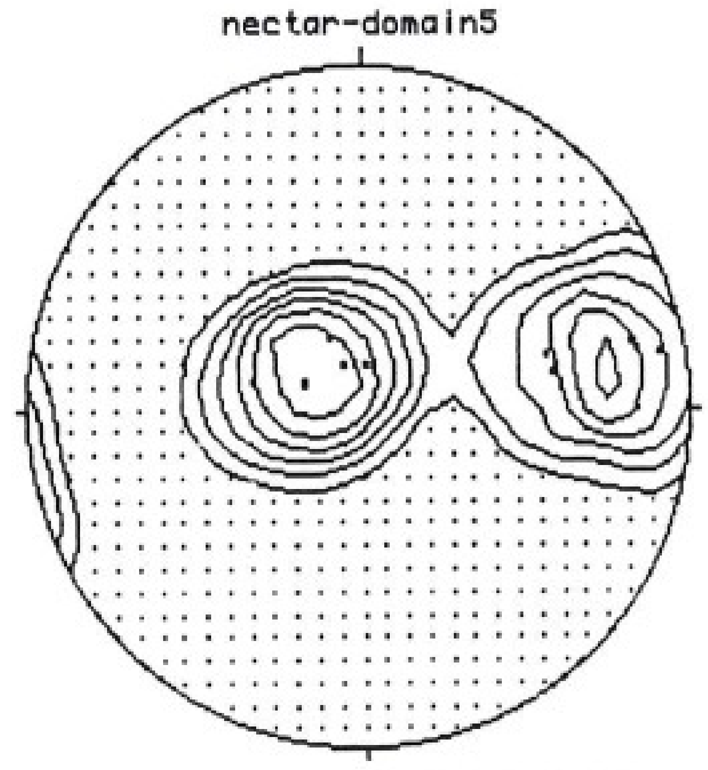
9 Data. Contoured at 1 2 3 4 5 6 x

nectar-domain4



10 Data. Contoured at 1 2 3 4 5 x

nectar-domain5



14 Data. Contoured at 1 2 3 4 5 x

Appendix 3 - Thin Sections

Depot Creek

A2000/DCA1

Plate 5 A.

Sample Description

Magnesite conglomerate, large yellow clasts set within a grey dolomite matrix. This rock belongs to the Skillogalee Dolomite.

Thin Section Description

Shows very little strain.

Mineral content is as follows:

> 20% Large yellow and buff coloured magnesite clasts. Very well rounded. Surrounded by sparite. Size is up to 2†cm by 1†cm. Some clasts contain ooids.
>
> 80% Matrix. This is made up of approximately 25% Quartz, 15% Microcline and Perthite and 40% Dolomitic cement.

A2000/DCD7

Plate 5 C

Sample Description

Grey with purple beds, ripple cross-bedding, very fine grained, no deformational structures. Calcareous shale. This rock belongs to the Brighton Limestone Formation.

Thin Section Description

> 5% Opaques- very fine grained.
>
> 50% Chlorite- green, first order yellow.
>
> Quartz and muscovite.

A2000/DCC1

Plate 5 B

Sample Description

Purple, fine grained, no structures (sedimentary or deformational). Calcareous. Siltstone unit of Skillogalee Dolomite.

Thin Section Description

> 10% Muscovite mica - very fine grained.
>
> 10% Quartz - fine grained.
>
> Minor plagioclase - very fine grained.
>
> Micritic cement.

A2000/DCD4

Plate 5 D

Sample Description

Very fine bedding laminae. No structures. Good slatey bedding cleavage. Grey fresh surface.

Thin Section Description

Very fine grained groundmass. Grainsize is homogeneous.

> 70% Quartz
>
> 15% Muscovite
>
> 5% Opaques

10% Carbonate Content (Micrite ?)

Nectar Brook
A2000/NBTIA
Plate 5 E
Sample Description
Fault brecciated quartzite. Taken from a fault. Fractures infilled by darker very fine grained material. ABC Range Quartzite.
Thin Section Description
Crystalline quartz with very fine grained quartz in the fractures.

A2000/NBF8
Plate 5 F
Sample Description
Very white quartz.
Thin Section Description
Crystalline quartz. A couple of fractures filled with quartz (smaller crystal sizes).

Pichi-Richi Pass
A2000/PRC1
Plate 6A
Sample Description
Layers of large well rounded, low sphericity clasts of very fine grained rock (brown) and quartz. Layers of medium grained sand and siltstone. Basal conglomerate of Wonoka Formation.
Thin Section Description
Siltstone and sandstone - medium grained.

40% Quartz
5% Opaques
2% Muscovite
53% Carbonate cement

Layers of Conglomerate

Clasts of quartz and very fine grained siltstones, matrix as above.

A2000/PRC6
Plate 6 B
Sample Description
Very fine grained Wonoka Formation, Carbonate.
Thin Section Description

90% Sparite
2% Muscovite
6% Quartz
2% Opaques

A2000/PRD8
Plate 7 A and B
Sample Description

Mesoscopic folds (order of 2 cm). Most likely crenulation folds. Cleavage is well developed (S1). Small 'pop up' structures at top of folds. Brachina Shale.
Thin Section Description
Very fine grained shale.

A2000/PRE13
Plate 6 C
Sample Description
Very fine grained carbonate. Greenish coloured. Strongly developed S1 cleavage. Wonoka Formation.
Thin Section Description

45% Quartz
2% Muscovite
30% Chlorite
25% Carbonate cement (Micrite)
Minor plagioclase and microcline

A2000/PRF10
Plate 6 D
Sample Description
Fine to medium grained carbonate rock. Well developed cleavage. Alignment of micaceous minerals giving a sheen to the rock. Beds of coarser medium grained sand grains and finer grained sediments.
Thin Section Description
Medium to coarse grained clasts of :

20% Quartz, microcline and plagioclase (up to 1 mm in diameter).
25% Muscovite
55% Micrite Cement

A2000/PRF12
Plate 8 C
Sample Description
Grey coloured, very fine grained carbonate rock. Wonoka Formation.
Thin Section Description
Very fine grained. Solution cleavage evident. Bedding present.

5% Muscovite
20% Chlorite
10% Opaques
65% Micrite and Sparite cement

A2000/PRF13
Plate 6E
Sample Description
Very strong cleavage (S1). Green looking very fine grained carbonate. Wonoka Formation. Large calcite veins parallel to bedding and S1 cleavage. Photo of outcrop shows level of strain.
Thin Section Description

Micritic cement with sparite in cracks. Very fine grained. Near vertical S1 fabric (poorly visible on section). Bedding is defined by compositional increase in chlorite. Folds in the S0 are produced by the crenulation cleavage S1. The Sparite veins trend along the S1.

20% Quartz
15% Chlorite
2% Opaques
2% Muscovite

A2000/PRF13#1
Plate 6 F
Sample Description
As previous.
Thin Section Description
S0 (bedding) defined by increase in chlorite composition. As previous.

A2000/PRF13#2
Plate 8 A
Sample Description
As previous.
Thin Section Description
Fabric very strong along S1. Very fine grained except for the sparite veining. Bedding defined by differences in mineral composition. Many fractures which have formed in the axes of folded bedding.

A2000/PRG1
Plate 8 B
Sample Description
Quartzite sandstone. Red coloured. Cross bedding. ABC Quartzite.
Thin Section Description
Pronounced alignment of iron minerals (opaque magnetite) along bedding. Fine to medium grained quartz grains, minor chert and microcline grains. No fabric.

A2000/PRL5
Plate 8 D
Sample Description
Grey coloured, very fine grained, massive, poorly developed cleavage. Wonoka Formation. Bedding present.
Thin Section Description
S0 produced by variance in mineral composition. Mica (muscovite) is sub-parallel to bedding.
Appendix 4 - Photographs

PLATE 5

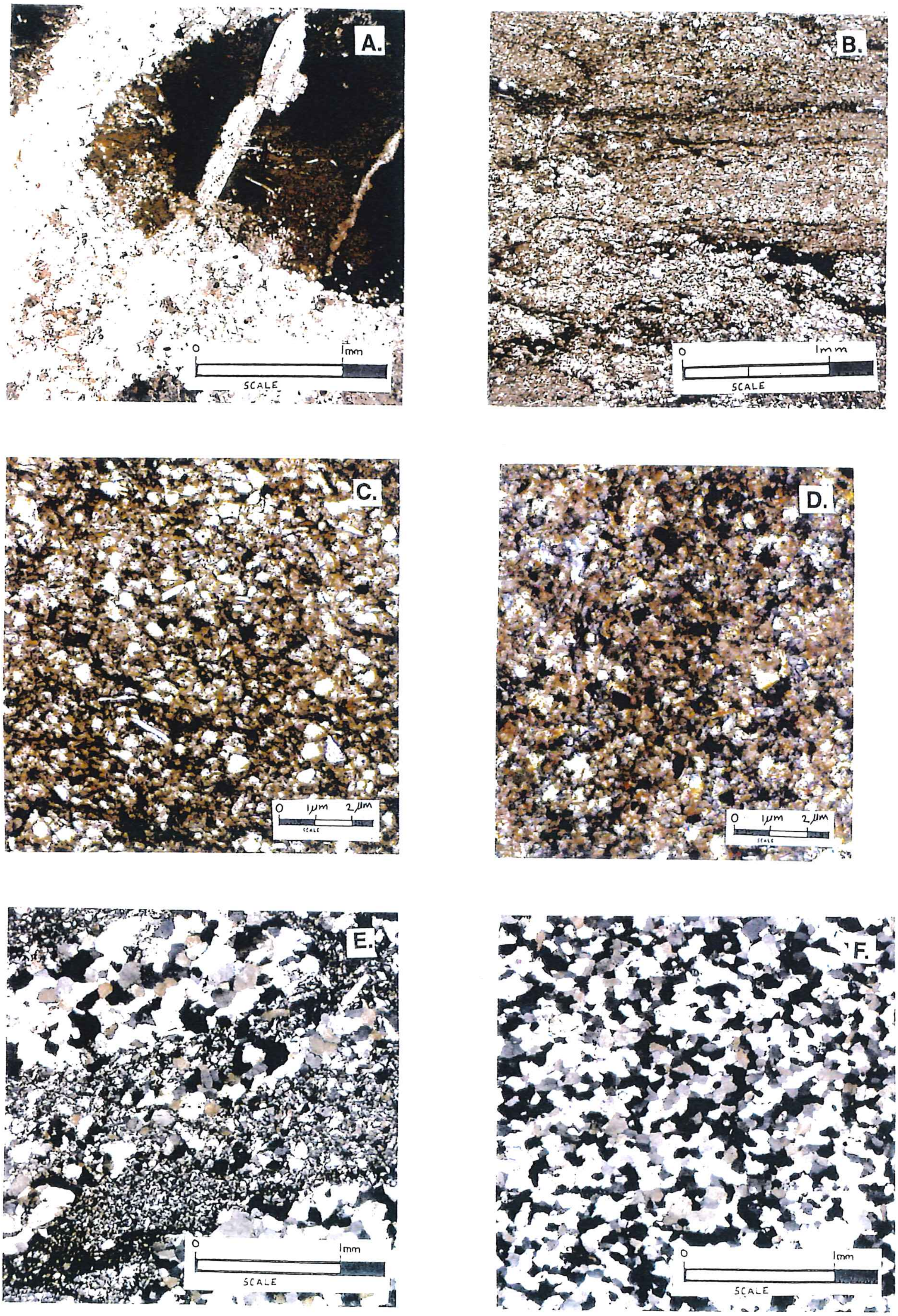
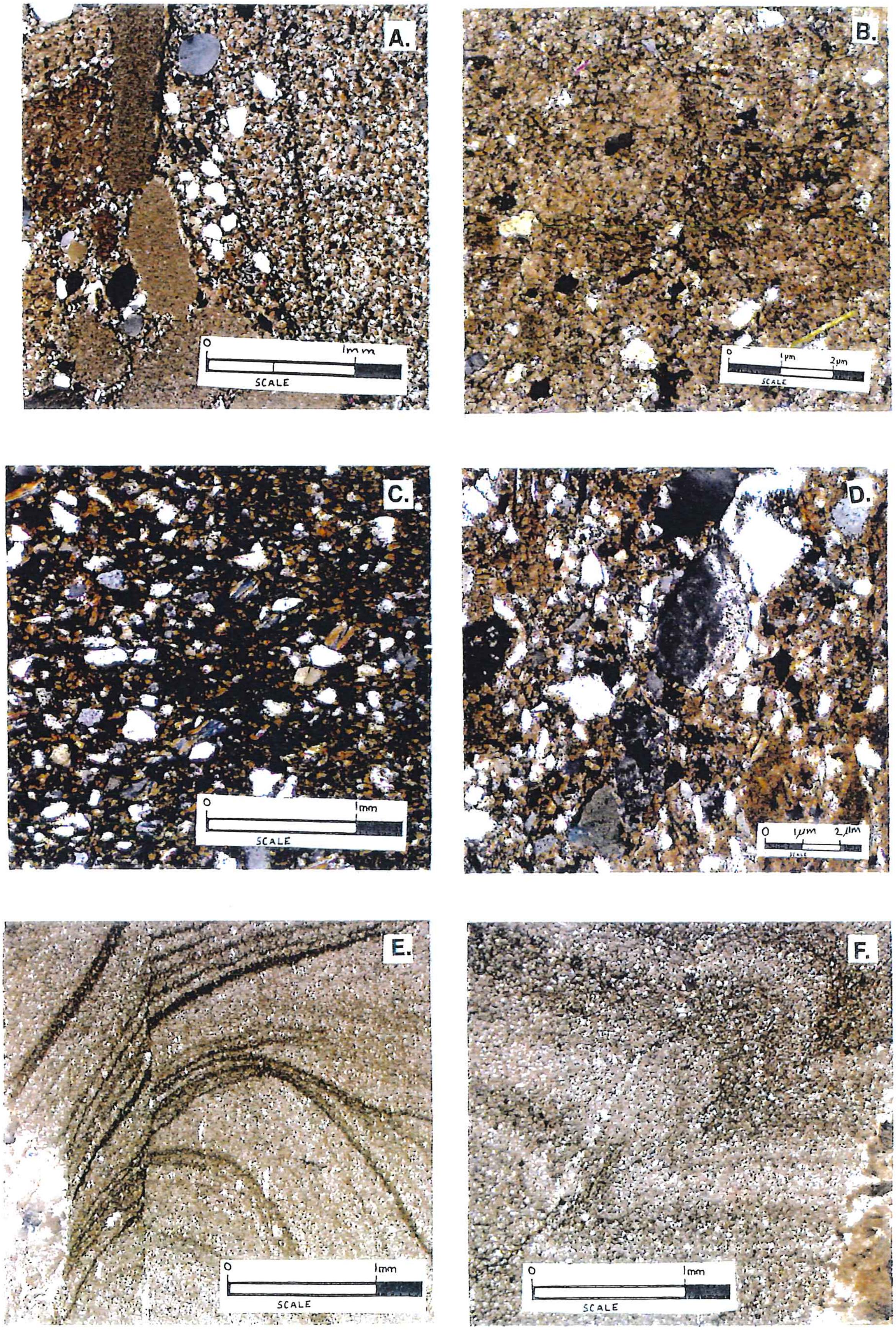

A.
0
1mm
SCALE
B.
0
1mm
SCALE
C.
0 1μm 2μm
D.
0 1μm 2μm
E.
0
1mm
SCALE
F.
0
1mm
SCALE

PLATE 6



A.
0
1mm
SCALE
B.
0
1µm
2µm
C.
0
1mm
SCALE
D.
0
1µm
2µm
E.
0
1mm
SCALE
F.
0
1mm
SCALE

PLATE 7