THE UNIVERSITY OF ADELAIDE

# GEOLOGICAL HISTORY OF THE WAUKARIE CREEK CANYON COMPLEX, SOUTHERN FLINDERS RANGES, SOUTH AUSTRALIA.

by K MEREDITH

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# Geological History of the Waukarie Creek Canyon Complex, Southern Flinders Ranges, South Australia.

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fullfilment of requirements for the Honours Degree
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# ABSTRACT

Many regional disconformities or 'sequence boundaries' have now been identified throughout the late Proterozoic Wilpena sediments of the Adelaide Geosyncline, South Australia. The most prominent of these appears near the base of the Wonoka Formation and has been related to the formation of incised valleys or 'canyons'. Early interpretations of these canyons suggested they were of submarine origin, cut and filled in a deepwater environment. However, more recent work has focused on a subaerial model whereby the incisions were cut fluvially.

Work was carried out on the Waukarie Creek Canyon Complex in the Southern Flinders Ranges. Observations gained from field mapping tend to favour a subaerial origin for canyon development. Some localities were found that provide evidence that there was some tectonic activity, expressed by deformation of sediments, prior to the formation of the Wonoka canyons. Palaeocurrents from flute casts and current ripples show that numerous reversals were found throughout the canyon, substantiating a tectonic influence on the formation of the canyons. This activity may be approximately coeval with the Beardmore Orogeny of Antarctica. The compressional Cambro-Ordovician Delamerian Orogeny subsequently deformed the sedimentary prism in a complex array of north-south trending tight folds and reverse faults.

# INTRODUCTION

Kilometre-deep incisions - commonly called canyons have been eroded into a specific stratigraphic interval within the late Proterozoic Wonoka Formation in parts of the northern and southern Flinders Ranges (von der Borch *et al.*, 1989). The nature and origin of these structures has been controversial for many years. The canyons were first described as being of submarine origin by several workers (von der Borch *et al.*, 1982; von der Borch *et al.*, 1985; Haines, 1987, 1988; Ayliffe, 1992). However, more recent study has focused on an alternative model - the 'Drowned River Valley' model suggesting the canyons were cut subaerially and filled by coastal onlap (Eickhoff, 1988; Eickhoff *et al.*, 1988; von der Borch *et al.*, 1988; DiBona *et al.*, 1990; Christie-Blick *et al.*, 1990; DiBona *et al.*, 1993; Dyson *et al.*, 1994 and Christie-Blick *et al.*, 1995).

To date, most of the studies have focused on the canyon system within the Northern Flinders Ranges. Relatively little work has been done on the southern canyon system. It is considered that the canyons in the southern area are associated with one single river system, with the headward end at Pichi Richi deepening to the south-east, terminating in the Yunta canyon complex which is thought to have cut through the wall rocks into a much deeper stratigraphic level (Haines, 1987).

The present study concerns the canyon system in the southern Flinders Ranges - especially the Waukarie Creek Canyon Complex at Pichi Richi and Saltia. Mapping was carried out, and some analytical work has been done to help determine the nature and formative mechanism of this canyon system. A subaerial model of canyon incision is favoured. Evidence of tectonic activity has been found to support the idea that regional uplift may have been the driving force to lower relative sea level by approximately one kilometre to allow for the canyon incision by fluvial processes. More work is needed to substantiate this view.

# CH. 1: GEOLOGICAL SETTING AND PREVIOUS INVESTIGATIONS

## 1.1 Regional Geology

The Adelaide "Geosyncline" (Figure 1) is a late Proterozoic to Early Cambrian bifurcating depositional and tectonic regime, stretching the vicinity of Arkaroola in the north, Olary in the north-east and in the south-west to Kangaroo Island.

Accumulations of thick sedimentary sequences in the Geosyncline began between 1100 and 800 Ma (von der Borch *et al.*, 1982; Haines, 1990). The western margin is marked by the Torrens Hinge Zone which represents the transition zone between the thin, flat lying Stuart Shelf sediments and the frontal thrust of a presumed allotchthon comprising thick, folded and slightly metamorphosed (lower greenschist facies) Neoproterozoic sediments of the "Geosyncline" proper (Jenkins, 1990; Jenkins and Sandiford, 1992; Drexel *et al.*, 1993). The southern boundary trends beneath the modern continental shelf sediments, the eastern and western margins are bounded by a series of thrust faults, while the northern margin is obscured by Cainozoic cover (Haines, 1987).

It has been suggested by several workers (eg. von der Borch *et al.*, 1985; Haines 1990) that the Adelaide Geosyncline comprises a rift fill and passive continental margin sequence developed marginal to the Australian Shield. The facies of the Adelaidean and Cambrian sequences can be shown to have evolved in accordance with progressive rifting and post-rift subsidence (von der Borch *et al.*, 1985). Diapirism played a major role in the development of the basin fill in the northern Flinders Ranges, but evidently was of minor importance in the area of interest to this study.

The Neoproterozoic to Cambrian sequence has been divided up into three unconformity-bounded Supergroups (Figure 2) based on the tectonic setting, palaeogeography and palaeoenvironments of the time (Preiss, 1987). The earliest sediments were deposited in restricted grabens of rift valley origin, and are known as the Callanna and Burra Group sediments, collectively forming part of the Warrina Supergroup. This sequence is followed by the Heyson Supergroup which is composed of glacial and marine sediments of the Umberatana Group as well as the late Proterozoic post-glacial Wilpena Group. The uppermost Moralana

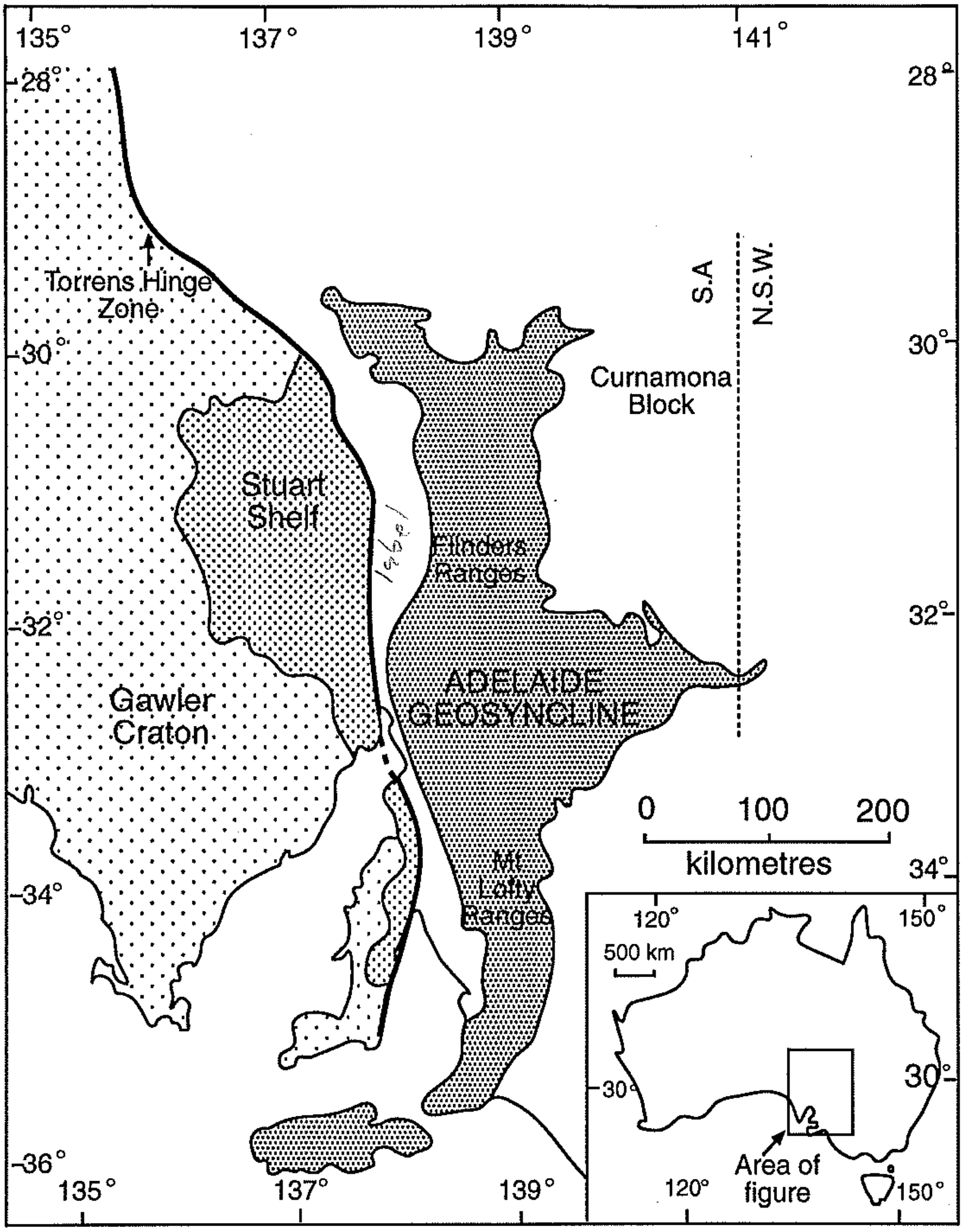


Figure 1: Location of the Adelaide Geosyncline in South Australia
(Adapted from Christie-Blick *et al.*, 1990)

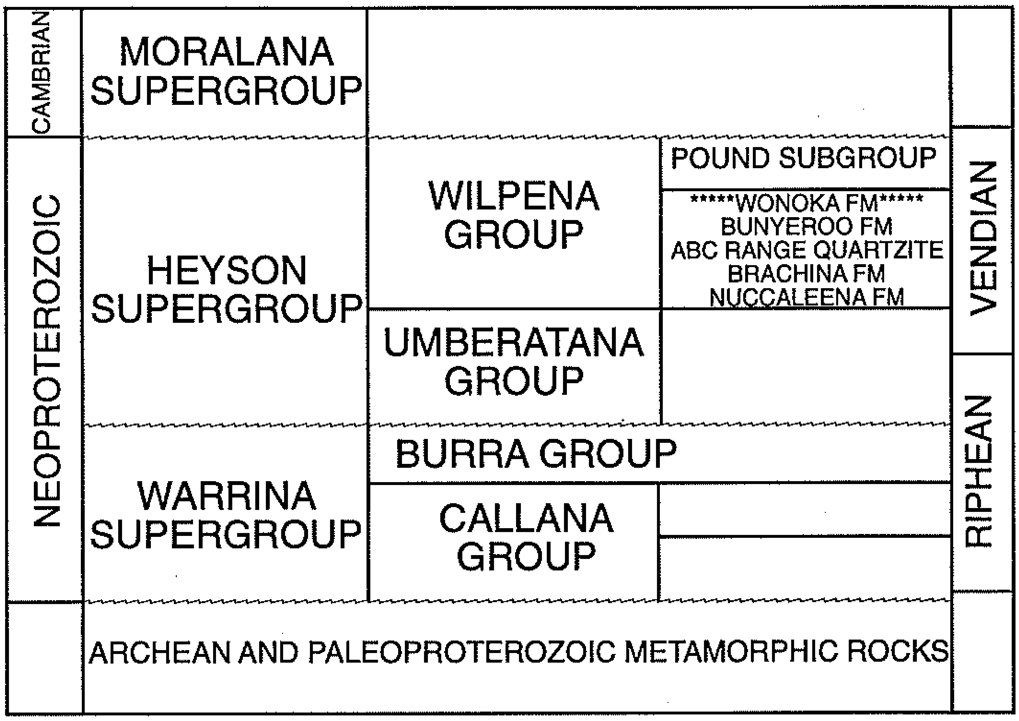


Figure 2: The Stratigraphic Position of the Wonoka Formation with respect to the threee major unconformity-bound Supergroups. (Adapted from Christie-Blick *et al.,* 1990)

Supergroup includes all the Cambrian sediments of this region (DiBona, 1989). This basin fill lies unconformably on metamorphic, igneous and sedimentary rocks which are of Archaean to mid-Proterozoic age.

The Adelaide Geosyncline succession underwent deformation and metamorphism during the Cambro-Ordovician Delamerian Orogeny and renewed tectonic activity in the late Cainozoic resulted in the uplift of the Flinders and Mount Lofty Ranges.

## 1.2 Location

The Waukarie Creek Canyon Complex is associated closely with the transition between the Bunyeroo and Wonoka Formations of the mid Wilpena Group. The system is situated about 15 kms east of Port Augusta and 13 kms south of Quorn (Figure 3) in the region known as the 'Southern Flinders Zone' (Preiss, 1987). This canyon complex stretches from Saltia in the west to Richman Valley in the east over a ground distance of about 10 km. The geology of the area is dominated by a complex array of north-south trending folds and faults.

In order to facilitate the exact reference of the specific locations mentioned throughout the text, an arbitrary (A-I/1-7) grid has been overlain on Map 1 (Appendix 1).

## 1.3 Previous Investigations

Several references to what is now known as the Wonoka Formation were made by Mawson between 1923 and 1949, when he compiled a series of papers detailing the structure and stratigraphy of the Flinders Ranges (Urlwin, 1992). Dalgarno and Johnson (1964) formally defined the base of the Wonoka Formation which was subsequently redefined by Gostin and Jenkins (1983) to the base of a thin, but laterally persistent dolomite horizon, now known as the "Wearing Dolomite". Dyson, (1996) has now upgraded it to formation status in its own right. This dolomite is equivalent to 'Unit 1' of the Wonoka Formation of Haines (1987; 1990), marking a change between a carbonate poor to carbonate rich style of sedimentation.

Coats (1964) was the first to recognise an unusually large-scale, late Proterozoic "slump structure" in the Patsy Spring area, Copley, northern Flinders Ranges and which was later studied and recognised as a deep "submarine" canyon by von der Borch *et al.*, (1982). Various workers such as von der Borch *et al.*, (1985); von der Borch *et al.*, (1988); von der Borch *et* *al.*, (1989); Eickhoff, (1988); Eickoff *et al.*, (1988); DiBona, (1989); DiBona *et al.*, (1990); DiBona *et al.*, (1993); Christie-Blick *et al.*, (1988); Christie-Blick *et al.*, (1990), Christie-Blick *et al.*, (1995); Christie-Blick, (1991); Haines, (1987, 1988, 1990); and Dyson, (1996) have subsequently identified and mapped numerous other canyons linked to the Wonoka Formation in the Flinders Ranges and the broadly coeval sediments of the adjoining Officer Basin.

Haines (1987, 1988, 1990) considered the Wonoka Formation primarily as a storm dominated, mixed carbonate-siliclastic shelf sequence and subdivided it into eleven mappable 'Units'. DiBona (1989) provided an alternative subdivision of the Wonoka Formation based on principles of sequence stratigraphy. More recently, Dyson (1996) has recognised several third-order transgressive-regressive sequences throughout the Wonoka sediments. Within the present study, however, Haines' units and the redefined boundaries of Dyson (1996) are used as these reference frames are more widely accepted.

The Wonoka Formation canyons are a series of deep (some greater than 1 km) incisions, infilled with a unique carbonate rich silty lithofacies interspersed with levels of olisthostonic conglomerates. Canyons are best developed both in the northern and southern Flinders Ranges, but most of the work to date has concentrated on the northern canyons due to the more extensive outcrop present. There is much controversy as to explain the origin and the environmental setting at the time of infilling of the canyons. The two main ideas at present are:

(1) Deep water "submarine" model, implying the canyons were eroded and infilled in an inferred basin-slope setting by subaqueous processes (von der Borch *et al.*, 1982; von der Borch *et al.*, 1985; Haines, 1987, 1988; Ayliffe, 1992)

(2) "Drowned River Valley" model, suggesting canyons were cut by fluvial processes and later infilled by coastal onlap (Eickhoff, 1988; Eickhoff *et al.*, 1988; von der Borch *et al.*, 1988, von der Borch *et al.*, 1989; DiBona, 1989; DiBona *et al.*, 1990; Christie-Blick *et al.*, 1990; DiBona *et al.*, 1993; Dyson *et al.*, 1994 and Christie-Blick *et al.*, 1995). This model requires base-level changes of the order of 1 km to account for the canyon cutting and filling.

This study focuses on furthering understanding of the tectonic and structural history of the Waukarie Creek Canyon Complex and providing additional evidence in favour of the subaerial model.

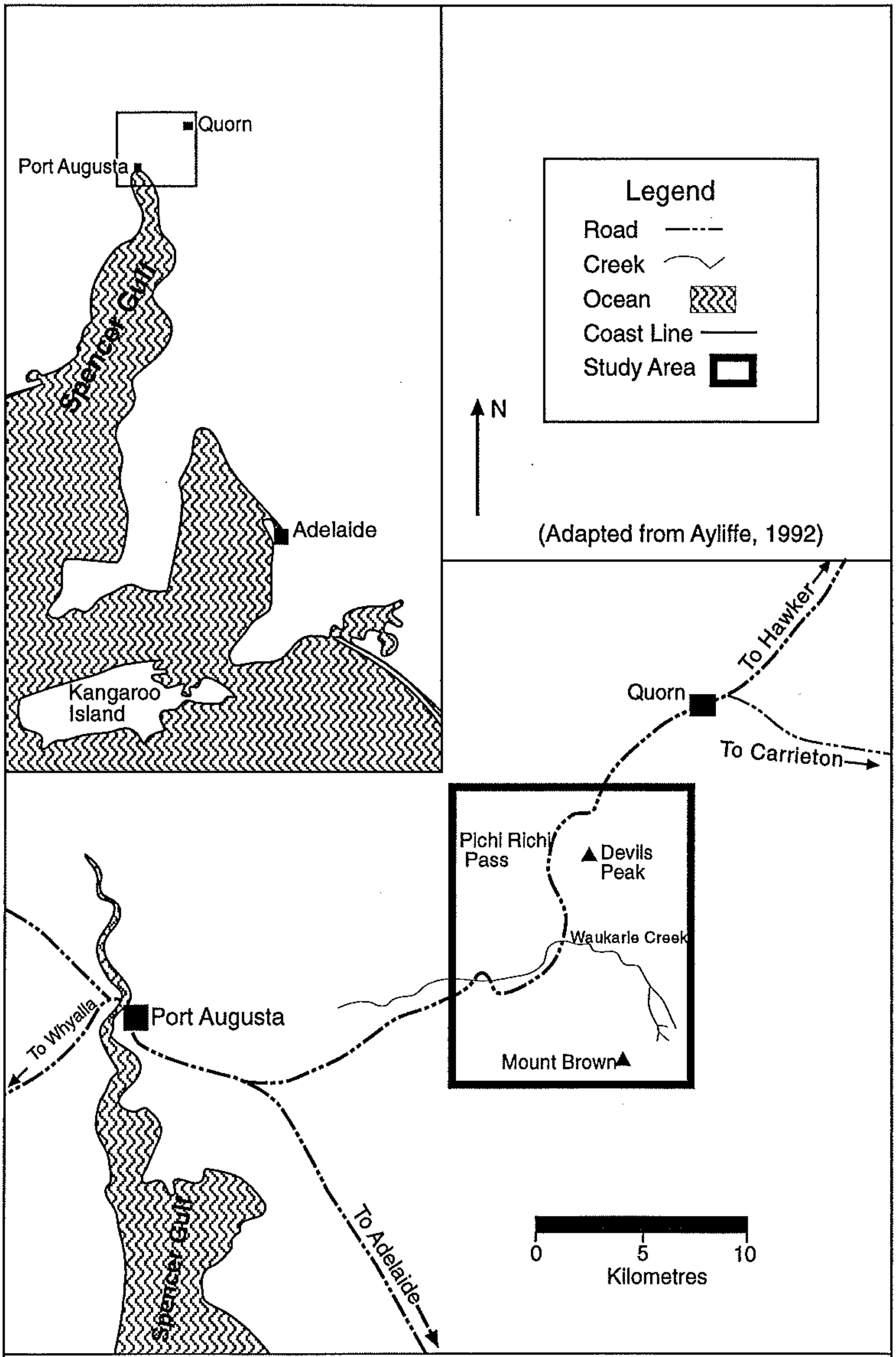


Figure 3: Locality Map of the Waukarie Creek Canyon Complex

# CH. 2: STRATIGRAPHY

The Wilpena Group comprises ca. 2.5 km thickness of sandstone, argillite, and carbonate rocks deposited in variable platform to shelfal environments extending from fluvial to relatively deep marine regimes (Christie-Blick *et al.*, 1988). Several transgressive-regressive cycles (Preiss, 1990; Drexel *et al.*, 1993; Dyson, 1996) are suggested to represent deposition in response to major tectono-sedimentary pulses (DiBona, 1989; Jenkins, 1990). Work by von der Borch *et al.,* (1988); DiBona, (1989); and Dyson (1996) defined numerous sequence boundaries within this succession, suggesting that episodic coarsening upward cycles form a series of unconformity-bound intervals, grouped into individual subgroups as shown in Figure 4.

## 2.1 Sandison Subgroup

The first cycle is represented by the Nuccaleena Formation, Brachina Formation and the ABC Range Quartzite collectively called the Sandison Subgroup of Dyson (1996). The Nuccaleena Formation and the lower part of the Brachina Formation represent a marine transgression, whilst the upper section of the Brachina Formation and the ABC Range Quartzite represent an overall shoaling of a broad terrigenous ramp from shallow subtidal/offshore and to possibly fluvial environments (Eickhoff *et al.*, 1988; Dyson, 1996).

### 2.1.1 Nuccaleena Formation

This forms a thin, lenticular micritic dolomite marker bed defining the boundary between the underlying Umberatana group and the overlying Wilpena group. This unit is interpreted as an intertidal dolomite with local supratidal conditions affecting sedimentation (Plummer, 1990).

### 2.1.2 Brachina Formation

Sharply overlying the Nuccaleena Formation is the Brachina Formation consisting of a thick succession of reddish purple to green shales coarsening upward to sandy siltstone and interrelated tuffaceous sandstones at the top. Deposition is thought to have taken place in a shelfal to deltaic setting. In its type section in the central western Flinders Ranges the Brachina Formation reaches thicknesses of about 1200 metres and is locally eroded by the Wonoka Canyons to within 100 metres of its base in the North Flinders Zone (Eickhoff *et al.*, 1988).

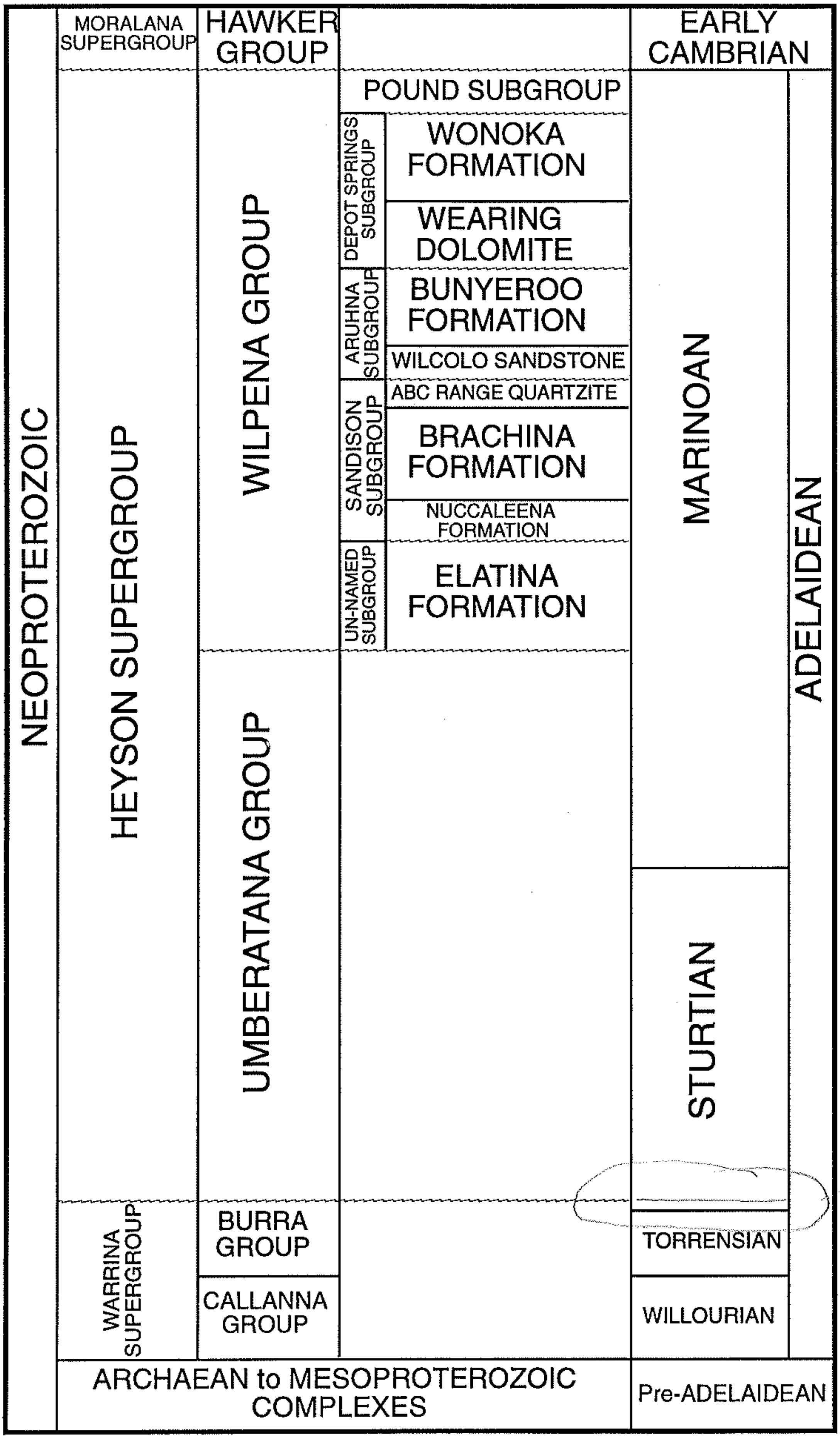


Figure 4: Stratigraphic Column of the Adelaidean Sediments in the Adelaide Geosyncline. (Adapted from Dyson, 1996)

### 2.1.3 ABC Range Quartzite

The ABC Range Quartzite consists of greyish red to white coarse to fine-grained quartzite which is cyclically interstratified with very fine-grained sandstone and siltstone (Christie-Blick *et al.*, 1990). This unit is characterised by many sedimentary structures such as cross-stratification, current ripples, ball and pillow structures and desiccation cracks (Plate 1A). Shoreface event beds varying in thickness from a few centimetres to a metre or so are seen throughout this unit in the Pichi Richi area.

The ABC Range Quartzite is widespread across the Flinders Ranges but pinches out towards the north and east due to the interfingering relationship with the underlying Brachina Formation (Christie-Blick *et al.*, 1990). The abundance of desiccation cracks and medium scale cross-bedding, including the presence of herringbone sets, suggests an intertidal sand-flat environment for deposition (Christie-Blick *et al.*, 1990)

## 2.2 Aruhna Subgroup (Dyson, 1996)

This subgroup encompasses the Wilcolo Sandstone and the Bunyeroo Formation, and has been interpreted by Dyson (1996) as a third-order cycle deposited during one eustatic fall and rise of sea level.

### 2.2.1 Wilcolo Sandstone (Dyson, 1996)

The ABC Range Quartzite is locally disconformably overlain by the Wilcolo Sandstone, characteristically consisting of a few beds of coarse grained gritty sandstone, interpreted by Plummer (1978: cited in Dyson, 1996) as being of fluvial origin. This sandstone locally represents an incised valley fill that was cut during a lowstand of relative sea level near the top of the ABC sandsheet (Dyson, 1996). The base of the unit is interpreted to be a sequence boundary.

### 2.2.2 Bunyeroo Formation

The Wilcolo Sandstone is abruptly, yet conformably, overlain by monotonous maroon shaley siltstone known as the Bunyeroo Formation. Overall there is a trend towards an upward fining succession which is punctuated by a series of subtle, upward coarsening packages (Dyson, 1996). The depositional environment is thought have been in deep, quiet water below storm wave base, in a middle to outer shelf setting, which was generally starved of coarse grained sediment and possibly represented the peak of transgression (Haines, 1990). The siltstone is structureless to parallel-laminated (Christie-Blick *et al.*, 1990).

About 80 metres from the base of the Bunyeroo formation is a thin (0 to 40 cm) layer of a meteorite-impact ejecta, consisting of a sand/breccia unit almost entirely containing angular volcanic fragments interpreted as the debris layer linked to a bolide impact at Lake Acraman in the Gawler Craton ca. 300 km to the west (Gostin *et al.*, 1986; Wallace *et al.*, 1996).

## 2.3 Depot Springs Subgroups (Dyson, 1996)

The Wearing Dolomite together with the Wonoka Formation represent another transgressive - regressive cycle known as the Depot Springs Subgroup (Dyson 1996).

### 2.3.1 Wearing Dolomite/ Unit 1 of Haines (1987)

The base of the Wearing Dolomite has been defined as a deep water sequence boundary by Dyson (1996). The Wearing Dolomite sharply and conformably overlies the Bunyeroo Formation and corresponds to Unit 1 of Haines (1987). Exposure is limited within the study area, perhaps with representation in the Dutchmans Stern Syncline to the north. Within the Waukarie Creek Canyon Complex it is likely that Unit 1 has been removed by canyon erosion. The Wearing Dolomite consists of a thin (up to a few metres thick) dolomitic horizon generally of a green/grey colour interbedded with pink dolomitic mudstone. Current interpretations indicate the Wearing Dolomite was deposited in a peritidal environment (R.J.F. Jenkins pers. comm., 1997).

### 2.3.2 Wonoka Formation

Within the Waukarie Creek Canyon Complex the Wonoka Formation is perhaps about 800 metres in thickness and is presently subdivided into mappable units based on the assumption of resemblances to Haines' (1987) divisions. The Wonoka sediments appear to be cyclic in nature, consisting of distinct repeated sedimentary packages. Dyson (1996) suggests that Units 3 to 7 represent regressive sedimentation.

The Wonoka Formation is dominated by shelf sedimentation and shallows upward from an outer-shelf siliciclastic and minor carbonate facies at its base into a thick storm-dominated middle- to inner- shelf carbonate environment and finally to the overlying deltaic and continental facies of the Bonney Sandstone (Haines, 1988; DiBona *et al.*, 1990).

Several regional unconformities or sequence boundaries have been identified within the Wonoka Formation and have been related to large relative sea level changes, subaerial exposure and erosion of the palaeoshelf. One of these low within the Wonoka Formation formed as a result of the erosion of the deep 'Wonoka Canyons" (DiBona *et al.*, 1993). The canyons are infilled by distinctive lithofacies variants.

### *2.3.2.1 Older Carbonate Platform Sequence*

This sequence resembles Haines (1987) lower lithostratigraphic subdivisions of the Wonoka Formation.

#### Unit 2 Equivalent

Within the Pichi Richi and Saltia areas, the assumed correlative of Unit 2 is seen as brown medium to thick bedded calcareous sandstone alternating with coarse siltstone and purple mudstone. The fine-grained sandstone has many sedimentary structures including load casts, flame structures, ball and pillow structures (Plate 1E), interference ripples and hummocky cross stratification (HCS). The interpretation of HCS has been in the past quite controversial, but it is now considered that it primarily results from some combination of unidirectional and oscillatory flow above storm wave base (Christie-Blick *et al.,* 1990). Internally, the sandstones often show Bouma sequences $T_{b\text{-}e}$ (Plate 1F) suggestive of turbidites.

Within this unit there are some structures (Plate 2A) that have been described by V.A. Gostin pers. comm., (1997) as sand volcanoes, formed by waters rising through sediments that are inundated with water (Conybeare *et al.*, 1968). Their presence indicates that the rate of sedimentation was quick and the sediments were subject to dewatering. Sand volcanoes are also associated with Bouma sequences which occur at locality C-2.6.

The uppermost part of Unit 2 and part of Unit 3 are interpreted as transgressive highstand system tract, with sedimentation mostly below wave base (Christie-Blick *et al.,* 1990). This is supported by the presence of flame structures, which have been described as disruptions of beds from turbidite flows (Conybeare *et al.*, 1968), as well as the Bouma sequences and sand volcanoes which are both consistent with deep water conditions.

Unit 3 Equivalent

Unit 3 comprises reddish calcareous mudstone, interbedded with varying amounts of pink thin bedded micritic limestone. These limestone units are generally less than 2 metres thick and occur in packages of two, three or four (Haines, 1987). Individual beds commonly have solemarks at the base and characteristically have sharp tops. The presence of unidirectional cross bedding and a very fine clastic component led Urlwin (1992) to interpret these carbonates as representing distal turbidites, but their sharp tops are consistent with tempestites (Einsele and Seilacher, 1991) deposited above storm wave base. Filamentous impressions attributed to 'algae' found near the top of this unit suggest deposition of this unit occurred in a relatively shallow environment.

#### *2.3.2.2 Canyon Infill facies in the Waukarie Creek Canyon Complex*

Wall Plaster

In several locations grey-brown, well laminated limestone is present on the erosional unconformity. In places it is seen to be brecciated and contain limestone and greenish yellow dolomite clasts comparable to those known to occur at the top of or immediately above Unit 2. This would indicate that canyon formation likely occurred some time shortly following deposition of Unit 2.

Basal Conglomerate

The basal conglomerates contain varied lithoclasts of different origin and are predominantly clast-supported, a feature which Tucker (1991) states is characteristic of a fluvial environment. The majority of the clasts are carbonates and are most probably from Unit 2, and early Unit 3 Wonoka sediments. Small quartzite clasts were observed, possibly derived from the underlying ABC Range Quartzite. The clasts were mainly subrounded to angular and varied in size from 2 mm to about 15 cm in length. Several pieces of Gawler Range porphyry were found (Plate 1B), one piece was well rounded and 30 cm in one dimension. The porphyry may have come from the Gawler Craton due to fluvial action, a notion supported by the common occurrence of fragments in the older canyon conglomerates. A less likely explanation for the presence of the porphyry is that it was reworked from an underlying level which contained the Acraman impact ejecta horizon (V.A. Gostin, pers. comm., 1997).

Conglomerates are confined mainly to the base of the canyons and adjacent to the walls.

Olisthostrome

An Olisthostrome unit has been described as a chaotic mixture of heterogeneous material that has accumulated by submarine gravity sliding or slumping of unconsolidated material (Jackson, 1997).

Olisthostrome units found in the Waukarie Creek Canyon Complex (Plate 1C) are about 2 to 3 metres in thickness with a variety of olistholiths varying in size from a few centimetres to about 1 metre in length. The clasts are subrounded to subangular and are presumed to be of early Wonoka Formation, Bunyeroo Formation and ABC Range Quartzite derived from the reworking the underlying strata during erosion of the canyon.

Canyon Fill Unit

Within parts of the Waukarie Creek Canyon Complex the canyon fill unit is indistinguishable from Haines' Units 5 and 6.

This fill is characterised by multicoloured (purple, yellow, orange, blue and green) thin to thick hard limestone interbedded episodically with thin green mudstone. HCS up to 2 metres in wavelength is seen. Upper surfaces have abundant ripple marks. Parts of the canyon fill are quite sandy and may locally form slumps adjacent to the canyon walls.

#### *2.3.2.3 Carbonate Platform Sequence*

Unit 4 Equivalent

Within the study area Unit 4 is the most widespread unit. Unit 4 is represented by the first major occurrence of olive-greenish limestone. The greenish nature of the limestone implies reducing conditions.

This unit is characterised by the cyclic alternation of green finely laminated silty- to fine sandy-limestone interbedded with green, brown and maroon mudstone, brownish calcareous siltstone and pink limestone. The reddish colour of the interbedded mudstone and siltstone dominated intervals are indicative of oxidising conditions on the outer shelf.

Sedimentary structures such as teepees, climbing and interference ripples as well as solemarks, including flute casts are common within Unit 4. Internal Bouma sequences are suggestive of distal turbidites. HCS is present with some hummocks up to 20 cm in wavelength.

Unit 5 Equivalent

Unit 5 is dominated by medium to thick bedded green limestone with interbedded mudstone minimal. Abundant ripple marks, climbing ripples (Plate 2B), planar lamination, flute casts (Plate 2C), ball and pillow structures and small and large scale (up to two metres in wavelength) HCS and other forms of soft sediment characteristics are common within this unit.

Unit 6 Equivalent

Unit 6 is defined by brown fine grained calcareous sandstones interbedded with brown and grey mudstone and red limestone. In the Saltia area Unit 6 is quite thickly bedded and displays HCS, swaley cross stratification (SCS), loadcasts, solemarks, climbing ripples and ripples.

Unit 7 Equivalent

Unit 7 is characterised by white green to grey argillaceous and silty micritic limestone. Soft sediment deformation including ball and pillow structures, planar laminations and well developed HCS (Plate 2E) are amongst the most common sedimentary structures seen. Intraformational conglomerates are present becoming more abundant towards the top of this unit signifying increased wave reworking upsection. Stylonodular bedding is common (Plate 2D), effecting most of the green limestones. Stylonodular bedding is a secondary structure - destroying or partly destroying the primary sedimentary fabric (Haines, 1987). A red limestone units are distinctive elements here and occur at cyclic stratigraphic spacings of several metres.

Unit 8 Equivalent

Unit 8 consists of purplish-grey hard limestone with green calcareous mudstone. The limestone is commonly planar laminated with occasional cross beds. Intraformational conglomerates are also abundant throughout Unit 8. The clasts are rounded, indicating that wave reworking or significant current transport has influenced the formation of these conglomerates. Unit 8 is characterised by the presence of a distinctive sandy purple marker horizon which was first identified by Haines (1987).

Unit 9 Equivalent

Unit 9 was not observed in the Pichi Richi area. Haines (1987) suggests it is a grey hard limestone interbedded with black calcarenites.

Unit 10 Equivalent

Unit 10 is seen at the base of Devils Peak where it comprises a siliciclastic sequence remarkably similar to the overlying Bonney Sandstone. It is at most 2 metres thick and is a red, micaceous sandstone. Unit 10 is highly cleaved within the study area.

## 2.4 Pound Subgroup

The Pound Subgroup is gradational above the Wonoka Formation and resembles the terminal Neoproterozoic sandstones which occur widely around the world at a comparable stratigraphic position (eg. near Death Valley, California, Namibia, the Varanger Peninsula, Norway and Northern Russia; R.J.F. Jenkins, pers. comm., 1997).

The Bonney Sandstone is the lower unit of the Pound Subgroup and regionally forms an interfingering relationship with the underlying carbonates (Haines 1987). Deposition of the Bonney Sandstone is thought to have occurred on coastal sandflats under oxidising conditions (Preiss, 1990). Overlying this is the Rawnsley Quartzite; a clean white mature quartzite, it is one of the most important late Proterozoic sediments as in contains soft-bodied fossils of the Ediacaran Member.

# PLATE 1

**Plate 1A:** Mudcracks on the base of an ABC Range Quartzite bed.

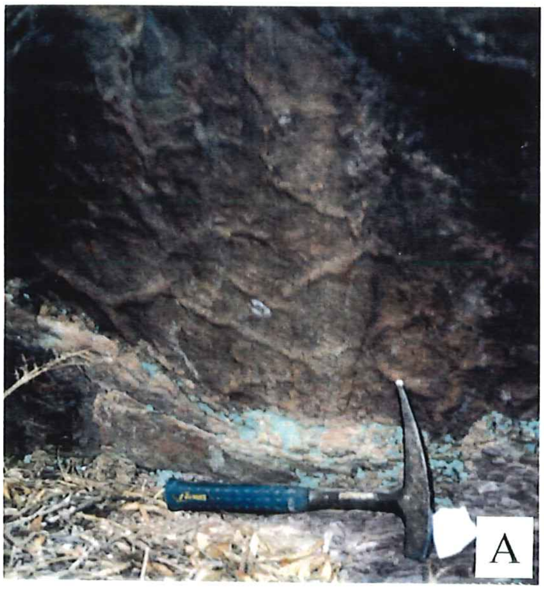
**Plate 1B:** Gawler Range Porphyry within the Basal Conglomerate unit of the Wonoka Canyon, near Saltia Syncline (locality D-2.8). The porphyry is about 15cm in length. Hammer is approx. 40cm.

**Plate 1C:** Olisthostrome Unit approximately 2 metres thick near Waukarie Creek (Locality D-4.2). Notice the metre sized clast on the left side of the photo.

**Plate 1D:** A clast of jointed Bunyeroo Formation lithology found within the conglomerate unit (Locality D-2.8). Pencil is 14cm.

**Plate 1E:** Ball and pillow structures within the Unit 2 layer of the Wonoka Formation near the Quarry (Locality C-2.8). Pencil is 14cm.

**Plate 1F:** Bouma sequences $T_{b\text{-}d}$ within Unit 2 at the Quarry (Locality C-2.8).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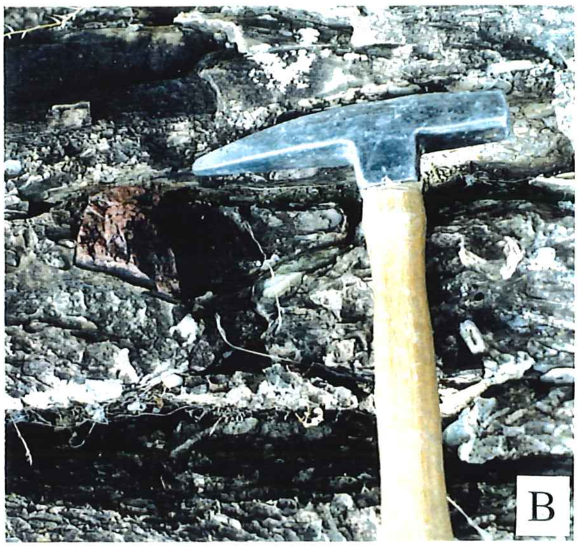
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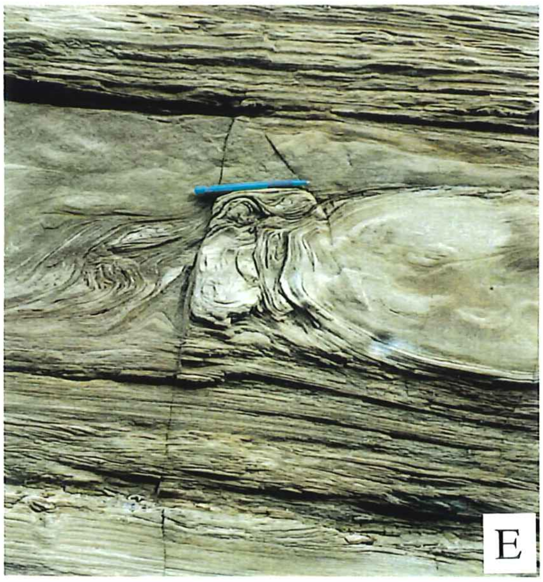
C


D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F

# PLATE 2

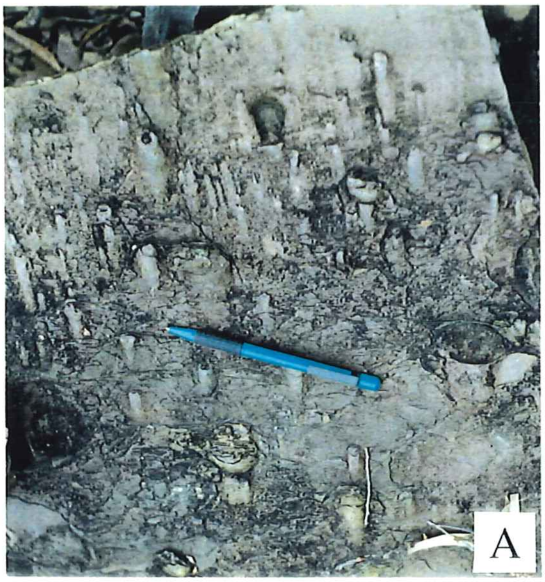
**Plate 2A:** Suspected sand volcanoes within a particular bed of Unit 2 at the Quarry (Locality C-2.8). Pencil is 14cm.

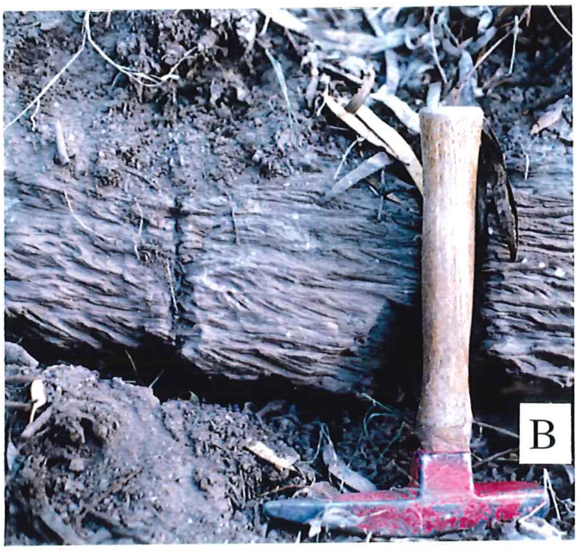
**Plate 2B:** Climbing ripples within Unit 5 west of Mount Brown (Locality C-3.9). Hammer is 40cm.

**Plate 2C:** Flute casts on the base of Unit 5 of the Wonoka Formation (locality C-3.9). Hammer is 40cm.

**Plate 2D:** Stylonodular bedding in Unit 7 of the Wonoka Formation (Locality B-4). Hammer is 40cm.

**Plate 2E:** Metre long Hummocky cross stratification seen within Unit 7 (Locality D-4.4). Hammer is 40cm.


A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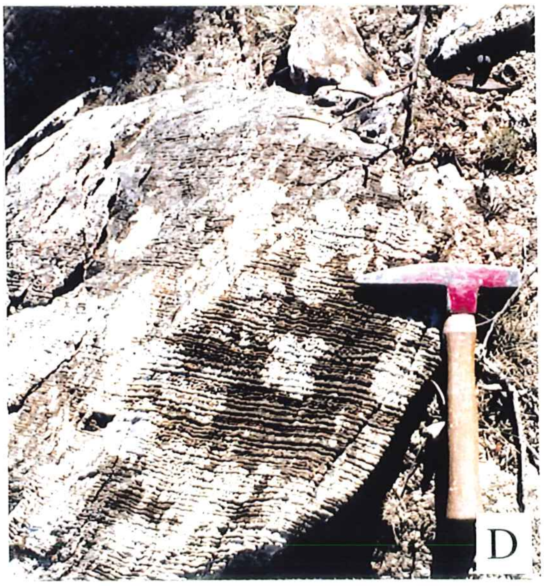

D


E

# CH. 3: STRUCTURE

The structure of the ABC Range Quartzite, Bunyeroo and Wonoka Formation will be of main concern here. A geological map (Appendix 1) was constructed from observations made in the field, and several cross-sections are presented (Figure 5). They display the general distribution of lithologies, geological boundaries, major faults and folds. Where evident, observations of bedding, cleavage and trend and plunges of the folds were collected.

The ABC Range Quartzite and Bunyeroo Formation sediments rapidly thicken to the east. It was calculated that the quartzite was approximately 700 metres at Saltia thickening to approximately 1400 metres at Richman Valley, some 12 kilometres to the east. The Bunyeroo Formation also follows this trend varying from approximately 300 metres at Saltia to ca. 800 metres at Richman Valley (Priess, 1987).

As seen from the geological map the canyon is located within broadly folded synclines commonly bounded either to the east or west by reverse faults. The folds trend in a north-south orientation with shallow plunges, perpendicular to the east-west direction of canyon incision.

## 3.1 Folds

The Waukarie Creek canyon has been broadly folded into a series of north-south trending folds. The ABC Range Quartzite appears to be tightly folded into chevron folds in Waukarie Creek (Plate 3B) suggesting that deformation was strong. From this outcrop it is assumed that vergence is towards the west due to asymmetrical disposition of the limbs of the anticlines. These folds were probably intensified as a result of the Delamerian Orogeny. A box fold also related to the compressional event was seen at locality (B-3.9). The styles of folds vary within the study area. Cross Section A - A'' shows that Richman Valley appears to be broad, open fold, whilst Saltia Syncline is a tight fold.

South of Devils Peak is a structurally complex zone. Folds in this area are dominantly upright and close to the south. Minor faults are observed trending at approximately 323°.

West of the major north-south active fault is a tightly folded area (locality D-3.2)(Plate 3A). The folds are z-shaped because of the south plunging antiform to the west of the photo.

## 3.2 Faults

North-south trending faults dominate the area. Most of the major faults are high angle reverse faults with the eastern side elevated. Mapping also revealed that there was a number of riedel faults at approximately 30° from the major faults. Cross Section B - B' reveals a major north-north-east trending westerly verging thrust fault (inclined at 55°E ) south of Saltia (locality B-1) causing a double ridge of ABC Range Quartzite.

The westerly directed thrusting and faulting seen within the study area have generally been associated with the first compressional stage of deformation of the Delamerian Orogeny (Preiss 1987; refer to Chapter 6.3.1).

## 3.3 Cleavage Development

Throughout the study area there appears to be only one dominant cleavage ($S_1$ ) trending at approximately north-south. Locally a second cleavage ($S_2$) is seen.

# PLATE 3

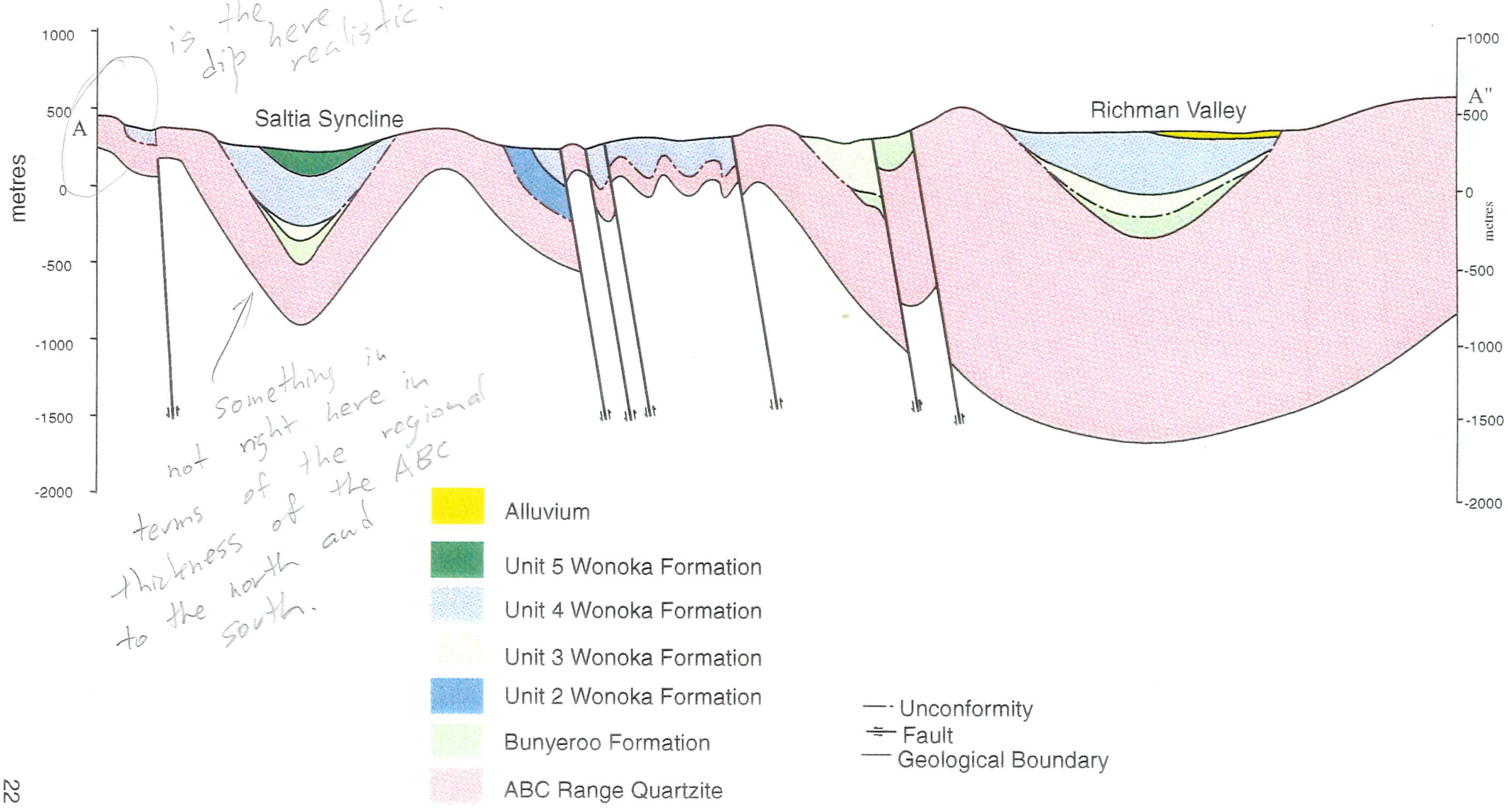
**Plate 3A:** Unit 4 of the Wonoka Formation. This area is tightly folded into a complex array of z- and chevron folds. View is looking south (Locality D-3.2).

**Plate 3B:** View looking north-west at chevron-drag folds within the ABC Range Quartzite along Waukarie Creek adjacent to a major reverse fault just off the photograph to the left (Locality D-3.9).


A


B

Figure 5A: Schematic Cross Section A-A' through the Waukarie Creek Canyon Complex Southern Flinders Ranges, South Australia.



is the dip here realistic?

something in not right here in terms of the regional thickness of the ABC to the north and south.

Figure 5B: Schematic Cross section through B-B' of Waukarie Creek Canyon Complex

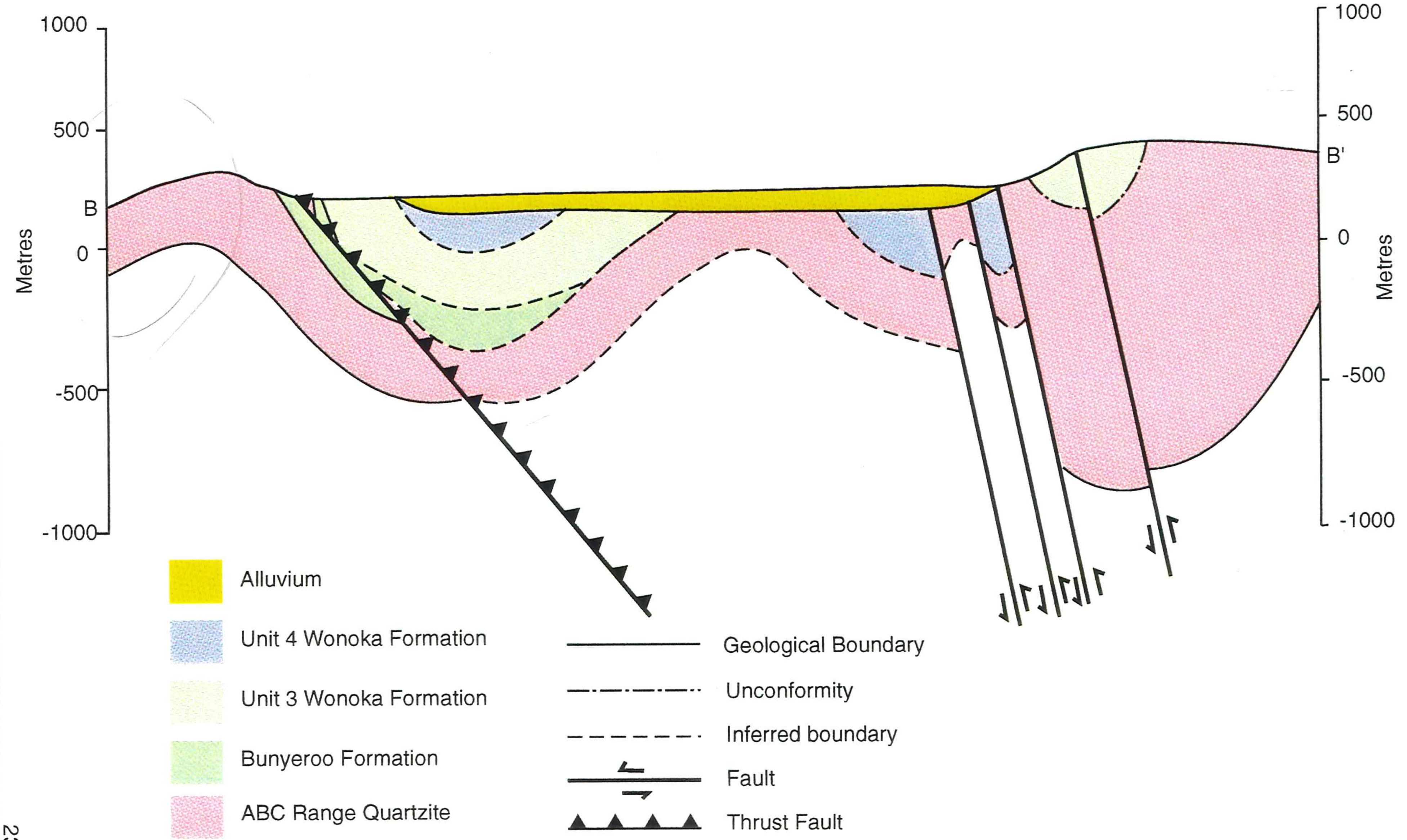
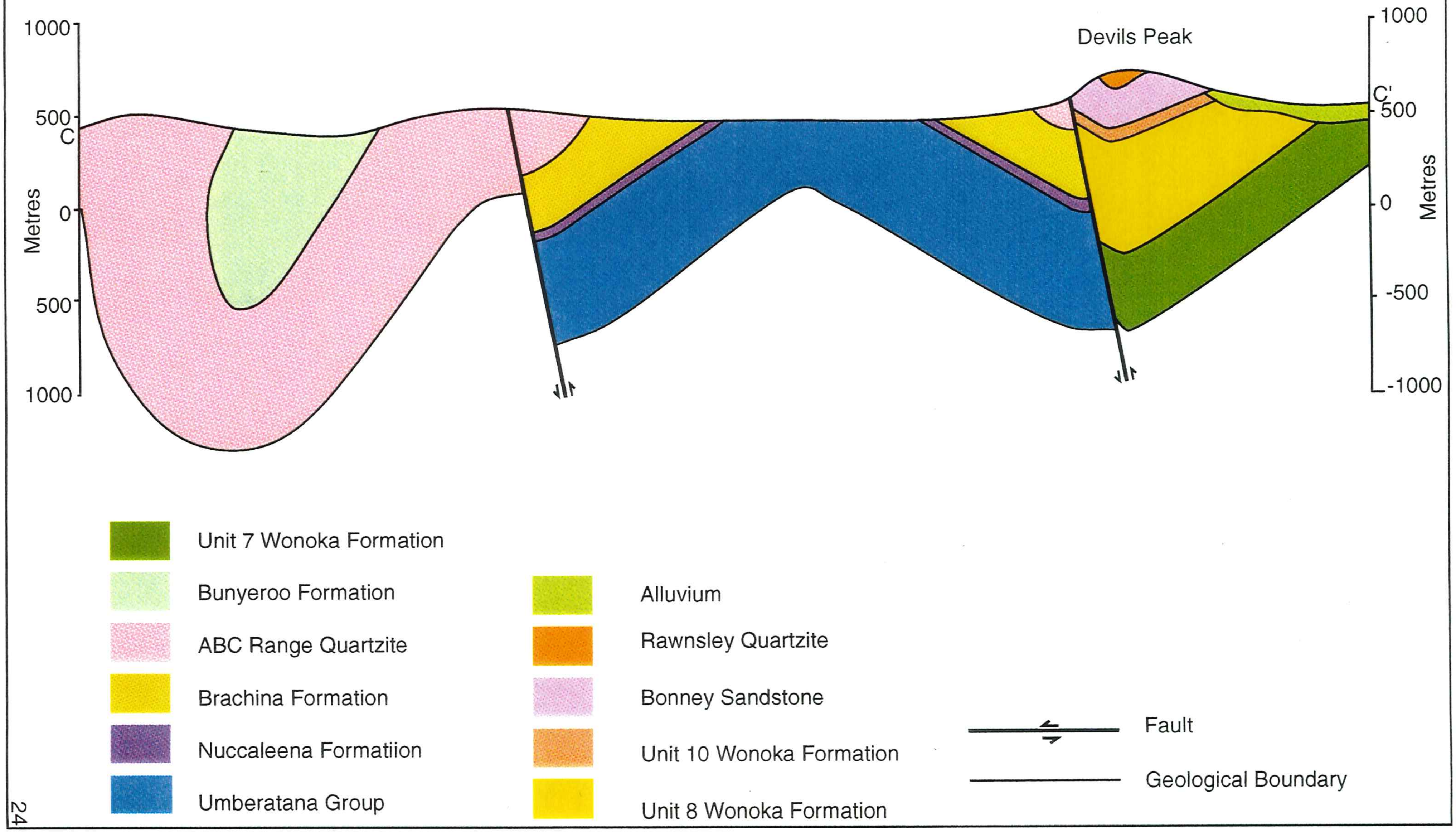


Figure 5C: Schematic Cross Section through C-C' of the Waukarie Creek  Canyon Complex



# CH. 4: MODELS FOR CANYON FORMATION

Two alternative theories concerning the formation of the canyons have developed over the years. Both models are summarised here.

## 4.1 Submarine Erosional Model

The incisions near the base of the Wonoka Formation were first described as being of submarine origin (Coates, 1964), implying that much of their erosion and infilling was submarine in origin and related to turbidity current activity, mass-movements or a combination of both of these process on the basin slope (von der Borch *et al.,* 1982; von der Borch *et al.*, 1985; Haines, 1987). This model requires a substantial seaward shift in coastal onlap to the shelf edge prior to canyon incision allowing canyon cutting clastics to be transported to a slope environment (von der Borch *et al.,* 1988). Widening of the canyon occurred by lateral erosion, whilst slumps were emplaced into the incisions which would account for the presence of wall rock clasts in the basal breccias (Eickhoff, 1988). In this setting the wallplaster was deposited under submarine conditions. After the canyon had been filled by marine onlap, deposition of the middle to upper units of the Wonoka Formation occurred.

## 4.2 Subaerial Erosional Model

An alternative theory to the deep water model implies that canyons were cut by subaerial erosion and were subsequently infilled by shallow marine sediments (Eickhoff, 1988; Eickhoff *et al.*, 1988; von der Borch *et al.,* 1988; DiBona *et al.*, 1990; Christie-Blick *et al.*, 1990; DiBona *et al.,* 1993; Dyson *et al.,* 1994 and Christie-Blick *et al.,* 1995). This theory requires a base level fall of the same order of magnitude as the depth of the actual canyon (von der Borch *et al.,* 1988). Therefore within the Waukarie Creek Canyon Complex a minimum base level fall of approximately 750 metres was required, this relative sea level fall would permit fluvial erosion to cut the canyons. Lateral erosion by the river system caused continued widening of the canyon.

A subsequent rise of relative sea level of the same magnitude was then required to account for the onlapping canyon fill by shallow marine waters (von der Borch *et al.,* 1988). The canyon thalweg was the main sediment conduit and the wallplaster developed subaerially as large portions of the canyon shoulders were exposed at the time of incision (Eickhoff, 1988).

### 4.2.1 Major Problems associated with the Subaerial Model

The main problem related to the subaerial model of canyon formation is the apparently large relative sea level fall which is required to produce these canyons. It has been stated by Eickhoff (1988) that sea-level fluctuations of a purely eustatic nature have a maximum range of the order of 200 m, which is clearly insufficient to satisfy the requirements of the subaerial erosional model. Therefore, a period of tectonic uplift or a combined uplift and eustatic sea level fall is required to account for the erosion of the canyons. Conversely, the alternative submarine erosional model requires only a small fluctuation in relative sea level to initiate submarine erosion of the canyons and a cutting event of this magnitude is commonplace for submarine canyons (Christie-Blick *et al.*, 1990).

### 4.2.2 Mechanisms possibly involved in lowering base level if a Subaerial Model of incision is adopted

#### *4.2.2.1 Regional Uplift*

A regional lowering of depositional wave base is required to account for the wide distribution of these canyons throughout the Adelaide Geosyncline if the subaerial model of formation is to be accepted. Regional uplift would likely have been of tectonic origin. Christie-Blick *et al.*, (1990) suggested that a possible mechanism for tectonic uplift involves inhomogeneous extension of the lithosphere, with the amount of extension balanced at all levels on a regional scale possibly by detachment faulting.

#### *4.2.2.2 Messinian-Style Sea level change in an Isolated Basin*

This is an alternative model to regional uplift involving the evaporitic lowering and subsequent rise of sea level. It is thought that when the Mediterranean dried out in the mid-Tertiary large channels below Israel and the Rhone and Nile Valleys formed subaerially and then filled gradually by the sea (von der Borch *et al.*, 1988). Although there is no evidence for correlative salt deposits associated with large scale evaporitic drawdown in the study area, Christie-Blick *et al.*, (1990) states that this mechanism accounts for extensive distribution of these Wonoka Canyons throughout the Flinders Ranges, and therefore this model can not be disregarded.

## 4.3 Comparison of the models

Both of these interpretations have important implications for possible eustatic sea level changes which have a bearing on the global correlation of the late Proterozoic depositional sequences (von der Borch *et al.,* 1988). Interpretation of the canyon fill facies is the key factor in determining which depositional model best represents the Waukarie Creek Canyon Complex. The application of either of the two models must require an increase in the rate of fall of eustatic sea level, a decrease in the rate of tectonic subsidence and/or localised tectonic uplift to initiate canyon erosion (von der Borch *et al.,* 1988). If a eustatic control was involved in canyon formation it would be suspected that a signal of this nature would leave its record in other late Proterozoic basins of this age throughout the world. If evidence of this nature at equivalent sequence boundaries is observed, then a eustatic control would be plausible. If such evidence was not discovered then a more local base level control perhaps one related to tectonic uplift must be considered (von der Borch *et al.*, 1988).

# CH. 5: MECHANISMS OF CANYON FORMATION

The canyons were cut and filled during the deposition of the late Proterozoic Wonoka Formation and were initially interpreted by Thomson (1969), von der Borch *et al.,* (1982), von der Borch *et al.,* (1985) and Jenkins and Gostin (1983) (cited in Christie-Blick *et al.,* 1990) as submarine canyons. However, the discovery of evidence of shallow-water and perhaps fluvial deposits at the lowest stratigraphic intervals of the infill cast doubt on this interpretation (Christie-Blick *et al.,* 1995). Eickhoff *et al.,* (1988) reported HCS and wave ripples near the bottom of the fill which have been taken to imply sedimentation above storm wave base (Christie-Blick *et al.,* 1990).

An alternative subaerial model was then adopted. Eickhoff (1988) was one of the first to put a strong argument across for this model. However, later von der Borch *et al.,* (1989) and others followed.

## 5.1 Erosional Unconformity

An erosional unconformity related to the cutting of the Wonoka Canyons was observed on the eastern side of the Saltia Syncline at location D-2.6 (Plate 4A). Down cutting occurred through the lower Wonoka units, Bunyeroo Formation and into the underlying ABC Range Quartzite. Cross section A - A'' (Figure 5A) shows that within the syncline at Richman Valley the canyon eroded within approximately 240 metres from the base of the Bunyeroo Formation implying that a minimum depth of 560 metres of sediment was removed. However, a minimum depth of 750 metres of sediment was estimated to have been scoured from the Bunyeroo Formation and ABC Range Quartzite at Saltia.

Above this unconformity, located within a conglomeratic horizon well rounded pebbles of unknown origin were observed (Plate 4F). V.A. Gostin pers. comm., (1997) indicated that it takes 10's of kilometres of transported for pebbles of this size to become rounded, implying these pebbles have been carried a distance from their source area: possibly fluvially.

Within the Waukarie Creek Canyon there is no evidence to indicate that canyon erosion was associated with multiple cutting events as suggested by Eickhoff (1988). A single event is assumed here.

## 5.2 Timing Of Incision

The best method for determining the timing of canyon incision is on the basis of the lithologies of the lithoclasts deposited within the canyon fill. Within the Waukarie Creek Canyon lithoclasts of different sizes of ABC Range Quartzite, Bunyeroo Formation and early Wonoka Formation are seen in the breccias along the thalweg of the canyon. This indicates that the incision occurred during early Wonoka time, probably some time within Unit 3 (R.J.F. Jenkins, pers. comm. 1997), however due to poor outcrop and alluvial cover it is unclear as to the exact stratigraphic position of the erosional contact.

## 5.3 Wall Plaster

A thin but extensive limestone unit commonly observed on the canyon walls above the erosional unconformity is often referred to as the wallplaster unit.

Stable isotope work and major element analysis was carried out, complete results are shown in Appendix 3. The stable isotope results ($\delta^{18}O$ = -17.543% PDB and $\delta^{13}C$ = -9.075% PDB) fall within the range indicative of a signature which suggests subaerial exposure. Eickhoff (1988) also carried out some analyses on the wallplaster which also produced very negative values for $\delta^{18}O$ (-15.43% PDB) and an average $\delta^{13}C$ of -8.086% PDB. It was also noted that these values are considerably more negative than the $\delta^{18}O$ values from the carbonates from the underlying marine Umberatana Group, hence supporting non-marine conditions for the precipitation of the limestone crust (Eickhoff, 1988). Eickhoff, (1988) recognised that this limestone unit could in fact have formed in an environment comparable to that for the development of calcrete with the canyon shoulders and large portions of the canyon walls subaerially exposed.

The samples would be expected to be high in manganese and have less than 1000 ppm strontium if they were formed subaerially (Y. Bone, pers. comm., 1997). XRF analysis revealed that there was both a high manganese and low strontium content of the wallplaster, possibly indicating a non-marine depositional environment.

Cathodoluminescences (CL) microscopy was carried out on the same wallplaster samples (Photo 1) and revealed that this unit had undergone a considerable amount of diagenetic alteration. It must therefore be concluded that even though the stable isotopes gave a potentially non-marine signature, this is the signature of the secondary process rather than the primary signature.

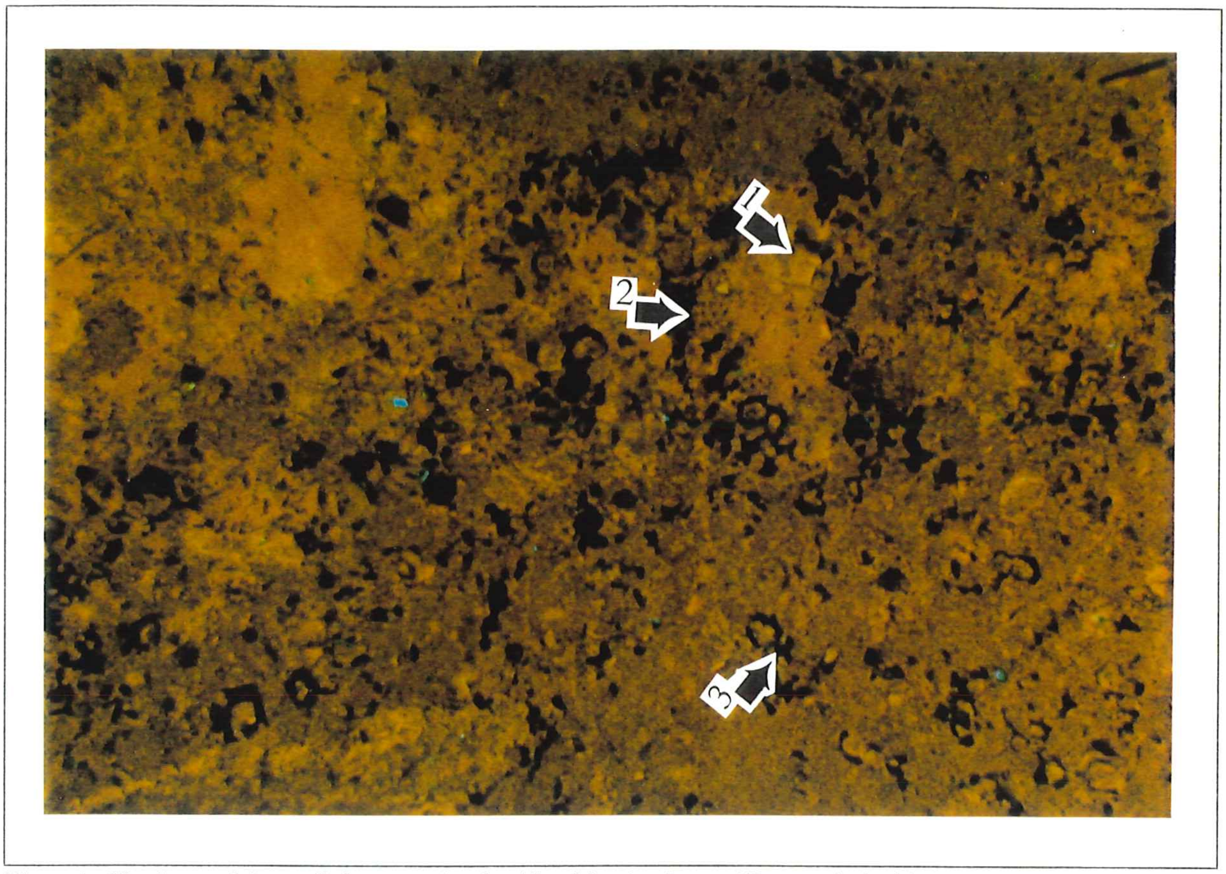


Photo 1: CL photo of the wallplaster under the 10x objective lense. CL revealed a high luminescence due to the high Mn content. The sample appears to be diagenetically altered. Arrow 1 shows a piece of dolomite, Arrow 2 points to possible organic matter, Arrow 3 is pointing to the black specs resembling the dissolving of the dolomite - "De-dolomitization".

## 5.4 Wall Rocks

The wall rocks of the Waukarie Creek Canyon consist of the ABC Range Quartzite, Bunyeroo Formation and the lowermost Wonoka Formation. These wall rocks are thought to have been consolidated prior to the canyon cutting event. Evidence for this was obtained from locality D 2.9 where the unconformity between the ABC Range Quartzite and the basal conglomerates of the Wonoka Formation was observed. The unconformity surface is sharp but not smooth. It appears that the ABC Range Quartzite was cut away leaving 'knobs' with a relief of about 14 cm (Plate 4B). The presence of these knobs provides good evidence that the ABC Range Quartzite was lithified prior to the canyon cutting unconformity. The presence of jointed Bunyeroo Formation clasts within the Olisthostrome unit of the Wonoka Formation (Plate 1D) also suggests lithified prior to the canyon formation.

l.c.

At the same locality above the unconformity a probable palaeosol was observed. This would indicate that water depths at the time of incision and fluvial action were minimal. This palaeosol may be correlated with a fossil soil horizon seen in Central Australia at the same

c l.c

resembling this palaeosol were observed within an olisthostrome unit near Mount Brown (locality A-3.5).

## 5.5 Wall Slump Horizons

Material was most likely transported into the incisions and deposited by slumping as the walls were cut during canyon development (von der Borch *et al.*, 1989). The slumping may have been emplaced in a submarine setting or subaerially. A wall slide was found in the canyon to the far east at B-4.2 (Plate 4C). The canyon wall sediments had rolled up into a ball as it slid down the side of the incision.

A gravity slump was observed west of Mount Brown within the Unit 3 horizon (Plate 4D). It appears that the slumping occurred prior to the consolidation of this unit as minor thrust planes in the underlying muds of Unit 3 were observed, possibly indicating little resistive strength in the sediments. A olisthostrome unit (Plate 4E) was also observed here as a result of the slumping. Subrounded to angular clasts of limestone and a yellow dolomite known to occur elsewhere (near Hawker) at the top of Unit 2 (R.J.F. Jenkins, pers. comm., 1997) were present.

A large piece of Gawler Range porphyry was found at a stratigraphic level equivalent to unit 3. The sample was thin sectioned (Appendix 4) to find evidence of shock lamellae and fractures to show that it was related to the Lake Acraman impact ejecta. However, no such features were seen. Due to the angularity and size of the specimen, it is interpreted that this porphyry and other smaller comparable clasts in older Wonoka Formation conglomerates most likely reflect fluvial transport from an adjacent part of the Gawler Craton.

## 5.6 Infill of Canyons

The presence of clast-supported conglomerates mantling the thalweg of the canyon incision, typical of a riverine system, followed higher in the canyon profile by matrix-supported olisthostrome and conglomerates (characteristic of submarine processes) suggests that the canyon fill sediments deepen upwards. Consequently, occurring coeval with the rise in sea level would be an increase in dominance of deeper water sedimentary structures, and a decrease in shallow water indicators such as HCS and ripple marks. The canyon fill has some attributes of 'event layers' but few, if any actually represent classic turbidites with Bouma Sequences.

All of the canyon fill facies appear to be highly cyclic (Christie-Blick *et al.*, 1995), and calcareous to some degree. The canyons are mainly infilled with hard limestone which contain many sedimentary structures, including ripple marks and isolated occurrence of HCS, both of which are indicative of sedimentation above storm wave base.

## 5.7 Conclusion

The abundance of wave generated and wave-modified sedimentary structure within the canyon fill and the presence of rounded pebbles and probable palaeosol near the base of the canyon favours the subaerial erosional model. More work on different wallplaster samples may substantiate or refute this interpretation.

# CH. 6: TECTONIC ACTIVITY

The tectonic setting of the Flinders Ranges is complicated by large-scale faulting and overthrusting especially at the margins of the Ranges (Glaessner and Parkin, 1958; Preiss, 1987).

## 6.1 Deformation Prior to Canyon Filling

A faulted contact between the ABC Range Quartzite and the basal Wonoka conglomerates was seen near Pichi Richi Pass (Figure 6). It is evident from this outcrop that there was deformation to the ABC Range Quartzite before the Wonoka Formation conglomerate was wrapped around it. The quartzite has minor thrust faults present resulting in two disharmonic folds plunging to the south, the direction of transport is west over east.

The presence of the Bunyeroo Formation in the major synclines within the Waukarie Creek Canyon Complex may also provide evidence for a prior deformational event. Mapping of the area (Appendix 1: Map 1) revealed that the outcropping Bunyeroo Formation sediments were restricted to the depressions at Saltia Syncline, Locality D-4 syncline and Richman Valley. An explanation for this phenomenon (Figure 7) would be that the ABC Range Quartzite and Bunyeroo Formation were folded prior to the deposition of the Wonoka Formation accounting for the preservation of the Bunyeroo Formation in this way . It would be expected that if the ABC Range Quartzite and the Bunyeroo Formation were flat lying at the time of Wonoka incision, Bunyeroo sediments would be preserved on the syncline walls as well.

This early deformation may possibly be related to the Beardmore Orogeny of Antarctica. The Beardmore Orogeny has been thought to have produced late Proterozoic deformation and magmatism in the Transantarctic Mountains, where an angular unconformity between a folded Precambrian suite and the overlying Lower Cambrian limestone was observed (Thomson *et al.*, 1991). Magmatic activity associated with this orogenic event has been dated at 620 - 680 Ma (Thomson *et al.*, 1991).

Alternatively, the Penguin Orogeny of Tasmania may have been responsible for this Precambrian deformation. Multiple folding affecting particularly the Oonah and Burnie Formations of the Rocky Cape Region and the metamorphism of the Arthur Lineament comprising of a belt of relatively high strain and greenschist to amphibolite facies metamorphism (Turner *et al.*, 1989) have been attributed to the Penguin Orogeny. This event

# PLATE 4

**Plate 4A:** The unconformity between the ABC Range Quartzite and the Basal Wonoka Conglomerate on the eastern side of Saltia Syncline (Locality D-2.9). Hammer is 40cm.

**Plate 4B:** The unconformity surface (Locality D-2.9). Notice the relief of approximately 14cm "knobs" scoured out of the ABC Range Quartzite by the canyon cutting event. Hammer is 40cm

**Plate 4C** Mud ball (Locality D-4.3). Notice the layers that have rolled up as it has slid down the canyon wall. Hammer head is 12cm.

**Plate 4D:** Slump horizon within Unit 3 of the Wonoka Formation, including a large subrounded clast of a Unit 2-like lithology (Locality A-3.4). Hammer is 40cm.

**Plate 4E:** Olisthostrome unit at the base of the slump horizon (Locality A-3.4). Yellow dolomite clasts suggest that Unit 2 was lithified prior to canyon cutting. Hammer is 40cm.

**Plate 4F:** Contact between ABC Range Quartzite and the Wonoka Formation. Well rounded pebbles are suggestive of fluvial deposition (Locality A-3.5). Hammer is 40cm.


A


B


D

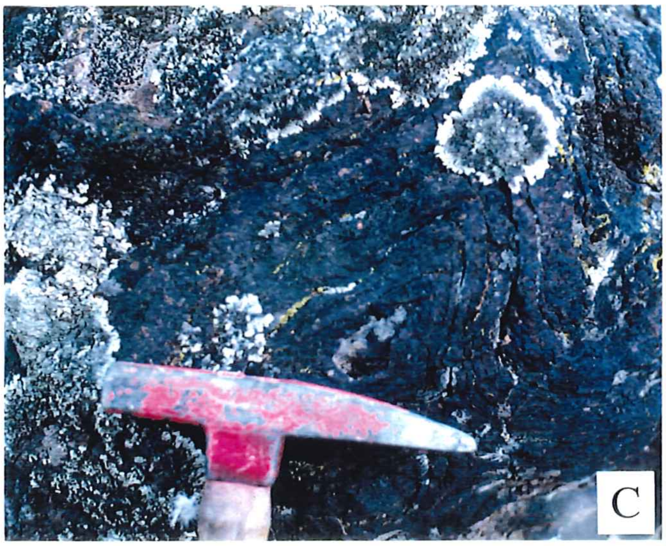

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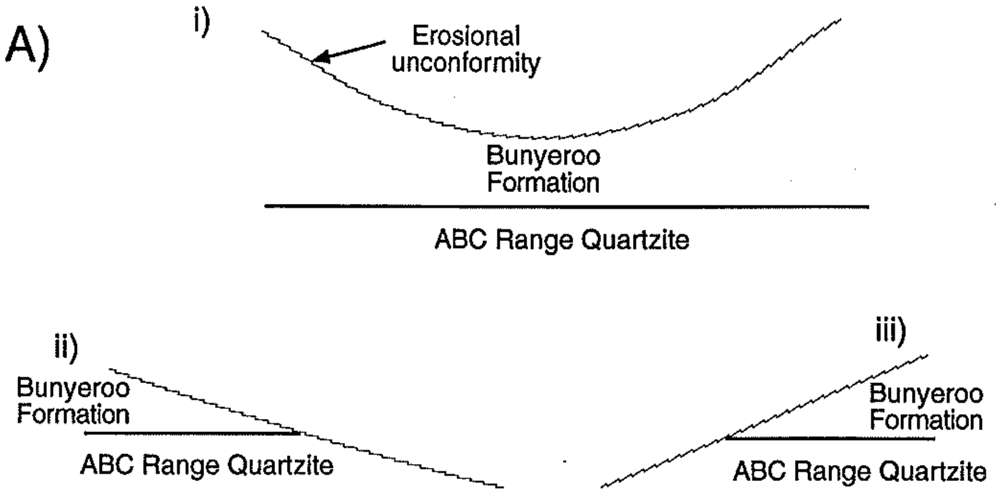
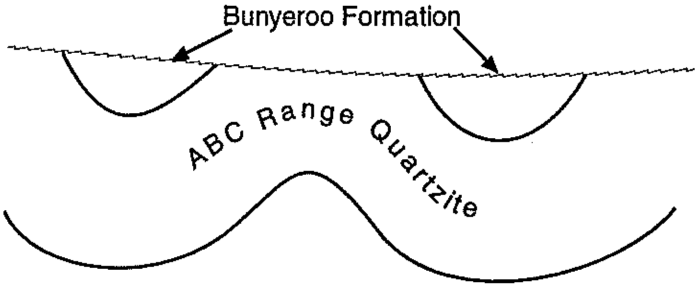
Figure 7: Possible evidence for deformation to the ABC Range Quartzite and the Bunyeroo Formation prior to Wonoka Deposition.



If both the ABC Range Quarzite and the Bunyeroo Formation were flat lying at the time of incision, it would be expected that the Bunyeroo sediments would appear on the sides on the syncline, as shown in A ii and iii.

B) Alternatively, the ABC Range Quartzite and the Bunyeroo Formation may have been folded prior to the deposition of the Wonoka Formation.



This implies that the canyon may have used the synclines as templates for erosion. Incision in places may have eroded out the Bunyeroo sediments and cut down into the Quartzite,as in D-3, or may have preserved the Bunyeroo sediments at the base as at the D-4 syncline. This model would explain the absence of the Bunyeroo Formation on the walls of the syncline and explain its occurrence at the base.

(Not drawn to Scale)

is thought to have been dated from slates of Burnie and Oonah Formations falling within the range of 630-690 Ma. Isotopic ages gained from slates, amphibolites and the Cooee Dolerites of this region have dated the Penguin Orogeny beginning at about 750 Ma and lasting some 100 Ma (Adams *et al.,* 1985).

## 6.2 Syndepositional Tectonism

Palaeocurrents were measured and the results are seen in Figure 8. It is evident from these results that there are numerous reversals of current directions throughout the canyon. If submarine processes were responsible for the formation of the canyon, a unidirectional prominent thalweg current trend would be expected, with possible downslope currents at the canyon sides (Jansyn, 1990). However the fluctuating current directions observed may be suggesting that at the time of the formation of the canyon that tectonism was affecting sedimentation. This allows ponding to occur and subsequently the palaeocurrents are randomly orientated.

The slumping also evident north-west of Mount Brown as discussed in Chapter 5.5 may have also occurred as a direct result of this syndepositional tectonism.

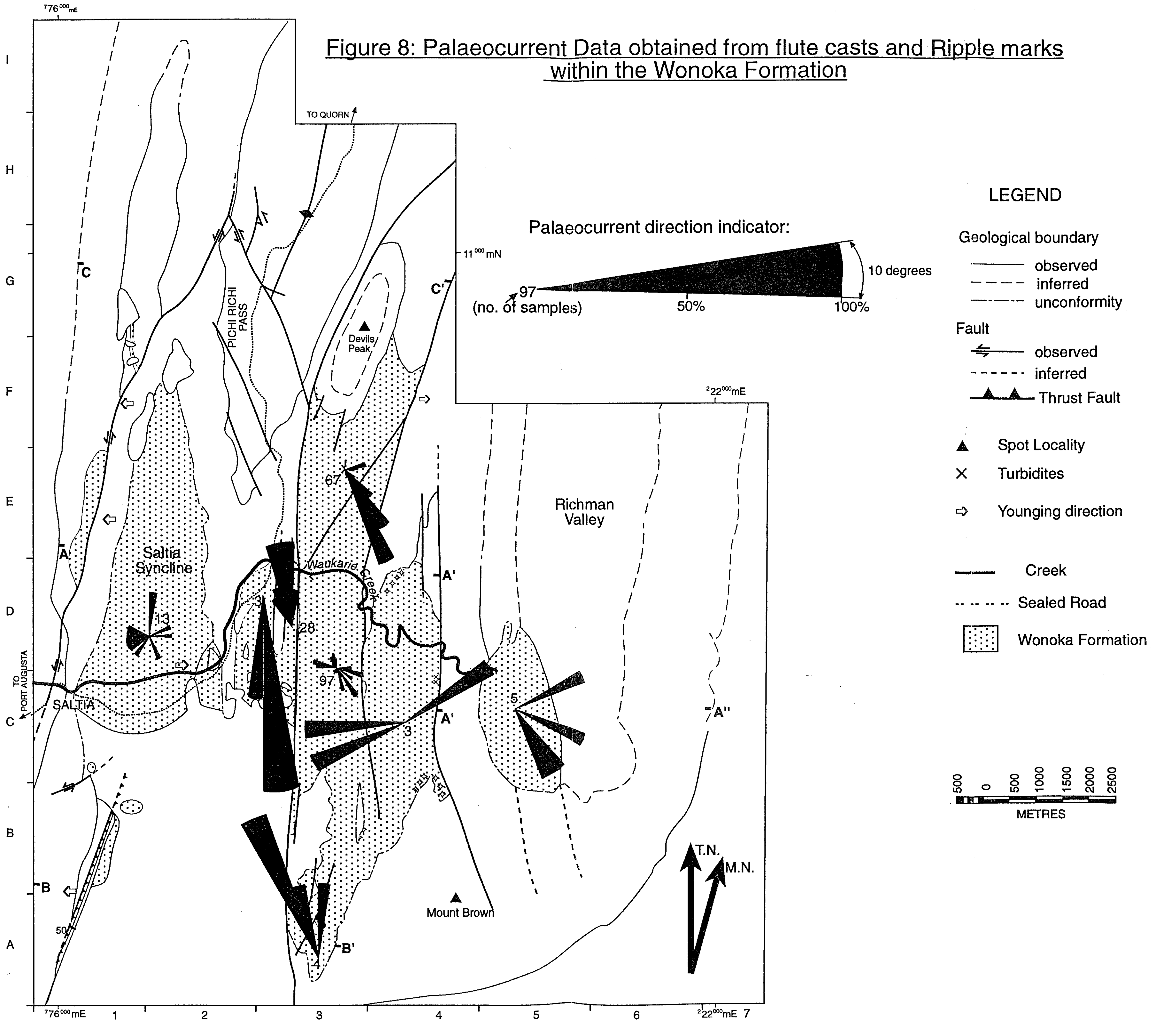
Jansyn (1990) suggests that all canyons may have initially began with extensional tectonism along lineaments created when blocks were downfaulted and tilted, and adjacent crustal blocks uplifted as a result of thermal disequilibrium,

## 6.3 Post-Depositional Tectonism

### 6.3.1 Delamerian Orogeny

The Delamerian Orogeny (named by Thomson, 1969, cited in Preiss, 1990) bought an end to Cambrian deposition in the Adelaide Geosyncline. There are two separate compressional events recognised to be associated with the Delamerian Orogeny in the Flinders Ranges. The first early event was produced by east to west compression resulting in linear north-south folds which are seen as relatively tight folds in the southern Flinders Ranges. The later north-south compressional phase had little to no effect on the southern Flinders Ranges, but produced strong east-west folds in the Northern Flinders Ranges and north-east trending folds in the Nackara Arc region (Lemon, 1996).

# Figure 8: Palaeocurrent Data obtained from flute casts and Ripple marks within the Wonoka Formation



### 6.3.2 Tertiary Movements

The compressional folding of the Delamerian Orogeny was reactivated at the beginning of the Tertiary era, when the pre-Tertiary land surface began to rise. A period of subsidence in the early and middle Tertiary was followed by further uplift which appears to have reached its maximum at the end of the Tertiary time. This uplift continued throughout Quaternary time as evidenced by faulting which affects Pleistocene and later alluvial deposits (Glaessner and Parkin, 1958), resulting in the uplift of the Flinders and the Mount Lofty Ranges to their present physiogeographic position.

# CH. 7: CONCLUSIONS

The major findings within this study associated with the Waukarie Creek Canyon Complex are:

- Within the Waukarie Creek Canyon Complex canyon observations of clasts within the canyon fill suggest incision of the canyon occurred at a stratigraphic position within Unit 3 of the Wonoka Formation. Incision scoured away sediments of the underlying ABC Range Quartzite, Bunyeroo Formation and the lower Wonoka units to a depth of approximately 750 metres in Saltia Syncline. Evidence was found that the wall rocks were well lithified prior to the erosional event. Eickhoff (1988) suggested that canyon incision may have been related to multiple events but this theory is not supported here.

- Rounded pebbles within the conglomerates, probable palaeosol, the lack of definite submarine sedimentary structures as well as the presence of typically shallow water indicators, for example hummocky cross stratification and ripples suggests that a subaerial model is appropriate. The respective occurrence of the clast-supported and matrix-supported conglomerates and olisthostrome units suggest a deepening upward regime for the canyon fill.

- The presence of reversals in current direction, slumped features possibly related to tectonic activity and observations of a prior deformation in the ABC Range Quartzite and Bunyeroo Formation could possibly indicate that tectonic processes may have been responsible for the uplift of the area allowing the canyons to be cut by the action of rivers.

- The Precambrian tectonic event may be correlated to the Beardmore Orogeny of Antarctica or the Penguin Orogeny of Tasmania. However, more detailed study would be needed to be substantiate this observation.

- The model of formation of the canyon involves the initial cutting by a meandering river, subsequent entrenchment of the river system during uplift and marine backfilling of the canyon during a period of subsequent submergence (Eickhoff, 1988).

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# APPENDICES

# Appendix 2: Laboratory results from the Wallplaster Unit of the Wonoka Formation.

## A2.1 XRD Analysis

A representative section of a sample was selected, crushed and milled. Five drops of deionised water was mixed with a microspatula full of the sample. This mixture was spiked with about one third volume of milled quartz and ground into a thin slurry. This slurry was smeared onto a glass slide and left to dry.

Analysis of the samples took place using a Phillips PW 1050 Diffractometer, using a graphite monochromator and cobalt Ka radiation source with a wavelength of 1.790Å.

The GW BASIC program X PLOT was used to identify the constituent minerals. To quantify the Mg content of the calcite a Mg CALC program was used.

Analysis of the samples by this method revealed that calcite was dominant with minor quartz and plagioclase feldspars and trace amounts of dolomite present in the samples. The calcite has 2.5 mol% $MgCO_3$ (ie. low-Mg calcite).

## A2.2 XRF Analyses - Major Elements

Samples were selected, then crushed using the jaw crusher reducing the size of the sample to gravel sized pieces. The samples was then milled using a tungsten carbide mill vessel to reduce it to a fine powder suitable for analysis.

The appropriate equipment was then scrubbed and dried. The sample was placed into vials and heated in the oven at 110° for a few hours to evaporate off the absorbed moisture. Subsequently, the sample was weighed into alumina crucibles and ignited in a furnace at 960° overnight to yield the loss on ignition values.

One gram of the ignited sample material was then weighed and 4 grams of flux was added to it. This mixture was later fused using a propane-oxygen flame at approximately 1150° and placed into a preheated mould to produce a glass disc for analysis.

Analysis then took place using a Phillips PW 1480 X-ray Fluorescence Spectrometer, and an analysis program calibrated against several international and local Standard Reference Materials (SRM's). A dual-anode (Sc-Mo) X-ray tube was used, operating at 40kV, 75mA.

The results over page are presented on a "dry basis" in tabular form as oxides. The resulting data has been collected from the whole sample including any organic material that may have been present.

| Sample Name | $S_iO_2$% | $Al_2O_3$% | $Fe_2O_3T$% | Mn% | Mg% | CaO% | $Na_2O$% | $K_2O$% | $TiO_2$% | $P_2O_5$% | $SO_3$% | LOI% | Total % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KMWP | 8.91 | 1.92 | 0.60 | 0.45 | 2.07 | 44.67 | 0.98 | 0.24 | 0.12 | 0.11 | 0.08 | 37.84 | 97.99 |
| A1WP | 8.11 | 1.57 | 0.57 | 0.08 | 1.49 | 45.68 | 0.86 | 0.24 | 0.11 | 0.14 | 0.05 | 38.70 | 97.60 |
| B6WP | 8.56 | 1.45 | 0.71 | 0.05 | 1.85 | 45.43 | 0.64 | 0.31 | 0.12 | 0.17 | 0.07 | 38.61 | 97.95 |
| D12WP | 14.49 | 1.69 | 1.01 | 0.16 | 1.77 | 42.49 | 0.74 | 0.20 | 0.11 | 0.10 | 0.06 | 35.63 | 98.45 |
| F15WP | 10.51 | 2.35 | 0.46 | 0.38 | 1.92 | 43.18 | 1.40 | 0.11 | 0.15 | 0.12 | 0.06 | 37.17 | 97.81 |
| V3WP | 9.98 | 2.13 | 2.21 | 0.14 | 1.43 | 43.61 | 0.83 | 0.40 | 0.15 | 0.13 | 0.25 | 36.97 | 98.22 |
| V12WP | 9.28 | 1.57 | 0.72 | 0.06 | 1.83 | 45.03 | 0.71 | 0.19 | 0.13 | 0.10 | 0.10 | 38.16 | 97.88 |
| WP1 | 6.38 | 1.59 | 0.73 | 0.06 | 1.68 | 46.72 | 0.57 | 0.40 | 0.12 | 0.14 | 0.05 | 39.44 | 97.88 |

XRF results from the Wallplaster unit of the Wonoka Formation.

## A2.3 XRF Analysis - Trace Elements

About 10 grams of the powdered sample was mixed thoroughly with about 1ml of a binder solution, and pressed to form a pellet. The pellet was then allowed to dry at room temperature for a day, and heated in the oven at 60° for 1 to 2 hours ensuring that the sample is completely dry.

The samples were analysed again using the Phillips PW 1480 X-ray Fluorescence Spectrometer. Several analysis programs were applied covering 1 to 7 suites of trace elements, with conditions optimised for the element being analysed. The programs were calibrated against many international and local SRM's. The dual-anode and a Au tube were used for the analysis. Matrix corrections were made using the Compton Scatterpeak or mass absorption coefficients calculated from the major element data.

The results are present in tabular form and expressed as ppm.

| Sample Name | Zr ppm | Y ppm | Sr ppm | Rb ppm | U ppm | Th ppm | Pb ppm |
|---|---|---|---|---|---|---|---|
| KMWP | 52.9 | 11.6 | 484.7 | 12.2 | 1.1 | 6.3 | 3.5 |

## A2.4 Stable Isotope Analysis

Approximately 15 micrograms of the crushed and milled sample was placed into small metal buckets. The buckets were then placed on the carousel of the Optima Mass Spectrometer ready for analysis. The position and weights of the samples was programmed into the computer, and the analysis began.

The reference gas used was $CO_2$. Each sample was automatically dropped into the same vessel of acid at approximately 12 minute intervals. The gas released is then automatically transported to the spectrometer. The computer calculated and plotted the results.

| **Sample Name** | **$\delta^{13}C$ (PDB)** | **Precision** | **$\delta^{18}O$ (PDB)** | **Precision** |
|---|---|---|---|---|
| KMWP | -9.075 | 0.005 | -17.543 | 0.009 |
| A1WP | -8.498 | 0.004 | -15.651 | 0.005 |
| B6WP | -8.863 | 0.007 | -14.618 | 0.012 |
| D12WP | -8.640 | 0.003 | -15.345 | 0.007 |
| F15WP | -7.854 | 0.007 | -15.378 | 0.013 |
| V3WP | -8.839 | 0.009 | -10.220 | 0.009 |
| V21WP | -8.550 | 0.005 | -17.358 | 0.009 |

## A2.5 Cathodoluminescence (CL)

Thin section samples were cut at 30µ and polished suitable for CL analysis. The microscope used was the Technosyn Cold Stage Luminoscope and photographs taken using the Kodak Ektopress PC 1600 film. Operating conditions were recorded for each photo. The resultant photomicrographs are present in Photo 1..

# Appendix 3 Thin Section Description

Gawler Range Porphyry

This sample appears to be highly altered. \

*Crystals*

Quartz: Most of the crystals are subangular to subrounded with large reaction rims. Fluid inclusions were seen.

Makes up about 20% of the whole rock

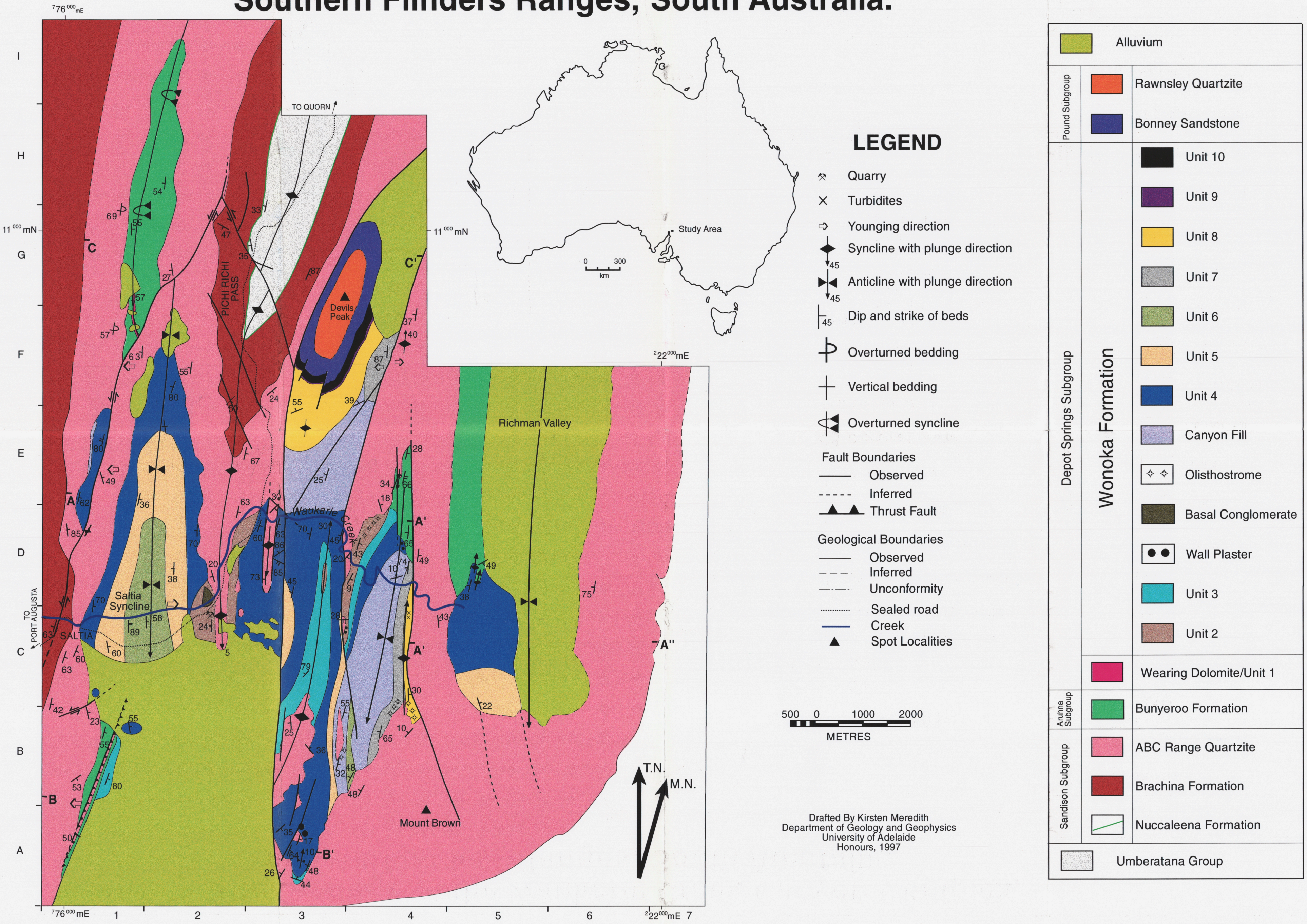
Feldspars: The most common felspar observed was plagioclase. These crystals are angular, highly altered, and make up about 10% of the composition of the sample. Microcline made up about 5% of the sample.

*Matrix*

The matrix consists of fine grained red material.

The makes up 70% of the sample.

# MAP 1: The Geology of the Waukarie Creek Canyon Complex, Southern Flinders Ranges, South Australia.



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