THE GEOLOGY OF THE GAWLER RANGE VOLCANICS IN THE TOONDULYA BLUFF AREA AND U-PB DATING OF THE YARDEA DACITE AT LAKE ACRAMAN

by

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ABSTRACT

At Toondulya Bluff a sequence of "older" Gawler Range Volcanics dip in an easterly direction beneath the overlying Yardea Dacite, and are intruded by the comagmatic Hiltaba Granite. The volcanics occur as a series of tuffs and lava flows.

Geochemical evidence suggests these volcanics are related to each other by fractional crystallisation, with plagioclase, clinopyroxene, k-feldspar and titano-magnetite, and accessory zircon and apatite controlling differentiation trends. The Si-rich Hiltaba Granite and Yardea Dacite formed from the final, highly fractionated melts.

Geothermometry suggests the volcanics and granite crystallised at temperatures within the range of 680^{o} - $850\,^{o}$C.

The initial magma from which the lithologies were derived, was formed by partial melting of a lower crustal source probably of granulitic composition.

Lake Acraman is believed to have been a site of meteoritic impact in the late Proterozoic ($\sim$600 Ma ago). Fragments of dacitic ejecta have been identified within the Bunyeroo Formation, Flinders Ranges and dating of these fragments gives an age of c.1575 Ma using single zircon ion probe dating techniques (Gostin et al in prep).

U/Pb dating of the Yardea Dacite at Lake Acraman reveals it to be of comparable age to these fragments (1603-1631 Ma).

The lower intercept of the discordia line reveals there has been no resetting of the U/Pb system in response to the postulated meteoritic impact.

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OUTLINE OF THE THESIS

The aims of this thesis were twofold. Firstly, to map the Toondulya Bluff area in detail, obtain an understanding of its geology using geochemical and petrographic data and to propose a petrogenetic model for the lithologies from the results obtained.

The second aim of the project was to obtain a U-Pb date for acid volcanics on the western margin of Lake Acraman and compare this with dates obtained by Compston (Gostin et al in prep) using single zircon techniques, on fragments of suspected Gawler Ranges Volcanics within the Bunyeroo Formation of the Flinders Ranges. The Toondulya Bluff area was chosen for a detailed geochemical study rather than the Lake Acraman area, from which the sample for dating was obtained, because it was known to contain a variety of different igneous rock types and apart from the regional mapping of Blissett in 1982 for his compilation of the Wirrulla 1:100,000 sheet, no work had been done in the region.

PART 1

THE GEOLOGY OF THE GAWLER RANGE VOLCANICS IN THE TOONDULYA BLUFF AREA

CHAPTER 1 : INTRODUCTION

1.1 LOCATION OF THE STUDY AREA

The study area is situated at Toondulya Bluff on the western margin of the Gawler Ranges which are surrounded to the south and west by Quaternary sands and salt lakes. The map area, approximately 20 km^2 lies on the property of Kondoolka Station and is approximately twelve kilometres northwest of Hiltaba Homestead. The low, rounded hills of the area attain a maximum elevation of 240 metres above the surrounding plains
(ie 390 metres above sea level).

1.2 PREVIOUS INVESTIGATIONS

A.H. Blissett of South Australian Department of Mines and Energy, has worked on the Gawler Ranges since the early 1970's. In 1982, he mapped the Toondulya Bluff area as part of his regional work in compiling the Wirrulla 1:100,000 preliminary map sheet. This project follows up with a more detailed geological investigation.

In 1980 C.Giles completed postgraduate studies on the geochemistry of volcanic and plutonic rocks exposed in the Lake

Everard district to the north of Toondulya Bluff. The rocks he analysed bear some resemblence to those outcropping at Toondulya Bluff (Blissett 1975).

1.3 METHODS OF STUDY

(1) A black and white aerial photograph of 1:40,000 scale obtained from the Department of Lands, and enlarged to approximately 1:12,000 was used in the mapping of the study area.

(2) 20 thin sections were described

(3) 21 representative samples were analysed for major and trace element abundances

(4) Energy dispersive electron microprobe analysis was carried out on 7 samples.

(5) Use of program LSMIX to model fractional crystallisation processes pertaining to the volcanics and Hiltaba Granite

CHAPTER 2 : FIELD RELATIONSHIPS

2.1 REGIONAL GEOLOGY

The Gawler Craton is the extensive shield area which comprises much of the Eyre Peninsula. With the Willyama Block, it forms the Gawler Province which is part of the Early and Middle Proterozoic superprovince or chelogen (Rutland et al 1981). The Gawler Craton consists of Archaean to Early Proterozoic gneisses, granites and metasediments and Middle Proterozoic sediments, volcanics and granites (Parker et al 1981). It is bound to the east by the Torrens Hinge Zone and sediments of the Adelaide Geosyncline, to the north and northwest by the Musgrave Orogenic Domain and to the southwest by faulting associated with the Mesozoic separation of Australia from Antarctica (Parker et al 1981).

Two major periods of orogenesis and magmatism have been defined for the Gawler Craton. The earlier episode known as the Sleafordian Orogeny spanned the period between 2500 and 2300 Ma and was followed by a quiescent interval of approximately 500 Ma (Webb 1979). The second active interval known as the Kimban Orogeny contained several magmatic and metamorphic phases spanning the interval 1800-1400 Ma.

The Gawler Range Volcanics postdate main tectono-thermal events affecting the Gawler Craton, having erupted at the close of the Kimban Orogeny over the nearly consolidated Gawler Craton. The Gawler Range Volcanics outcrop over a 250,000 km area in the Northern Eyre Peninsula. They are thought to have erupted as a series of ash falls and as lava flows or domes. The Hiltaba Granite and associated rhyolite or rhyodacite dykes intrude the western flanks of the volcanic pile in the Gawler Ranges.

The volcanics have been divided into "younger" and "older" sequences (Blissett and Radke 1975). The younger sequence which comprises the greater part of the Gawler Range Volcanics in volume, is called the Yardea Dacite and is a porphyritic dacite grading to rhyodacite. This unit is flat lying or gently undulating except around the margins where it is upturned , and assemblages of "older" Gawler Range Volcanics are exposed at a number of localities. (Blissett and Radke 1975)

At Toondulya Bluff a sequence of "older" dacites, rhyodacite and rhyolite is in contact with a "younger" massive porphyritic rhyodacite which comprises part of the Yardea Dacite. The comagmatic Hiltaba Granite also intrudes at this locality.

2.2 LITHOLOGICAL DESCRIPTIONS

2.2.1 Sparsely porphyritic dacites

The oldest exposed unit in the Toondulya Bluff area is a brown dacite which is fine grained and exhibits a fine, planar lamination. It is characterised by a paucity of phenocrysts. The base of this brown sparsely porphyritic dacite (s.p.d.) is concealed by Quaternary deposits.

It is conformably overlain by a petrographically and geochemically similar dacite which was recognised as a separate cooling unit in the field due to its difference in colour. It is black and varies from sparsely porphyritic to aphanitic in texture. At one locality, the fine lamination within the black s.p.d. is vertical and upright flow-folding may imply this is a small dyke, formed as magma is injected into the extrusive unit (Plate 2). Alternately the distortion of the layers at this locality and slump structures elsewhere at the base of the unit may represent basal surge deposits.

At the contact, the brown and black sparsely porphyritic dacites interlayer and merge into each another (Plate 5) suggesting that they extruded contemporaneously rather than as successive flows, with each unit tapping a different part of the same magma reservoir.

The sparsely porphyritic dacites are similar to the Childera Dacite and Mangaroongah Dacite of the Lake Everard area 35 km to the north of Toondulya Bluff (Blissett 1975), which are considered to be welded ash-flow tuffs (Giles 1980). There is no evidence however, that the sparsely porphyritic dacites of the Toondulya Bluff area are also of pyroclastic origin, although a consistent planar lamination in the units, and the presence of distorted layers at the base of the black s.p.d. may favour the units being tuffs rather than lava flows.

The top of the black s.p.d. is in sharp contact with the overlying red s.p.d. which is a homogeneous, massive unit displaying little evidence of layering. At the base of the red s.p.d. small, lenticular units extend approximately 1000 metres along the strike of the layers, pinching in and out and attaining a maximum thickness of 0.5 m (Plate 2). These units are highly porphyritic, containing up to 80% phenocrysts, and xenoliths of the underlying dacites (Plate 4). Petrographic evidence has revealed the presence of shards in the chlorite rich matrix, implying these units are poorly welded tuffs .

The sharp contact at the base of the red s.p.d. may suggest a period of quiescence prior to the eruption of this unit, during which the main conduit closed off. When volcanic activity resumed, pressure from volatile components within the magma caused explosive volcanism and pyroclastics were deposited prior to extrusion of the main magma body.

2.2.2 Porphyritic Rhyodacite

Field evidence suggests that the rhyodacitic unit overlying the sparsely porphyritic dacites, extruded as a lava dome. The units at Toondulya Bluff dip predominantly in an easterly direction (Figure 1), but within the rhyodacitic unit the structure is more complex and suggests the existence of a domal feature. The dome is composed of rhyodacitic lavas and tuffs which show zones of contorted flow folding and flow brecciation. These features are characteristic of very viscous magmas with restricted flow, forming dome shaped piles around the central vent (Plates 6 & 7) . Some of the rocks which show contorted flow banding also display evidence of pyroclastic origin (Plate 7). These are most likely to be rheoignimbrites (Rittman 1958) formed when tuffs erupt onto a slope, fluidise and flow as a mass following deposition.

Bands of amygdaloidal lavas within the rhyodacite represent the upper, more gaseous zones of cooling units.

2.2.3 Rhyolite

Overlying the rhyodacite is a rhyolite lava which can be easily recognised in the field due to its abundant quartz phenocrysts approximately 1-2 mm in diameter. The rhyolite displays a flow banding in places and must consist of several individual flows. This is indicated by cannibalism of flows, with younger flows ripping up large portions of older, nearly solidified flows, and incorporating them into their structure.

Only very brecciated material and rhyolite scree lie between the rhyodacite and rhyolite. There is no preservation of the contact. It is possible that this may be a faulted contact and preferential weathering of brecciated material within the fault zone has occurred. There is no means of confirming the presence of a fault however, as evidence of displacement is very difficult to obtain from the extremely weathered rocks in the area.

2.2.4 Yardea Dacite

Overlying this sequence on the eastern side of the area is a dacite known as the Yardea Dacite. It differs from the "older" Gawler Range Volcanics in that it is highly porphyritic and has a high silica content (>73% compared with 64 - 69% for the sparsely porphyritic dacites). Slow cooling conditions within thick ash sheets would explain the coarse texture of the rock. At Toondulya Bluff the phenocryst assemblage of the Yardea Dacite is dominated by k-feldspar with only minor plagioclase, and primary and secondary amphiboles, suggesting the Yardea Dacite is rhyodacitic rather than dacitic in composition at this locality. Abundant mafic xenoliths are present within the unit.

At the base of the Yardea Dacite is a black dacite approximately 2 metres thick, containing fresh clinopyroxene and plagioclase, which is absent in the overlying brown-coloured Yardea Dacite. This black dacite has been documented by Giles (1980) in the Lake Everard district and has been recognised elsewhere in the Gawler Ranges (Blissett and Radke 1975). The black basal dacite is finely laminated and phenocrysts are fragmented indicating a pyroclastic origin.

The main unit of the Yardea Dacite is mostly lacking any internal structure. In places, patches of finer grained material are found and the presence of shards within these units attests to their pyroclastic origin. They probably represent less welded material within the densely welded tuffaceous unit.

2.2.5 Hiltaba Granite

The Hiltaba Granite which intrudes across the strike of the volcanic pile contains several phases, the predominant phase being a medium grained, pink coloured granite. This has been intruded in places by a white microgranite and a red, coarse grained, almost pegmatitic, biotite-rich granite.

Field relationships revealed the coarse, red granite intruding the white microgranite but also containing xenoliths of the microgranite, suggesting these two phases intruded contemporaneously.

2.3 STRUCTURAL INVESTIGATIONS

All rocks within the Toondulya Bluff area have been affected by a prominant rectangular joint pattern which allows easier weathering and erosion of the volcanic pile (Plate 1). A major set of vertical joints strike northeasterly and northwesterly and a third set strikes north-south and dips approximately 10° to the east (Figure 2).

This is consistent with the prominant rectangular regional joint pattern of the Gawler Range Volcanics. It has been suggested that this pattern was inherited from ancient lineaments (Blissett and Radke 1975).

Since the eruption of the Gawler Range Volcanics, the Gawler Craton has remained essentially stable and unburied, unaffected by subsequent orogenic events. As a result, the Gawler Range Volcanics have undergone little deformation and no metamorphism (Blissett and Radke 1975). At Toondulya Bluff however, the "older" Gawler Range Volcanics are upturned and dip towards the east.

Doming by extrusion of the Hiltaba Granite where in contact with the "older" volcanics is also suggested by the near-vertical nature of layering surrounding the granite (Figure 1).

CHAPTER 3 : PETROGRAPHY

3.1 INTRODUCTION

Detailed thin section descriptions of lithologies of the Toondulya Bluff area are given in Appendix 1 which also includes a sample locality map. This discussion summarises conclusions drawn from examination of these thin sections. Where mineral compositions are stated, they were determined by electron microprobe analysis.

The names given to the lithologies are field terms only, established by Blissett in 1982 when he mapped the area, and based on the relative proportions of plagioclase, potash feldspar and quartz in the phenocryst assemblage. According to the chemical classifications of Streckeisen (1976) and O'Connor (1965) all rocks in the area plot within the rhyolite-granite field due to their high silica content (Figures 7 & 8).

3.2. SPARSELY PORPHYRITIC DACITES

3.2.1. Brown sparsely porphyritic dacite

The brown s.p.d. contains phenocrysts up to 2mm in diameter, randomly distributed through a fine grained felsic groundmass of quartz and potash feldspar. The phenocrysts in order of abundance are plagioclase (Ab88-Ab37), ilmenite and titano-magnetite and actinolite (Ca27-29 Mg34 Fe30)

The actinolite is pleochroic, pale green (x) - green (y) - blue-green (z) and is an alteration product replacing primary clinopyroxene. It is probable that the cpx altered to amphibole during cooling, upon addition of water to the volcanic pile.

Plagioclase is oligoclase (Ab83An17) to Labradorite (Ab37An63) in composition. Polysynthetic twinning is rare and poorly defined. Some plagioclase crystals have undergone sericitisation and have corroded and pitted cores (Plate 11) and others are altered to epidote (Plate 12).

The presence of apatite distributed interstitially throughout the groundmass reflects the high P_2O_5 content of the brown s.p.d. (Figure 7). Opaques which form a major groundmass constituent account for the brown colour of the rock in hand specimen.

3.2.2. Black sparsely porphyritic dacite

The black s.p.d. is mineralogically and texturally similar to the brown s.p.d. In addition to single plagioclase crystals, composite plagioclase grains also occur. Plagioclase within these aggregates displays definite polysynthetic twinning and occurs as euhedral grains with sharp contacts between individual phenocrysts.

The black colour of the rock is explained by the presence of fine decussate biotite occurring throughout the groundmass.

3.2.3. Red sparsely porphrytic dacite.

The red s.p.d. differs significantly in minerolagy to the underlying units although the groundmass is still composed of intergrowths of quartz and potash feldspar.

These minerals are no longer confined to the groundmass however and the k-feldspar makes a major contribution to the phenocryst assemblage. Plagioclase is albite (Ab95) in composition. Secondary amphibole is absent. No ilmenite was identified by microprobe anaylsis and opaques (magnetite) occur in lower abundances. Apatite and zircon occur as accessory phases.

This change in mineralogy reflects the geochemistry of the rocks (Figures 4, 5 & 6) and can be explained by the natural process of magmatic differentiation, if the assumption that a quiescent interval occurred prior to the extrusion of the red s.p.d. During this interval the source magma could have cooled to the stage where k-feldspar, zircon and apatite crystallise out of the melt.

Finely disseminated iron-oxide inclusions which typically occur in the feldspars (especially potash feldspar) account for the red colour of the rock in hand specimen.

The pyroclastic units which occur within the red s.p.d. are highly porphyritic with up to 80% of the rock being composed of phenocrysts of plagioclase and k-feldspar, apatite, zircon, secondary amphibole and opaques.

There is no evidence of layering within these units, even on a fine scale. Fragmented remnants of originally euhedral crystals litter the groundmass and fractured phenocrysts are common (Plate 15). This fracturing and shattering indicates explosive volcanic activity with the magma extruding violently in a pyroclastic eruption. Devitrified, chloritic shards occurring within the groundmass further testify to the pyroclastic origin of the rock (Plate 8).

The original glassy groundmass now consists predominantly of chlorite and minor sericite, with finely disseminated opaques.

3.3. PORPHYRITIC RHYODACITE

This lithology is a fine grained, porphyritic, massive to finely laminated rhyodacite. The mineralogy consists of potash feldspar (Or92), albite (Ab95), quartz and opaques, with accessary biotite, zircon and apatite. The groundmass consists of graphically intergrown quartz and k-feldspar.

The phenocryst assemblage consists mainly of subhedral feldspar phenocrysts up to 5mm in width. The feldspars are partly to completely altered to sericite and contain inclusions of quartz, apatite and zircon. They are reddish-brown in colour, due to haematite staining.

Quartz crystals are smaller, up to 1.5mm in diameter. The quartz is euhedral to subhedral, displaying undulose extinction, and has a sporadic distribution throughout the groundmass.

The rhyodacite often exhibits flow banding with layers approximately 2mm in width. The flow banding is defined by alternating cryptocrystaline layers of quartz and k-feldspar. Flow banding is emphasised by the fact that the k-feldspar is red due to alteration whereas the fresh quartz bands are clear.

The upper zones of individual flows within the rhyodacite were vesicular, and vesicles now have amygdaloidal infillings of secondary quartz, albite and calcite (Plate 9).

3.4 RHYOLITE

At the time of extrusion of the rhyolite, the parent magma must have been silica saturated as quartz is no longer confined to the groundmass, but has crystallised out as large anhedral to subhedral phenocrysts 1-2mm in diameter. K-feldspar and minor albite also occur as phenocrysts. Magnetite and ilmenite are no longer major constituents, of the mineral assemblage, occuring only as accessories along with zircon.

In thin section, the rhyolite displays a flow banding of alternating k-feldspar and quartz rich layers. The layers are sub-parallel and are wavey and irregular, contorting around the phenocrysts.

3.5 YARDEA DACITE

The Yardea Dacite is a much coarser grained volcanic than the "older" Gawler Range Volcanics of the Toondulya Bluff area, containing phenocrysts 2-10mm in diameter, of k-feldspar, albite, pimary hornblende, secondary actinolite and opaques set in a microgranophyric groundmass. Accessory phases include sphene apatite, zircon and biotite.

The large k-feldspar phenocrysts have a high Na content (Ca:Na:K = 34:41.5:55.1) and have a biaxial positive sign, a rare phenomenon in potash Feldspar. (only isosanidine, iso-orthoclase and isomicrocline display biaxial positive signs). They, have a dusty appearance produced by finely disseminated iron-oxide inclusions, and they have been altered to sericite and clay. Glomeroporphyritic aggregates of plagioclase are common, as well as individual crystals.
Opaques include ilmenite, magnetite and titanomagnetite which have often been altered to leucoxene, with a secondary phase of sphene. The sphene is often visible giving the opaques a black and brown

striped appearance (Plate 10). The opaques occur with other accessory minerals such as zircon and apatite.

Both primary hornblende and secondary, pleochroic, green coloured actinolite can be recognised. The actinolite replaces initial cpx.

The Yardea Dacite contains basic xenoliths which are plagioclase rich with sharp boundaries, rimmed with ragged fragments of hornblende (Plate 16).

Finer grained phases within the Yardea Dacite have the same mineralogy and geochemistry but contain devitrified shards in a fine grained groundmass. These may be patches of less welded material in the thick densely welded unit.

The zone of black dacite at the base of the Yardea Dacite contains phenocrysts with a fragmented appearance, set in a fine grained, finely laminated groundmass. The unit contains fresh cpx which occurs as composite aggregates mantled by actinolite, and is absent in the overlying Yardea Dacite. The cpx has undergone two stages of alteration. Firstly, the rims were altered to actinolite. At a later stage, the fresh cpx was altered to a clay mineral although the original cpx structure is preserved (Plate 14).

The black dacite has undergone less crystallisation during devitrification and still retains evidence such as fragmented phenocrysts which attest to the pyroclastic origin of the Yardea Dacite.

3.6 HILTABA GRANITE

The Hiltaba Granite is a holocrystalline medium grained intrusive granite with a mineralogy comprised of quartz, K-feldspar, biotite, plagioclase and opaques, in order of abundance. Zircon, apatite, allanite and fine grained interstitial, purple flourite are accessary constituents.

The most interesting feature of the Hiltaba Granite is its granophyric texture, which is a dominant feature of the groundmass (Plate 17). Granophyric texture is an indication of low pressure conditions during cooling and crystallisation of a magma. This implies that the Hiltaba Granite intruded the volcanic pile at shallow crustal levels.

Plate 1 : The rectangular joint pattern which occurs throughout the area.

Plate 2 : Vertical flow folding at the base of the black sparsely porphyritic dacite.

Plate 3 : A lenticular pyroclastic unit within the red sparsely pophyritic dacite.

Plate 1

Plate 2

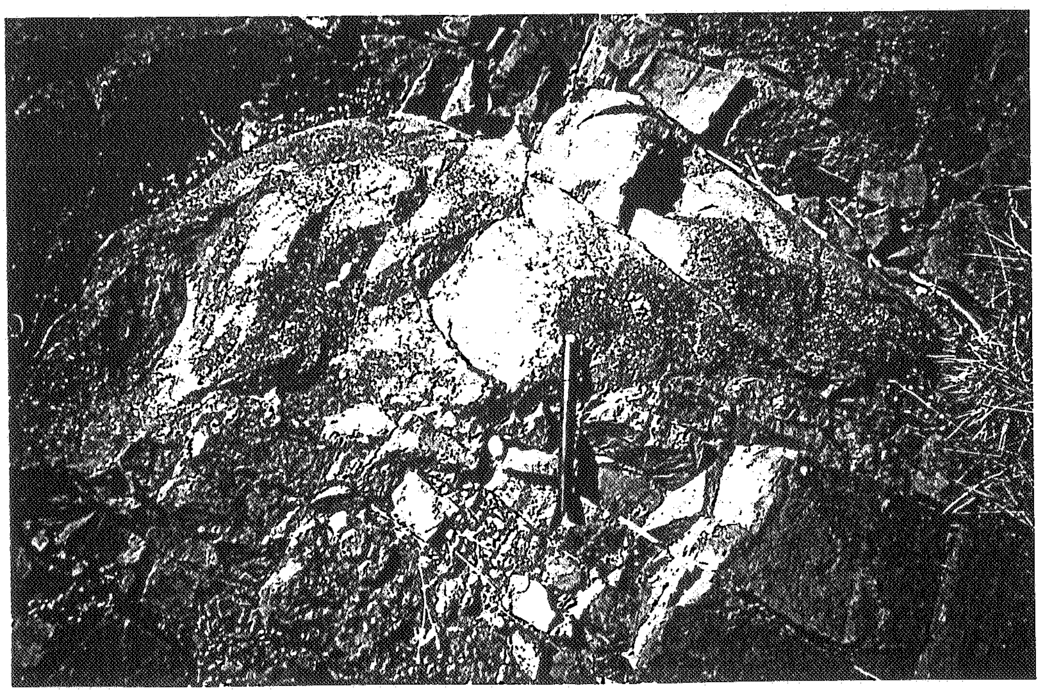


Plate 3

Plate 4 : A xenolith of brown sparsely porphyritic dacite within the pyroclastic unit which occurs at the base of the red sparsely porphyritic dacite.

Plate 5 : The contact between the brown and black sparsely porphyritic dacites, showing interlayering between the two.

Plate 6 : Contorted flow banding within the porphyritic rhyodacite. Intense weathering which occurs in creek beds enhances this feature.

Plate 7 : Flow brecciation within the porphyritic rhyodacite formed as parts of the flow solidify, fracture and become incorporated into the flow as solid components. The presence of phenocrysts which pierce the layering attest to the pyroclastic nature of this rock.

Plate 4 0 3 cm

Plate 5 0 6 cm

Plate 6 0 5 cm

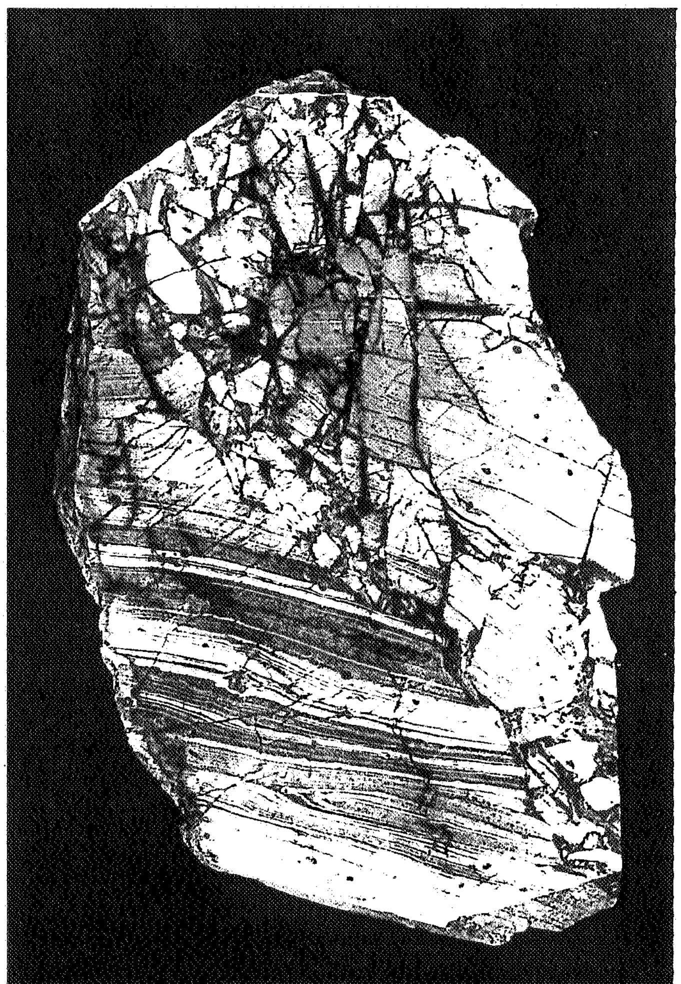


Plate 7 0 5 cm

Field of view = 2.5 x 1.5mm

Plate 8 : Pyroclastic unit within the red sparsely porhyritic dacite. Small, irregular shaped, chlorite rich shards occur in the groundmass of this highly porphyritic unit.

Plate 9 : Rhyodacite : Amygdules have a variety of infillings and occur in a variety of sizes, within the groundmass of the rhyodacite.

Plate 10 : Yardea Dacite : Opaques altered to sphene (sph) and leucoxene (l). Accessory zircon (z) and apatite are also present.

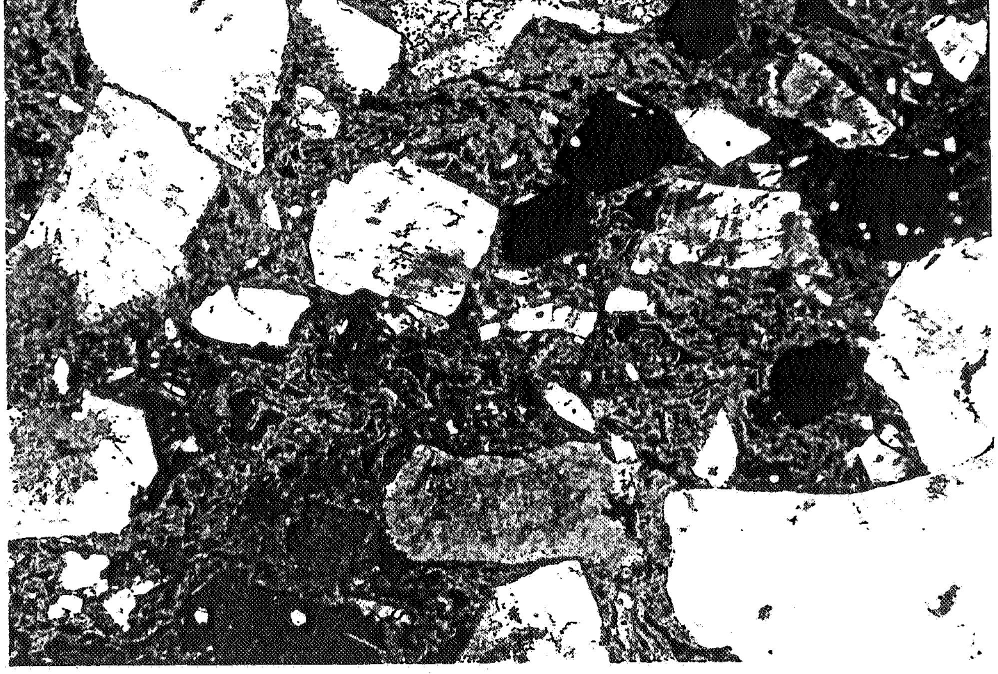


Plate 8

Plate 9

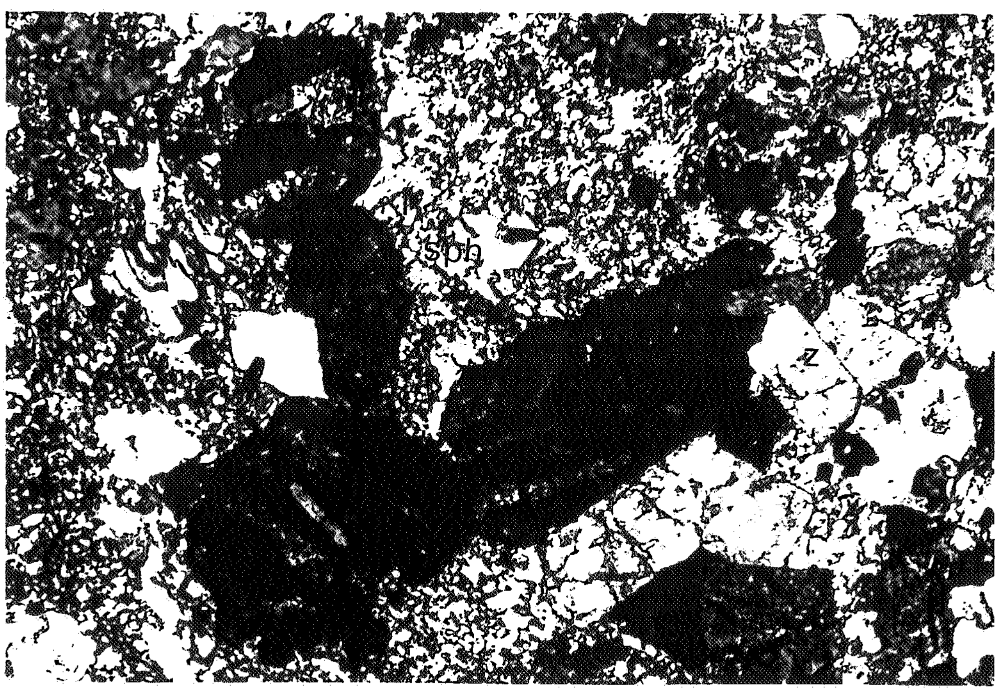


Plate 10

Plate 11 : Brown sparsely pophyritic dacite : Typical alteration of feldspar phenocryts. The core is corroded and sericitised.

Plate 12 : Brown sparsely porphyritic dacite : Plagioclase phenocryst exhibits alteration to epidote due to a process known as saussaritisation. Opaque minerals concentrate at the site of alteration.

Plate 13 : Basal black unit of Yardea Dacite : Opaque minerals are typically rimmed with a halo of small actinolite crystals.

Plate 14 : Basal black unit of Yardea Dacite : Clinopyroxene (cpx) displays two stages of alteration. Firstly the rim is altered to actinolite. Secondly the core is replaced by an amber coloured clay mineral, although the original cpx structure is preserved. Note flow banding wrapping around the cpx phenocryst.

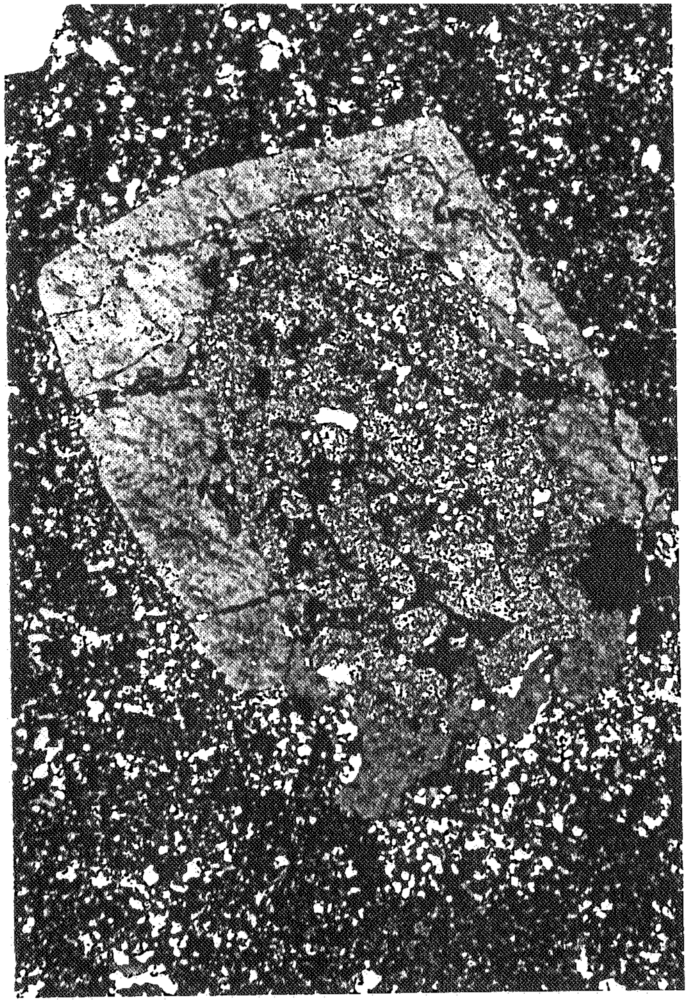


Plate 11

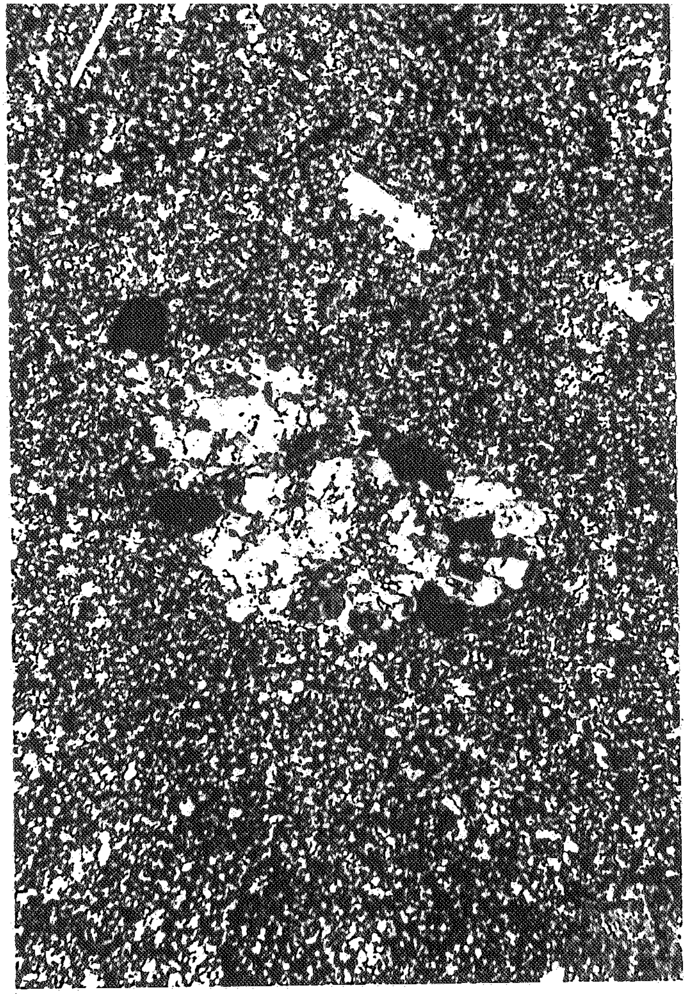


Plate 12

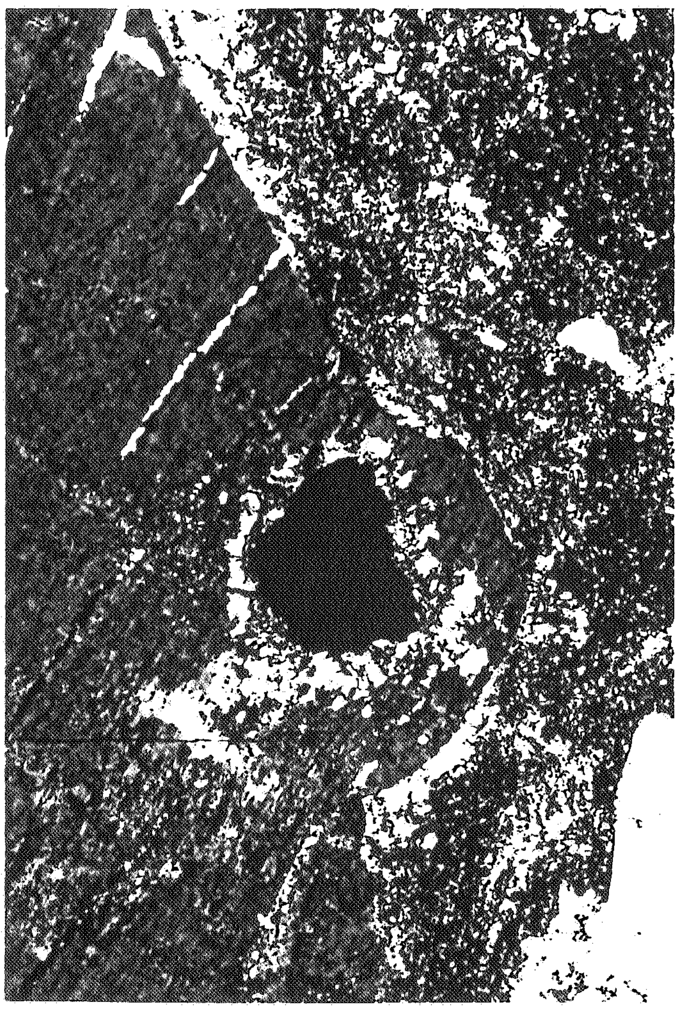


Plate 13

Plate 14

Plate 15 : Pyroclastic unit within the red sparsely porphyritic dacite : Fractured and fragmented phenocrysts within a chlorite-rich, devitrified matrix.

Plate 16 : Yardea Dacite : Mafic xenolith (x) composed almost entirely of plagioclase and rimmed with small, ragged hornblende grains (H).

Plate 17 : Hiltaba Granite : Granophyric intergrowths of quartz (Q) and potassium-feldspar (Kf).

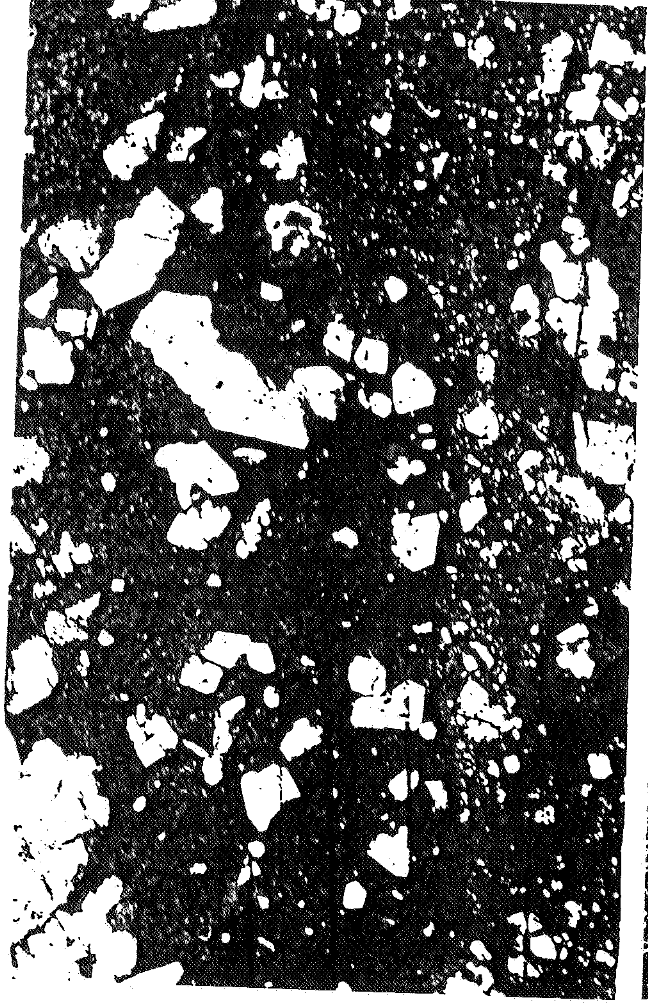


Plate 15

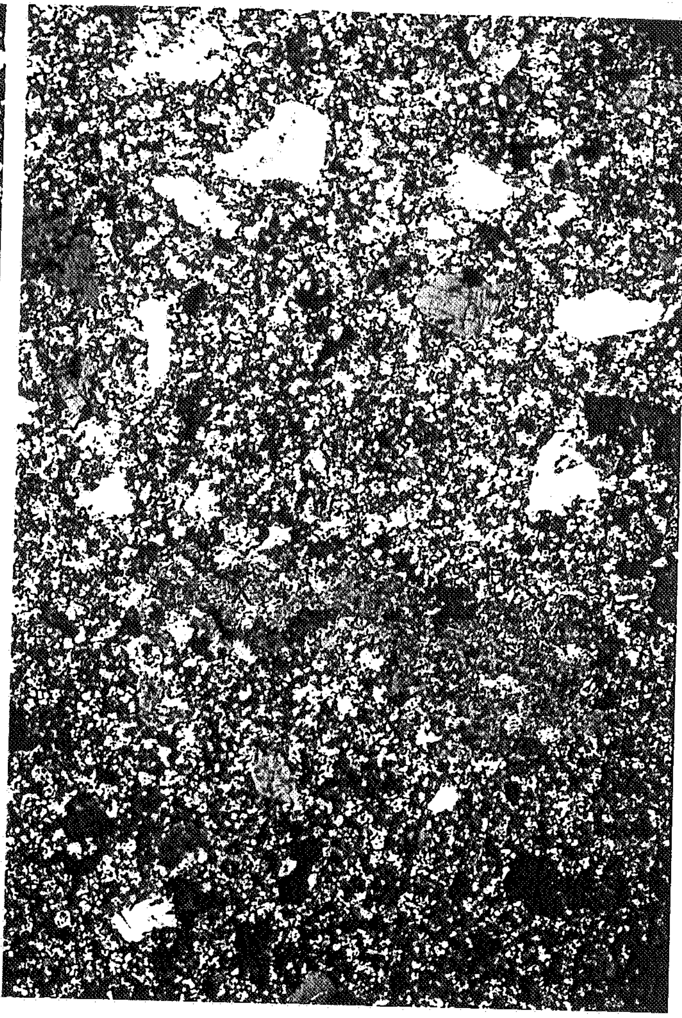


Plate 16

Plate 17

When comparisons are made between orogenic and non-orogenic igneous suites of Phanerozoic and Cainozoic age, similar trends are revealed. Comparisons made between the A-type Merrimbula and Gabo Suites and the I-type Bega Batholith (Lachlan Fold Belt) of similar SiO_2 content, reveal the A-type granites have lower abundances of MgO and CaO and higher $Na_2O + K_2O$. High field strength cations such as Ga and Nb are significantly enriched.

A similar geochemical signature is recognised in non-orogenic Cainozoic acid magmas extruding on stable continental crust as opposed to orogenic island arc settings. In each case the non-orogenic suites have a bimodal nature, lacking lithologies of andesitic composition.

In conclusion, comparative geochemistry reveals that the geochemical relationship between orogenic and non-orogenic acid igneous suites is similar for Cainozoic, Phanerozoic and Proterozoic examples. This suggests that the Proterozoic post-tectonic igneous provinces were not formed by processes and under conditions unique to the Proterozoic era.

4.3 GEOTHERMOMETRY

4.3.1 K-Feldspar Geothermometry

By obtaining compositions of K-feldspar in the Yardea Dacite by microprobe analysis, some constraint was placed on the temperature of crystallisation of this unit. The alkali feldspars were found to be of the Sodium-Potassium type (anorthoclase) with an average Na:K ratio of 43:57. No perthitic texture was revealed in thin section, implying complete solid solution between the two end members of the $KAlSi_3O_8$ - $NaAlSi_3O_8$ system. From Figure 15 (Tuttle and Bowen 1958), it can be seen that this occurs above a temperature of 650 °C, imposing a minimum restraint to the crystallisation temperature of the Yardea Dacite.

4.3.2 Ilmenite-Magnetite Geothermometry

Ilmenite and magnetite pairs were analysed in order to estimate temperature and oxygen fugacity conditions prevalent during crystallisation using the experimental results of Buddington and Lindsley on the stability of various co-existing Fe-Ti oxides. From the results they obtained, equilibrium temperatures and oxygen fugacities can be estimated using the chemical composition of magnetite-ilmenite pairs. Usually the pairs occur as ilmenite exsolution lamellae in magnetite hosts but as this was rare in the lithologies of the Toondulya Bluff area the pairs were taken as co-existing titano-magnetite and ilmenite phases. The mole percentages of ulvospinel, magnetite and ilmenite for each ilmenite-magnetite pair were calculated using the method of Carmichael (1967).

Results are shown in figure 16. Temperatures for the Gawler Range Volcanics are in the range 680° - 850 °C with corresponding oxygen fugacities $fo_2 = 10^{-15} - 10^{-19}$ bar. The temperature range is consistent with the limits applied by K-feldspar geothermometry.

4.4 PETROGENESIS

The geochemical trends discussed above, when combined with mineralogical evidence, lead to the conclusion that the "older" Gawler Range Volcanics can be related to each other by a simple model involving fractional crystallisation of plagioclase, clinopyroxene and magnetite in the initial stages of extrusion, and k-feldspar and magnetite during the later stages of differentiation. Mathematical modelling using the LSMIX program attests to the validity of this fractionation model. The program uses a least squares analysis to determine whether a particular residual liquid can be derived from a given parental magma, upon fractional crystallisation of different proportions of various minerals. The results of the analysis are given in Appendix 4.

Figure 7 plots trace element abundances normalised against primordial mantle using the normalisation factors given by Wood et al (1982). Average values for each lithological unit have been plotted. The resultant pattern shows the samples to be strongly fractionated. The similarity of the plots for each lithology implies they all have a similar source and origin, and that the Hiltaba Granite is comagmatic with the Volcanics.

Although major and trace elements of the Yardea Dacite display a continuity with those of the "older" Gawler Range Volcanics, it is unlikely on the basis of field evidence, that it forms part of the fractional crystallisation sequence relating these earlier extrusives. It forms part of a ash-flow sheet which is uniform over an outcropping area of 12 000 km^2 and blankets the older sequence of volcanics. For such an extensive ash-flow field, several magma chambers and eruption centres are expected and thus although the "older" volcanics and the Yardea Dacite may share a common origin, they were probably derived from separate magma chambers.

Silica rich magmas such as those from which the volcanics and Hiltaba Granite were crystallised can be produced by partial fusion of continental crustal material (upper or lower crust) or by differentiation of more mafic magmas possibly generated in the mantle.

In the latter case it is unlikely that the primary liquid was mantle derived. Large volumes of basaltic magma would have been required to generate such extensive acid magmas and there is no field evidence that such volumes of mafic material exists.

A comparison of the igneous suite with MORB, a mantle derived basalt (Figure 13) shows it is highly fractionated and LIL element enriched with a high K_2O/Na_2O ratio, suggesting a crustal contribution to the primary magma.

Webb (1978) gives Sr IR values of .7041 for the Hiltaba Granite and .7056 for the volcanics (constraints not cited) which eliminate the possibility of a mantle derived magma as these values lie above the mantle growth curve at 1600 Ma (Figure 14). Similarly the high Sr ratio also discounts upper crustal rocks as a source for the primary liquids. Average Rb/Sr ratios for the upper crust are too low to account for the high Sr ratio of the Hiltaba Granite. Such values indicate an older crustal source.

Furthermore, the volcanics, especially the low silica dacites, are of non-eutectic composition and could not have been produced by direct partial melting of upper crustal material. As they do not plot on the eutectic minimum, formation by partial melting would necessitate temperatures far in excess of those reached during regional metamorphism. Such temperatures would not have been attained in the upper crust as the lithologies have not undergone metamorphism and only little deformation. There would be a better possibility of generating such temperatures in the lower crust which is in contact with the mantle.

The Qtz-Ab-Or ternary diagram (Figure 10) indicates that the Hiltaba Granite is a eutectic melt and therefore could have either been derived by direct partial melting of the crust, or it could represent the final residue remaining after fractional crystallisation of a more intermediate or basic magma. In view of the fact that the geochemistry of the granite is so similar to the volcanics the latter is more likely. Mathematical modelling supports the possibility that the acidic granite is derived from the volcanics by differentiation of clinopyroxene, plagioclase, k-feldspar, magnetite and accessories such as apatite Such an origin would explain the highly differentiated nature of the granite with its high Rb, low Sr and Ba contents supporting the concept of extreme fractionation (Figure 11).

CHAPTER 5 : DISCUSSION AND SUMMARY

Comparison of the Gawler Range igneous suite with other Proterozoic post tectonic provinces in Australia and other continents shows that they all have a marked similarity in geochemistry.

In addition the provinces also have many tectonic features in common. They all unconformably overly stable, recently cratonised basement following a major period of orogenic activity in the lower Proterozoic. They are essentially undeformed being only tilted or gently folded, and they have suffered little metamorphism.

They have a distinct bimodal character with large volumes of acid magmas and minor basaltic liquids (Note the Phanerozoic and Cainozoic examples examined also displayed this feature). Absence of magmas of intermediate composition suggests the basaltic and acid magmas are not comagmatic although they are related in space and time.

Many authors studying post-tectonic Proterozoic igneous provinces have proposed models for their origin, all of which are remarkably similar. The models involve mantle plume activity into the lower crust, triggering partial melting. The mantle liquids are believed to be the source for basic magmas and the acid magmas were generated by the partial melting of the lower crust,the composition of which is believed to be that of a granulite (Figure 17).

In view of the geochemical similarity between the volcanics and granites at Toondulya Bluff and lithologies of these provinces, a similar model can be applied to the origin of these lithologies.

Thus in summary, the final extrusive and intrusive sequence seen at Toondulya Bluff was derived from a two stage process. Initial

Figure 15 : $NaAlSi_3O_8$ - $KAlSi_3O_8$ binary diagram showing subsolidus relations between k-feldspar and albite.

Figure 16 : (a) T vs log fo_2 projection, from Buddington and Lindsley (1964).

(b) Titanomagnetite vs T diagram, from Buddington and Lindsley (1964).

——— = lithologies from the study area.

Figure 15

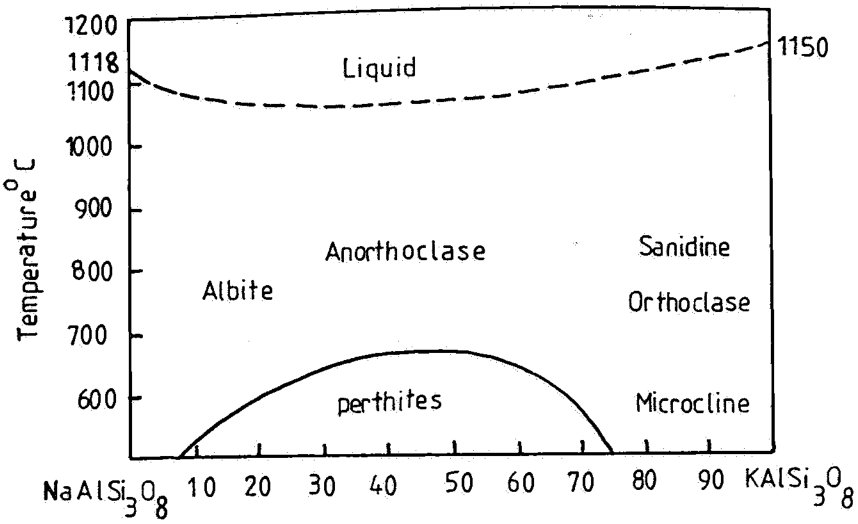


Figure 16 (a)

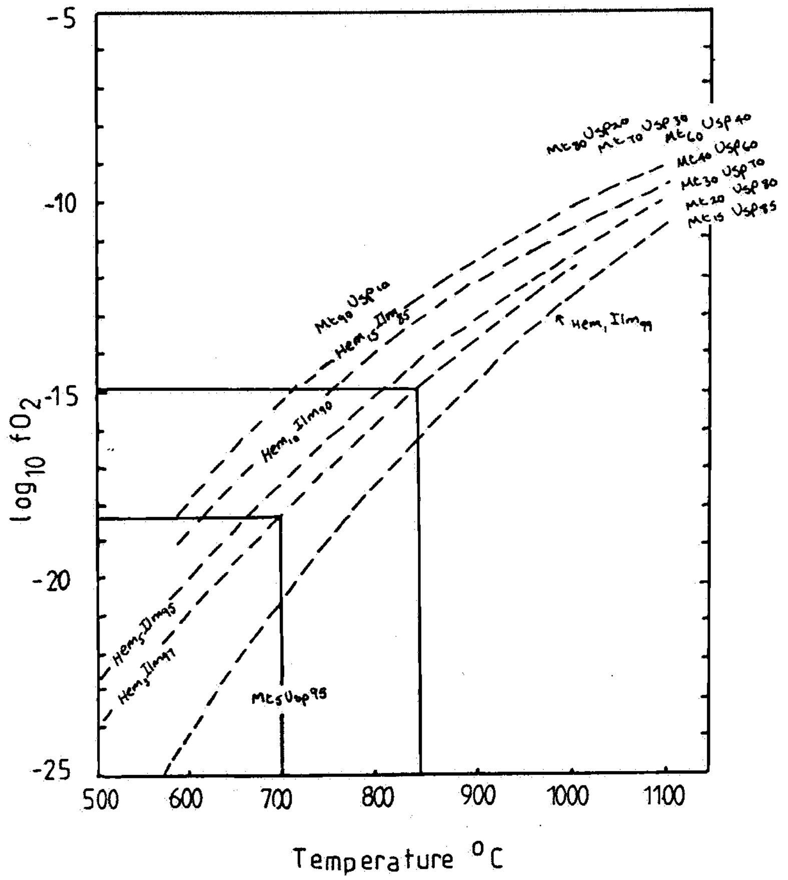


Figure 16 (b)

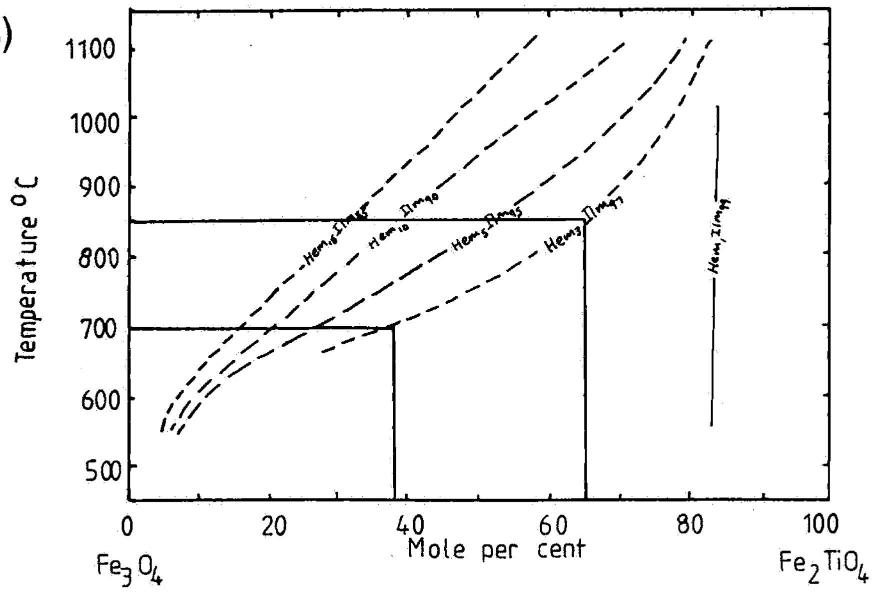
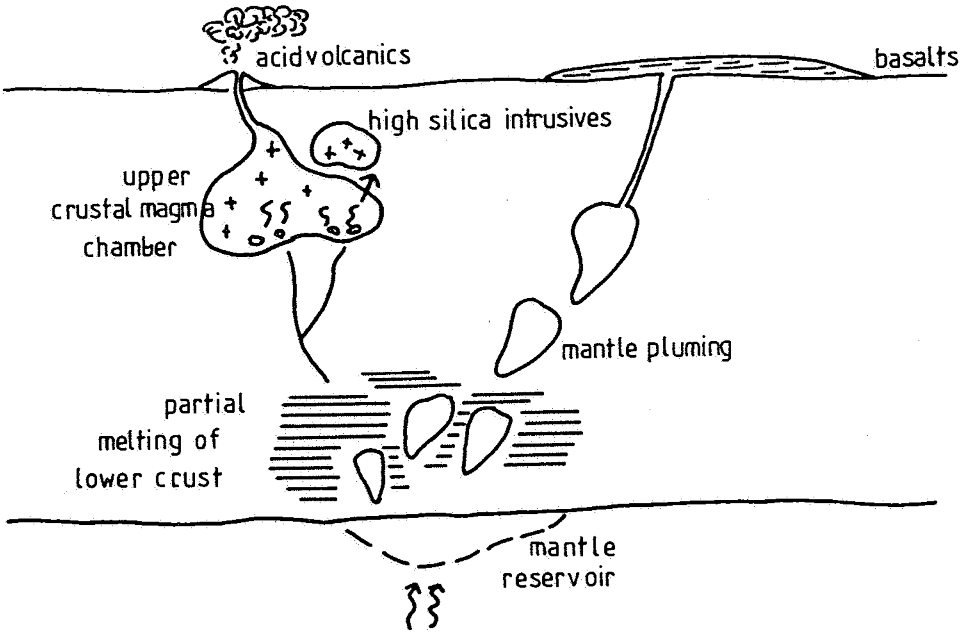


Figure 17 : Proposed model for the evolution of Proterozoic post-tectonic igneous provinces, based on models of Emslie (1978), Bridgwater and Windley (1981) and Giles (1980).

Figure 17



acidvolcanics
basalts
high silica intrusives
upper
crustal magma
chamber
mantle pluming
partial
melting of
lower crust
mantle
reservoir

melting of a lower crustal source produced the primary liquid from which the lithologies fractionated. The "older" Gawler Range Volcanics probably represent direct crystallisation from these non-eutectic primary melts. Crystal settling in upper crustal magma chambers would then have yielded the Hiltaba Granite by differentiation processes. The Yardea Dacite may have been formed in a similar manner. Giles (1980) suggested the Yardea Dacite may also have incorporated the crystal cumulates formed during differentiation into its melt. The possibility of the Yardea Dacite containing zircon xenocrysts has already been mentioned (Chapter 4). The glomeroporphyritic aggregates of plagioclase and clinopyroxene may also indicate incorporation of cumulates in the Yardea Dacite.

6.4 RESULTS

Results of the U - Pb isotopic analyses are summarised in Table 1, and the Concordia plots are reproduced in Figure 19. As can be seen from Figure 19a, five of the six fractions plot to produce a normal fit linear discordia with an upper intercept of 1582^{+36}_{-35} Ma. The zircon fractions fall into two groups. The two lower points are metamict zircon fractions (4 & 6), which have lost more radiogenic lead than fractions 2,3 & 5. The sixth fraction (1) plots above concordia in an unusual, reversely discordant position. As the sample was not reloaded and remeasured, it is unknown whether this result is a true plotting or if there was an error in results obtained from the mass spectrometer. The isochron gives a good fit because of the length of the discordant line, but the MSWD of 43 is high.

If the reversely discordant fraction is omitted, the upper and lower intercepts are 1617^{+77}_{-64} Ma and 132^{+153}_{-160} Ma respectively, with a MSWD of 38 (Figure 19b). The result can be further improved by eliminating either point 6 or point 4 and improving the fit of the isochron.

Monitoring of Pb showed that of these two points, fraction 6 was most likely to have been contaminated during the chemical procedure used in extracting U and Pb from the zircons. removing this point from the plot results in a reasonable fit isochron (Figure 19c) with errors within the limits of experimental uncertainty. This isochron gives an upper intercept of 1631^{+75}_{-61} Ma and a lower intercept of 197^{+168}_{-176} Ma.

Eliminating point 4 also produces an isochron of reasonable fit, with an upper intercept of 1603^{+82}_{-63} Ma and a lower intercept 64^{+218}_{-269} Ma (Figure 19d). Elimination of this point is plausible, as upon regression of the isochron in Figure 19b, this point showed the greatest deviation from the line of best fit.

The age of 1582 $^{+36}_{-35}$ Ma can be eliminated on the assumption that the reversely discordant point is invalid. This gives the Yardea Dacite at Lake Acraman an age between 1603 and 1631 Ma. It is impossible to further improve on the certainty of the age, because of the poor fit of the points along the isochron. Statistically, the date of 1603 $^{+82}_{-63}$ Ma is most likely to be correct. ??

6.5 INTERPRETATION OF ISOTOPIC MEASUREMENTS

The age of the Yardea Dacite at Lake Acraman is compatible with the dates obtained by Compston (Gostin et al in prep) for dacite fragments within the fragmental layer in the Bunyeroo Formation. The Yardea Dacite is approximately 30 Ma older than the fragments. This is to be expected, as the shattered dacite exposed at Lake Acraman today, would have been below the level of the original crater floor in the late Precambrian. Williams (in prep) calculated that since uplift of the area during the Mesozoic, approximately 1 km of material has been removed by erosion. One would therefore expect the rocks present at Lake Acraman today to be considerably older than those exposed 600 Ma ago.

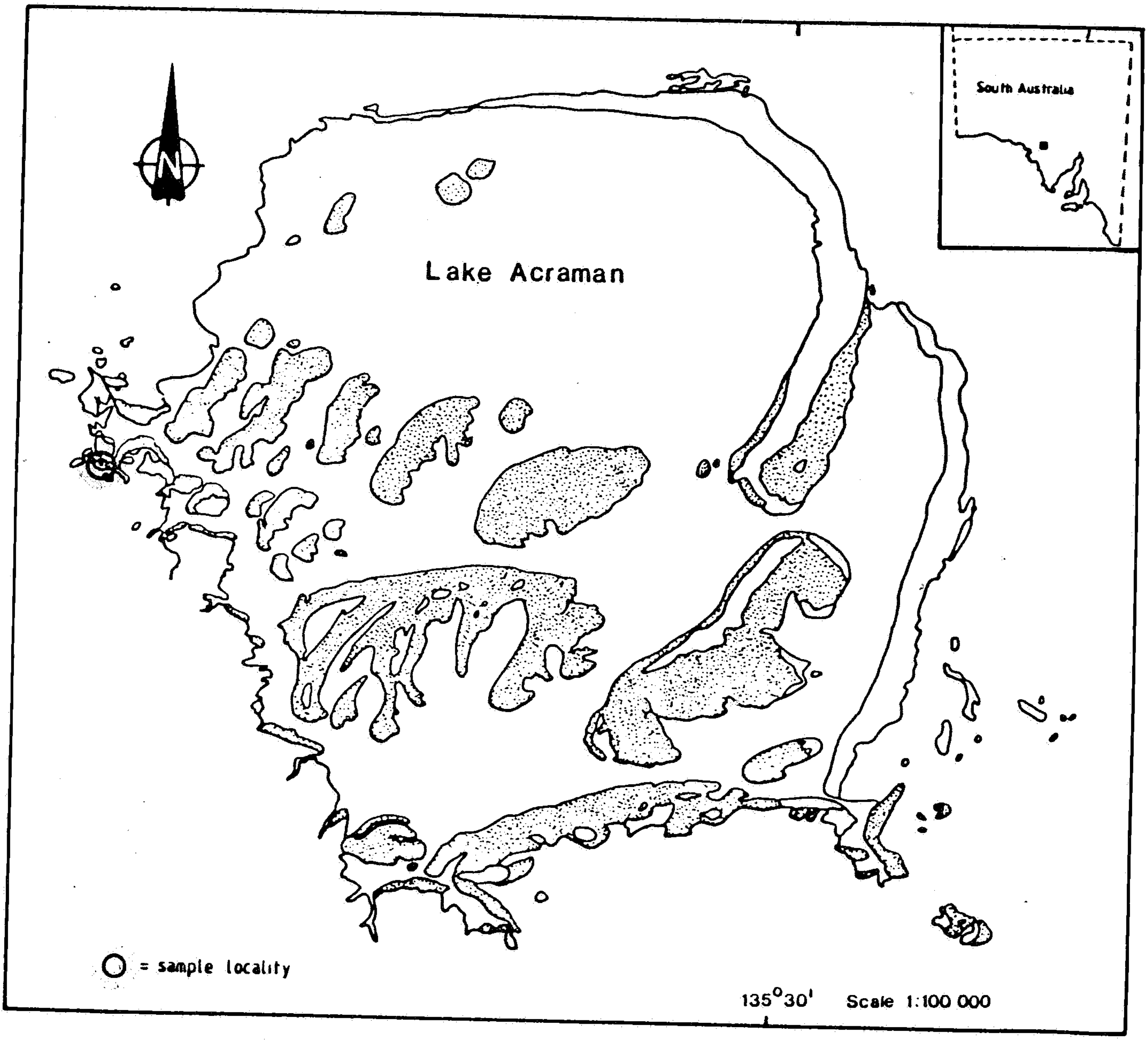
There has been no evidence that the U - Pb systematics of the zircons were reset during the late Precambrian. The lower intercepts obtained in each model that was considered show that the zircon has held all of its radiogenic lead until comparatively recent times. This does not however, rule out the possibility of meteoric impact.

Recent studies have been made on the retention of U and Pb in zircons from shocked granites in the Devonian Siljan impact structure in Sweden. It was concluded that although the zircons were mechanically disrupted by the impact, and showed post - shock alteration features, the U and Pb were highly retained (Aberg and Bollmark 1985). They concluded that under a calculated average shock pressure of 15-20 GPa, there is no disruption to the U-Pb system.

The effect of impact related shock pressures on the Rb-Sr systematics of rocks related to the Ries Crater, Germany, has also been recently researched (Horn et al 1985). It was again demonstrated that shock pressures up to 15 GPa and temperatures as high as 300°C did not disturb the Rb-Sr isotopic systems of the rocks. As the Rb-Sr system is more likely to be affected by post-crystallisation events than the U-Pb system, it can be concluded that meteoric impact does not involve enough time to open the U-Pb mineral system.

It is thus concluded that on the basis of age comparison, the dacite fragments within the impact ejecta layer in the Bunyeroo Formation may have originated from Lake Acraman, although the U-Pb system yields no evidence of meteoric impact at this locality.

Figure 18 : Sample Locality map for the Yardea Dacite obtained for geochronological studies.

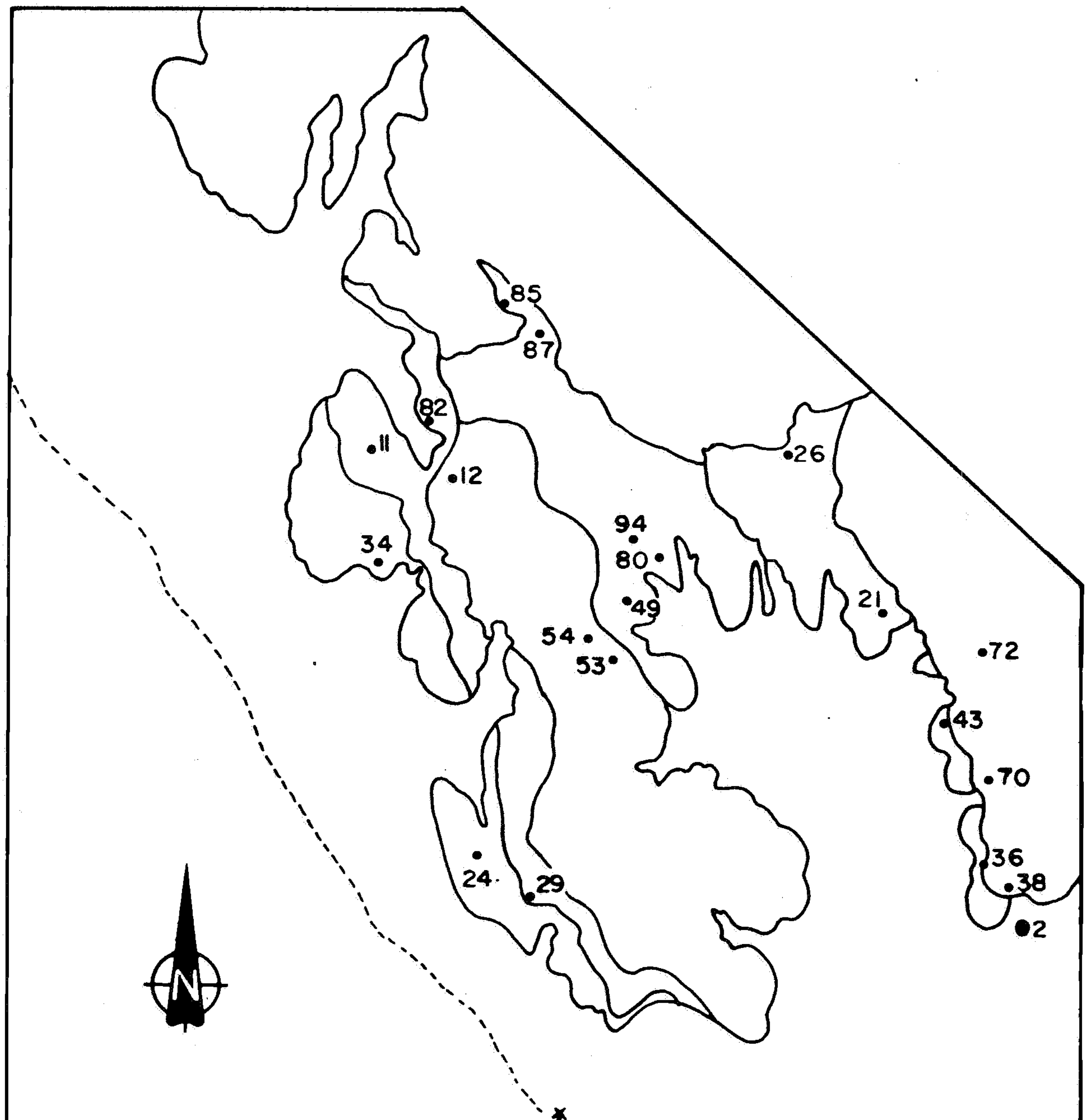

South Australia
N
Lake Acraman
= sample locality
135°30'
Scale 1:100 000

APPENDIX 1

SAMPLE LOCALITY MAP AND THIN SECTION DESCRIPTIONS OF REPRESENTATIVE SAMPLES

SAMPLE LOCALITY MAP

All samples are prefixed 849/



THIN SECTION DESCRIPTIONS

849/24 Brown sparsely porphyritic dacite

In thin section, the brown s.p.d. appears massive, with no evidence of flow banding or layering. The rock is composed of phenocrysts of plagioclase, opaques and minor clinopyroxene (altered to secondary amphibole) randomly distributed through a microcrystalline, brown groundmass.

The subhedral plagioclase phenocrysts, 1-4 mm in diameter, cover a wide range of compositions from Orthoclase ($Ab_{83}An_{17}$) through Andesine ($Ab_{51}An_{49}$) to Labradorite ($Ab_{37}An_{63}$). Some have reverse zoning with more calcic rims than cores, for example core ($Ab_{84}An_{16}$) to rim ($Ab_{67}An_{33}$), and some are antiperthitic, with patchy exsolution of k-feldspar only revealed by microprobe analysis. The phenocrysts exhibit no twinning and are partially or completely replaced by disseminated sericite and haematite, giving them a dusty appearance. The plagioclase has been partially saussaritised, forming a fine grained intergrowth of epidote with albite, from original labradorite.

A green amphibole, probably a secondary alteration product of cpx, forms small, elongate crystals up to 1 mm in length and is also finely disseminated throughout the groundmass. The cpx may have altered to amphibole during cooling, as water circulated throughout the volcanic pile.

Opaques occur as phenocrysts up to 0.5 mm in diameter, often associated with saussarite and also forming a major constituent of the groundmass. They include both ilmenite and magnetite, the ilmenite being characteristically rich in Mn. Some of the opaques have ilmenite-magnetite exsolution lamellae.

The groundmass consists of quartz and haematite stained k-feldspar, with abundant opaques ($\sim$20% of the matrix). Interstitial apatite is also a major groundmass constituent. Quartz veinlets containing chlorite run through the rock.

849/11 Black Sparsely Porphyritic Dacite

As with the brown dacite, the black dacite is massive in thin section and phenocrysts are sparse.

Subhedral plagioclase crystals dominate the phenocryst assemblage having a size in the range of 0.5-5mm and a sporadic distribution throughout the black groundmass. The plagioclase phenocrysts occur as individual crystals and as glomeroporphyritic aggregates. Within these composite plagioclase crystals, the grain boundaries between individual crystals are sharp.

Many of the individual plagioclase phenocrysts contain abundant inclusions of the other minerals present, including opaques and potassium-feldspar. In addition, they contain thick cores of sericite microlites, a common phenomenon in zoned crystals, where the more calcic regions are altered first. In some cases the plagioclase crystals are completely sericitised. In contrast, the composite plagioclase aggregates are red in colour, having been altered to haematite rather than sericite. Another difference between the two is that isolated plagioclase crystals display no evidence of twinning, whereas grains within the composite crystals have distinct albite lamellae.

The opaques form larger grains than in the brown sparsely porphyritic dacite but are less abundant in the groundmass. Secondary green amphibole (originally clinopyroxene) occurs as micro-phenocrysts, only slightly coarser than the crystals constituting the groundmass.

The groundmass is composed of a microcrystalline mosaic of quartz crystals, interstitial with potassium-feldspar, which is red in colour, due either to haematite staining or clay alteration. Decussate biotite crystals are distributed throughout the matrix, whereas chlorite is absent.

Decussate biotite is a characteristic of hornfels, suggesting that the black sparsely porphrytic dacite has undergone more severe alteration than other units in the area, almost to the point of metamorphism.

849-54 Red Sparsely Porphyritic Dacite

The red sparsely porphyritic dacite is massive, with no evidence of layering in thin section. Potassium-feldspar and quartz are now present as phenocrysts instead of being confined to the groundmass, and apatite and zircon are accessory minerals.

The subhedral to euhedral plagioclase crystals present attain a maximum diameter of 1.5 cm but are usually in the range of 2-5mm. The crystals have the composition of albite ($Ab_{97}An_3$) and sometimes exhibit poorly defined weak multiple twinning. Potash feldspar coronas mantle the albite phenocrysts. Glomeroporphyritic aggregates of plagioclase form composite plagioclase phenocrysts which show diverse cleavage orientations, produced by the different crystals. The plagioclase crystals are riddled with inclusions of zircon, apatite, magnetite, potash feldspar and quartz which tend to concentrate in the cores.

Potassium-feldspar phenocrysts are large and have a cloudy appearance due to alteration. The potassium-feldspar often hosts albite exsolution lamellae recognised by microprobe analysis, but faintly visible using an ordinary optical microscope.

Subhedral to euhedral magnetite crystals 0.1-1 mm in diameter occur as phenocrysts. No ilmenite was identified by microscope analysis. Quartz crystals also occur as phenocrysts, 0.5-1.5 mm in diameter.

The groundmass is homogeneous, composed of a microcrystalline mosaic of equigranular quartz and altered potassium-feldspar, with magnetite as a major constituent. The crystals making up the quartz mosaic polarise independantly implying a random orienation of the grains. The entire groundmass has been chloritised.

The feldspar phenocrysts and potassium-feldspar in the groundmass are reddened by disseminated haematite and clay alteration, giving the rock its reddened colour.

849-3 Lenticular Pyroclastic Unit in Red s.p.d.

Within the red s.p.d. are elongate, lenticular units, approximately 1 metre thick which extend along strike for approximately 500 metres. The material within these lenticular units is highly porphyritic and contains xenoliths of the earlier extruded brown and black s.p.d.'s. These units are also dacitic in composition but have a phenocryst:groundmass ratio of 45:55 compared with 10:90 for the sparsely porphyritic dacites.

The phenocrysts are also much larger, averaging a 5mm diameter. Embayed feldspar crystal fragments are the most common (including both plagioclase and k-feldspar) and they are usually broken relicts of formerly euhedral crystals. Some display undulose extinction, implying extrusion under some pressure. Fragmentation results in small crystal fragments derived from larger phenocrysts littering the groundmass, and fractured phenocrysts are common. Such fracturing and shattering indicates explosive volcanic activity with the material extruding violently as a pyroclastic eruption, rather than as a more quiescent lava flow. Devitrified shards occurring within the groundmass further testify to the pyroclastic origin of the rock. Chlorite has replaced the original glassy material within these shards.

The matrix is finer grained than the s.p.d.'s and it has been extensively sericitised and chloritised, giving the rock a green colour in thin section. Opaques are a major groundmass constituent.

849-30 Lenticular Unit within the red s.p.d.

The rock contains fragments of plagioclase and k-feldspar, apatite laths, euhedral zircon crystals, secondary green hornblende and opaques, in a very fine grained matrix of chlorite and sericite. The phenocryst:groundmass ratio is approximately 80:20.

The feldspars have been partially or completely sericitised although some fragments are fresh. Some contain zircon inclusions and some of the plagioclase displays multiple (albite) twinning. They occur as jagged fragments with an anhedral habit.

The groundmass was probably originally glassy but now consists of chlorite and minor sericite with disseminated opaques comprising approximately 10% of the matrix. Within the groundmass are small shards up to 0.5mm in length. These originally glassy fragments have been pseudomorphed by chlorite. The shards do not appear to have been flattened or distorted, which indicates the rock has not been strongly welded.

849-80 Amygdaloidal Rhyodacite

A porphyritic rock, composed of phenocrysts of feldspar and quartz in a red, massive, microcrystalline groundmass.

The feldspar phenocrysts are partly to completely altered. K-feldspar crystals are the most common, although a few smaller albite crystals are found. They contain numerous inclusions of quartz, apatite and zircon. Microprobe analysis shows that the potash feldspars have a high Na content.

The quartz phenocrysts are euhedral to subhedral in habit. They occur up to 1.5 mm in diameter and display undulose extinction. They have a sporadic distribution throughout the groundmass.

The remaining phenocrysts are subhedral opaque minerals, predominantly magnetite with minor titano-magnetite (up to 10% Ti).

Biotite, apatite and zircon are accessory phases.

The groundmass consists of quartz, k-feldspar and opaques. Whilst the quartz has remained fresh, the k-feldspar has been haematised and partly altered to clay, giving the rock its red coloration. The groundmass is traversed by veinlets infilled with fine grained chlorite.

Amygdules occupy interstitial areas between the phenocrysts. They are spheroidal and disc shaped and attain a maximum diameter of 1.5mm. The cores of the amygdules have been infilled with secondary quartz, chlorite calcite and albite. Some have rims formed of fine grained, microcrystalline quartz.

The presence of amygdules indicates the rock was originally a vesicular, volatile rich magma.

849-85 Rhyodacite

This rock has a crystalline appearance in hand specimen and in thin section it displays a flow banding. It is brick red in colour. Phenocrysts are generally lacking, although when present they reach a length of 2.5 mm.

The phenocryst phases are quartz and k-feldspar. The quartz has a uniform extinction and a diameter of approximately 1 mm. The k-feldspar phenocrysts are partially or completely altered to sericite. Rare plagioclase, muscovite, magnetite and zircon complete the assemblage.

The prominant layering in the groundmass is formed of alternating layers of micro-crystalline and crypto-crystalline material. The micro-crystalline material is haematite stained and probably k-feldspar. The crypto-crystalline layers are fresh and composed mainly of quartz. Opaques are randomly distributed throughout the layers. Layers are approximately 1.5 mm wide and are subparallel although contortion occurs around the phenocrysts and the banding is frequently disturbed.

The overall texture displayed is indicative of flow. The groundmass may have crystallised from either a molten lava flow or a fluidised tuff flow.

849-87 Rhyodacite

This rock has the same brick red colour as 849-85 and in the field the two mix together on a mesoscopic scale and cannot be distinguished as separate mappable units. However, 849-87 is slightly coarser grained with larger phenocrysts and does not have the same crystalline appearance as 849-85. In thin section, flow banding is absent.

Large feldspar phenocrysts 2-7 mm in length are common. They are extremely altered (haematite stained and sericitised) and riddled with inclusions of quartz, sericite and chlorite. They occur as isolated crystals and also as glomerporphyritic aggregates. The feldspar phenocrysts are anhedral to subhedral, with serrated margins. Quartz phenocrysts and opaques are rare, and muscovite occurs as an accessory phase.

The groundmass is composed of a massive, microcrystalline mosaic of quartz and haematite stained k-feldspar with finely disseminated opaque mineral phases. It is micrographophyric in places.

The two phases represented by the rocks 849-85 and 849-87 are may be a single tuffaceous unit in which liquefaction has occurred only locally, producing characteristics such as flow structures, which are normally found in molten rock.

849-21 Rhyolite

In thin section, the rhyolite displays a flow banding. The layers are sub-parallel and are wavy and irregular, contorting around the phenocrysts. The bands are approximately 1 mm in width.

The matrix is fine grained and contains very little quartz. It consists mainly of k-feldspar and chlorite. Quartz however, is the main constituent of the phenocryst assemblage forming large, anhedral to subhedral crystals, 1-2 mm in diameter. The quartz phenocrysts are fresh and have serrated boundaries.

Minor plagioclase phenocrysts approximately the same size as the quartz also occur. They have been altered to sericite, haematite and chlorite. Less altered K-feldspar phenocrysts are also present. Magnetite and other opaques now occur only as accessory phases rather than as major constituents of the mineralogy. Zircon also occurs as an accessory mineral.

Chlorite veinlets form an intricate network throughout the groundmass.

849-26 has the same mineralogy and composition as 849-21, but displays no flow banding and quartz is more abundant in the groundmass.

849-43 Rhyolite

This rhyolite has a crystalline appearance in hand specimen and is black in colour rather than the normal brown observed for the rhyolite unit. It is also more porphyritic than 849-21, but has the same abundance of fresh quartz phenocrysts which characterise the rhyolite lithology.

In thin section the matrix is very fine grained and consists predominantly of fine grained chlorite.

The most common phenocryst is quartz which has a size range of 0.5-2mm. Clay altered feldspar phenocrysts of approximately the same size also occur. The phenocrysts have an anhedral, fragmented appearance.

Zircon occurs as an accessory mineral, and opaques are rare.

Fractured and fragmented phenocrysts attest to the pyroclastic origin of this rock.

849-70 Yardea Dacite

The Yardea Dacite is a much coarser volcanic than the "older" Gawler Range Volcanics of the Toondulya Bluff area , indicating a much slower rate of cooling. It contains phenocrysts 2-10 mm in diameter of k-feldspar, albite, primary and secondary amphibole, biotite and opaques set in a micrographophyric groundmass of quartz and k-feldspar.

The large k-feldspar phenocrysts have a high Na content (Ca:Na:K = 3.4:41.5:55.1), Some of the smaller k-feldspar phenocrysts are microperthitic. All albite phenocrysts (Ab96) are mantled by k-feldspar. The feldspars have a dusty appearance due to clay alteration and they contain inclusions of apatite, chlorite and sericite.

The opaques are ilmenite, magnetite and titanomagnetite and often have a secondary phase of sphene in association. This phase is often visible giving the opaques a black and brown striped appearance. The opaques attract accessory minerals such as zircon, apatite and sphene.

Biotite is a minor constituent in the Yardea Dacite, although it does not occur in any of the other volcanics. It can be found wrapping the secondary amphibole or as isolated fragments.

Two kinds of amphibole can be recognised. The primary hornblende displays the distinct 120 cleavage characteristic of the amphibole group and is tan in colour. The secondary amphibole (actinolite) is the same as that found in the brown s.p.d. and probably replaces clinopyroxene. Zircon and opaque phases often occur in association with the amphiboles.

The groundmass consists predominantly of quartz and haematite stained k-feldspar which have a micrographophyric texture. Biotite, calcite, apatite, zircon and opaques are also found in the groundmass.

849-36 Yardea Dacite

In hand specimen the rock has a black, glassy appearance. It contains large phenocrysts attaining a maximum diameter of 5mm with an average size range between 1-3mm, set in a very fine grained chloritic matrix. The groundmass displays a flow banding which contorts around the phenocrysts. Layers tend to be parallel but some cross lamination and slumping indicates soft sediment deformation.

Phenocrysts consist predominantly of k-feldspar and plagioclase (which displays albite twinning). These phenocrysts are relatively fresh and are embayed, with groundmass material infilling the embayments. The feldspar phenocrysts occur as anhedral fragments, probably remnants of originally euhedral crystals.

A third phenocryst phase is amber coloured clinopyroxene which occurs as individual crystals (2mm diameter) or as aggregates mantled by actinolite. The cpx has undergone two stages of alteration. Firtsly the rims were altered to actinolite, then at a later stage the fresh cores underwent clay alteration, giving the cpx its honey colouring. Some fresh cpx cores are still recognisable. Accessory apatite and zircon tend to concentrate with these phenocrysts which also attract fine grained opaques. Larger leucoxene crystals (0.5mm diameter) rimmed with actinolite also form part of the phenocryst assemblage.

The fragmented phenocrysts indicate this basal member of the Yardea Dacite erupted as a pyroclastic unit.

849-1 Hiltaba Granite

A holocrystalline, medium grained intrusive granite with a mineralogy comprised of quartz, k-feldspar, biotite, plagioclase and opaques, in order of abundance. Zircon, apatite, allanite and fine grained, purple fluorite are accessory constituents. The rock has an average grainsize of 2 mm.

The quartz has remained fresh whilst the k-feldspar displays partial haematite alteration, giving it a cloudy appearance under ordinary light. The k-feldspar is one of the rare varieties of alkali feldspar that displays a positive sign (i.e. isosanidine, iso-orthoclase or isomicrocline).

Some biotite is partly altered to chlorite and some is red in colour, an indication of high Ti-content. The biotite often occurs in clusters with opaques and small zircon crystals.

The presence of allanite and purple fluorite is in keeping with the high uranium content of the Hiltaba granite which has an average U content of 10 ppm (Nick Burn pers comm).

The most interesting feature of the Hiltaba granite is its granophyric texture. This intergrowth of quartz and alkali feldspar can be seen ~~as~~ easily under plane polarised light because the alkali feldspar is brown due to alteration whereas the fresh quartz is clear. The granophyric texture is such a dominant feature that it is even visible in hand specimen ! Such a texture is an indicator of low pressure conditions during cooling, implying that the Hiltaba granite intruded the volcanic pile at shallow crustal levels. It can be considered a sub-volcanic granite.

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