THE UNIVERSITY OF ADELAIDE

THE GEOLOGY, PETROLOGY AND GEOCHEMISTRY OF THE TOMMYS GAP AREA IN THE GILES CREEK SYNFORM, MACDONNELL RANGES, SOUTH-EASTERN ARUNTA BLOCK, NORTHERN TERRITORY.

by

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Degree of Bachelor of Science.

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ABSTRACT

The study area is located within the Giles Creek Synform, approximately 80km east of Alice Springs. Basement rocks are the Tommys Gap Metamorphics which are a part of the Division 2 group of rocks of the Arunta Inlier. These have been intruded by the Atnarpa Igneous Complex and overlain unconformably by the Heavitree Quartzite and Bitter Springs Formation of the Amadeus Basin Sequence. The igneous rocks comprise of granite, tonalite, diorite and a coarse crystalline basic rock.

The main aim of the study was to determine the magma origin and fractionation history of the igneous rocks using petrographical and geochemical techniques. Data indicates that all the igneous rocks were formed by fractional crystallisation rather than the restite model of White and Chappell (1977), and have calc-alkaline affinities. Unfortunately the lack of analyses makes it difficult to conclude whether they are a consanguineous suite or not.

Using the U - Pb isochron dating method, an age determination was performed on zircons from the tonalite and found to be 1863+/-31 Ma.

CHAPTER 1 : INTRODUCTION

1.1 LOCATION AND PHYSIOGRAPHY OF STUDY AREA

The study area is located in the East MacDonnell Ranges, approximately 80 kilometres east of Alice Springs. The map area, approximately 18 square kilometres in size, is situated within the western part of the Giles Creek Synform in the vicinity of Tommys Gap Dam.

The main topographic features of the study area are the sharp ridges which are formed of upper Proterozoic quartzite and rise to heights of 200 metres above the surrounding plains (750 metres above sea level). Lower hills are comprised of upper Proterozoic sandstone, carbonate and granitic rocks and have a relief of about 100 metres. Sand, gibber and alluvial plains contain many outcrops in the form of small rounded hills.

1.2 PREVIOUS INVESTIGATIONS

The earliest geological studies in the region took place during the 1890's and were concerned mainly with the gold discoveries in the Arltunga area, and mica discoveries in the Harts Range area (Shaw et al 1984b). The first systematic geological mapping of the Eastern Arunta region did not take place until the early 1950's, when Joklik (1955) investigated the economic significance of the abundant mica-bearing crystalline rocks of the Harts Range.

Since the 1960's BMR workers have mapped the Amadeus Basin and established basement-cover structural relations along the basin margin (Wells & others, 1967; Forman & others, 1967). The basement cored nappes near Arltunga were investigated in more detail between 1967 and 1971 (Stewart, 1971b; Forman, 1971; Shaw & others, 1971). In the vicinity of the Giles Creek Synform the geological investigation to date has been limited to regional 1:100 000 scale interpretation (BMR-Artunga-Harts Range Sheet). Staff and students from the Geology Department, University of Adelaide are currently re-examining the region.

1.3 AIMS OF STUDY

(1) To produce a geological map at the scale of 1:8330 of the study area.
(2) To investigate the petrography and geochemistry of the intrusive rocks in the area in an attempt to determine magma origin and fractionation history.
(3) To obtain an age of the intrusive rocks of the study area, to fix the minimum age of the basement and compare with other parts of the Arunta Inlier.

1.4 METHODS OF STUDY

(1) Two colour aerial photographs of 1:25000 scale, together with black and white enlargements of 1:8330 scale, were used to map the study area.
(2) 25 thin sections were described petrographically.
(3) Geochemical analysis of 25 samples representative of the lithologies in the study area.
(4) U - Pb isotopic analysis of zircons extracted from the tonalite of the study area.

CHAPTER 2 : FIELD GEOLOGY

2.1 REGIONAL GEOLOGY

The Giles Creek Synform is located in the south eastern margin of the Arunta Inlier of Central Australia. The Arunta Inlier is a complex ensialic mobile belt consisting of Precambrian metamorphosed and deformed igneous and sedimentary rocks. It is characterized by a 1500Ma polycyclic history of thrust-faulting along long-lasting zones of weakness, polymetamorphism and episodic granite intrusion, and is surrounded on most sides by Proterozoic and Phanerozoic sedimentary cover.

Stratigraphic sequences can be established locally, but because of extensive faulting cannot be extended throughout the Inlier. Due to this a stratigraphic model, known as the Division concept (Shaw & Stewart 1975), was established based on facies assemblages and lithological correlation. The model subdivided the Arunta Inlier into three broad stratigraphic groups, called Divisions 1, 2 & 3, of early to middle Proterozoic age. Division 1 comprises mafic, felsic and aluminous granulites, quartzofeldspathic gneiss and minor amounts of calc-silicate rocks. Division 2 is the most extensive of the three Divisions and contains abundant aluminous and silicic metasediments, lesser calcareous rocks and a few mafic flows or sills. Division 3, the least extensive of the three Divisions, is a quartzite-shale-carbonate sequence.

Shaw et al (1984a) have also divided the Arunta Inlier geographically into three latitudinal Tectonic Provinces (Northern, Central and Southern). Each of the zones has distinct lithologies, grades and times of metamorphism, abundances and types of granite, and metal contents (Shaw et al 1984b).

The Tommys Gap Metamorphics are the main rock unit within the study area and have been placed in the Division 2 group of rocks of the Arunta Inlier. The southern part of the Atnarpa Igneous Complex, consisting of diorite-tonalite-granite-aplite and hydrothermal veins, has intruded these rocks. Faulted contacts exist between the above mentioned units and the sedimentary rocks of the Amadeus Basin.

The Amadeus Basin is the remnant of an intracratonic depression which contains a thick succession of Late Proterozoic to Mid Palaeozoic sediments (Kennard et al 1986) and rests unconformably on the southern margin of the Arunta Inlier. Sedimentation commenced in the Upper Proterozoic (Adelaidean) with the deposition of the Heavitree Quartzite. After mild epeirogenic movement the Bitter Springs Formation was deposited (Kennard et al 1986).

2.2 LITHOLOGIES OF THE STUDY AREA

The study area contains both the basement rocks of the Arunta Inlier and the cover rocks of the Amadeus Basin. The distribution of these lithologies can be seen on the geological map (Figure 1) which accompanies this thesis.

2.2.1 TOMMYS GAP METAMORPHICS

The Tommys Gap Metamorphics occupy the core of the Giles Creek Synform and consists of calc-silicate rock, marble, quartz biotite schist, mylonite, orthogabbro and laterite/ironstone.

The calc-silicate rock is the most dominant, occupying most of the western margin of the field area. Since this lithology is surrounded by granite and tonalite on three sides, it is most likely that it suffered contact metamorphism at the time of intrusion, rather than being the result of a regional metamorphic event. The abundance of actinolite and epidote within the calcsilicate is characteristic of a contact metamorphosed impure limestone. The lack of any preferred orientation of the minerals within the rock also supports a contact metamorphic origin.

Marble within the basement occurs as three main bodies, two in the west and one in the east. This lithology is massive, medium to course grained, calcite rich and grey/green in colour. In places the marble is cut by numerous quartz, calcite, hematite veins which are random in orientation (plate 1-1). On rare occasions the marble shows slight signs of initial bedding which have been warped and folded.

A smaller outcrop of marble occurs just south of the E - W trending fault near the centre of the study area, completely surrounded by tonalite. This outcrop was first thought to be limestone of the Bitter Springs Formation which had had tonalite intruded around it, but is now known to be marble of the Arunta Inlier basement for two reasons. First, it is located on the basement side of the E-W trending fault and second, and more importantly, the tonalite is some 900Ma older than the Bitter Springs Formation so the tonalite could not have intruded around the Bitter Springs Formation (See dating, Chapter 5).

A quartz biotite schist is restricted to the south-eastern corner of the field area. This lithology is fine grained and grey in colour with the biotite grains showing a well defined foliation. Outcrop is in the form of low lying, rounded hills.

Adjacent to the quartz-rich metasediments is a band of mylonite (plate 1-2) about 80m wide and exhibits a foliation parallel to that found in the metasediments. The mylonite is predominantly quartz with all grains elongated in the direction of the foliation. Grainsize is fine to medium with the occasional quartz phenocryst up to 10cm. This mylonite is the result of a shear zone.

To the north of the mylonite is a large outcrop of orthogabbro. In hand specimen it appears to consist mostly of dark green to black pyroxene and amphibole and has varying amounts of plagioclase present. Grainsize ranges from medium to coarse. In places the orthogabbro has been brecciated and had an acid magma of some sort intruded into the interspaces (plate 1-3).

Laterite/ironstone is restricted to the western margins of the study area and ranges from homogeneous specular hematite ironstone to conglomeritic laterite. It has a distinctive red-brown colour due to its ferrigenous nature. Outcrops are best seen on hill tops and are up to 250 to 300 metres in size. The conglomeritic laterite contains remnant pebbles ranging in size from a few millimetres to 10 cms, within a fine grained hematite rich matrix (plate 1-5).

2.2.2 ATNARPA IGNEOUS COMPLEX

The Atnarpa Igneous Complex intrudes the Tommys Gap Metamorphics and has extensive outcrop in the Giles Creek Synform. Shaw et al (1984b) have described the Complex as a consanguineous suite of diorite - tonalite - granodiorite - granite - aplite and hydrothermal veins formed by fractional crystalization. The granodiorite is the only rock that does not occur within the study area; it is found further to the east.

DIORITE

This rock type is the least extensive of the igneous intrusives and outcrops about 500m north of Tommys Gap. The diorite has a primary mineral composition of hornblende, biotite and plagioclase. There is no preferred orientation of the crystals within the rock. Minor sulfide minerals are present along cracks and fractures.

TONALITE

Tonalite occupies a large area of the study area and outcrops as low lying, rounded to blocky hills. The tonalite almost completely surrounds the granite and in the east there are a few granitic dykes which cut the tonalite (plate 1-4), indicating that it is older than the granite. There is a variation in mafic mineral abundance within the tonalite, but overall the tonalite contains slightly more mafics than the granite. Biotite and hornblende grains produce a very steep to vertical foliation, in all but the western margins of the tonalite, with trends ranging from ENE-WSW to E-W.

In close proximity to the calc-silicate the tonalite has a green tinge due to the presence of epidote which is the result of metasomatic alteration. The northern margins of the tonalite abuts an E-W trending fault, and is here rather brecciated and jointed. This indicates that the tonalitic magma emplacement preceded faulting.

The small tonalite body situated within the marble in the north-west corner of the study area contains a small number of mafic inclusions (plate 1-6).

GRANITE

The granite is the most extensive of the igneous rocks in the study area and forms a large irregular body within the tonalite. Although the granite is a single body it shows a marked contrast from east to west. It contains roughly equal proportions of albite and microcline and is most leucocratic in the east and becomes less leucocratic, with increasing abundance of hornblende and biotite, towards the west.

In the western margin of the granite body, unaltered potassium feldspar gives the rock a pink to tan colour with the biotite and hornblende forming dark blebs to give the granite an overall speckled appearance. Towards the east, the granite becomes a dirty, creamy white due to kaolinisation of potassium feldspar. Here, the granite has been slightly sheared and jointed and the resulting planes make ideal ducts for fluids to enter and weather the rock. The lack of ferromagnesian minerals in the east may be due to weathering.

Aplite dykes are seen within the granite and the tonalite throughout the study area and range in thickness from a few centimetres to approximately one metre (plate 1-7).

2.2.3 AMPHIBOLITE

This lithology occurs as dykes at widely separated localities in the study area and intrude the Atnarpa Igneous Complex. It is black in appearance, fine grained and is generally fractured.

2.2.4 HEAVITREE QUARTZITE

The Heavitree Quartzite is the basal unit of the Amadeus Basin sequence and rests unconformably against the Arunta Inlier, but within the study area, the Heavitree Quartzite tends to have faulted contacts with the Arunta Inlier basement, and consequently the unconformity is not visible. Isotopic data on dykes in the basement (Black et al 1980) indicate that the formation is less than 900Ma in age.

The Quartzite shows very little variation in lithology over the extent of the study area. It exhibits continuous beds which are thickly laminated to very thickly bedded (0.5cm - >1m). Conglomerate beds occur throughout the Quartzite containing pebbles of quartz up to 1.5cm. These beds are usually 30-40cm thick and exhibit well defined fining up sequences which indicate that the Quartzite has been overturned. Tops of beds, when exposed, often show ripple marks (plate 1-8) with a wavelength and amplitude of approximately 4-5cm and 0.5cm respectively. In cross section the ripples are symmetrical which suggests they developed due to an oscillating current, most likely in a shallow water, tidal environment.

To the east of Tommys Gap the Quartzite shows remnants of pyrite crystals

2.2.5 BITTER SPRINGS FORMATION

The Bitter Springs Formation, consisting of interbedded dolomite and siltstone, conformably overlies the Heavitree Quartzite (Kennard et al, 1986). This Formation was deposited in slightly deeper water following a mild epeirogenic movement (Kennard et al, 1986) which caused a marine transgression. The Bitter Springs Formation has been subdivided into a lower Gillen Member and an upper Loves Creek Member (Wells et al, 1967). While the Loves Creek Member doesn't appear within the study area, the Gillen Member forms a continuous outcrop from east to west.

The Gillen Member, within the study area, consists of dolomite and red siltstone which have been folded along an E-W trending fold axis. The folding and faulting of the Gillen Member occured during the Areyonga Movement (Kennard et al, 1986). This phase of uplift and erosion is responsible for the loss of the Loves Creek Member. The dolomite is grey in colour, exhibits bedding on the scale of approximately 30cm and contains thin beds of shale. Thin quartz veins are abundant and randomly orientated. The red siltstone varies from massive to cross bedded and is faulted against the Atnarpa Igneous Complex to the south.

2.3 STRUCTURE

The Giles Creek Synform is interpreted as a synformal klippe which is an erosional feature of the Arltunga Nappe Complex (Shaw et al 1984b). The Arltunga Nappe Complex is situated on the north-eastern margin of the Amadeus Basin. It was originally described by Forman et al (1967) as consisting of two large fold nappes, the White Range and Ruby Gap Nappes, one on top of the other. They each have a crystalline core of basement rocks of the Arunta Inlier and a sedimentary envelope of Heavitree Quartzite and Bitter Springs Formation. Later work has shown that the Complex consists of only one large fold nappe (Stewart 1971b).

The Arltunga Nappe Complex was formed during the Late Devonian - Carboniferous Alice Springs Orogeny and has been folded about a broad horizontal east-west antiform (Shaw et al 1984b).

Within the study area, the siltstone of the Bitter Springs Formation contains a horizontal anticline which is an open, east-west trending feature. In fact all beds of the Amadeus Basin sequence strike approximately east-west and have been interpreted as being deformed during the Alice Springs Orogeny which was a thrust faulting episode (Shaw et al. 1984a).

All the major faults in the study area (Figure 1) are very steep to vertical which is not characteristic of a thrust faulting event. These faults are therefore interpreted to have occurred towards the end of the Alice Springs Orogeny, after the thrust faulting event which produced the nappe. They could well reflect movement along pre-existing faults within the Arunta Inlier basement.

The mylonite and quartz-biotite schist, within the study area, exhibit a foliation trending 058/70^{o} southeast. A lineation within the foliation defined by mica grains plunges 65^{o} to the south.

The Atnarpa Igneous Complex exhibits a foliation which is restricted to the eastern margins of the granite and tonalite. Towards the west of the study area the igneous bodies have a massive texture. The foliation shows a slight variation but generally trends 065/75^{o}.

2.4 METAMORPHISM OF THE STUDY AREA

The basement rocks of the study area have suffered at least five phases of metamorphism of varying grades (Shaw et al 1983). Within the Arunta Inlier, metamorphic grades range from granulite to low greenschist (Shaw et al 1984a).

At least two metamorphic events have been observed within the study area. The first, a contact metamorphic episode as a result of the intrusion of the granite and tonalite bodies. The second, a more regional event, is interpreted as occurring during the Alice Springs Orogeny.

The recognition of these two metamorphic events was on the basis of minerals present in the lithologies of the study area (See Petrography, Chapter 3). Contact metamorphism of the Tommys Gap Metamorphics produced calc-silicates and marble. The calc-silicates contain epidote and actinolite which are characteristic of contact metamorphism whilst the marble contains epidote. The lack of preferred orientation of minerals in both lithologies is also indicative of contact metamorphism (Ehlers & Blatt, 1982).

Petrographical analysis of the intrusive igneous bodies revealed that they contain chlorite, actinolite and epidote and have also been partially recrystallised. The presence of these in the one rock is characteristic of greenschist facies metamorphism (Ehlers & Blatt, 1982).

Work done by Armstrong and Stewart (1975) yielded a Rb-Sr total rock age of 335-312 m.y. for the retrograde greenschist zone which has affected the study area. This age corresponds to the Late Devonian - Carboniferous Alice Springs Orogeny.

PLATE 1 : FIELD PHOTOGRAPHS

See Appendix 1 for Observation Locality Map.

1.1 Quartz-calcite-hematite veins in basement marble. Observation Locality A.

1.2 Mylonite exhibiting a well defined foliation. Observation Locality B.

1.3 Acidic rock filling interspaces of brecciated orthogabbro. Observation Locality C.

1.4 Granitic dyke cutting through the darker tonalite body. Observation Locality D.

1.5 Laterite showing conglomeritic nature with hematite rich matrix. Observation Locality E.

1.6 Xenoliths within the tonalite. Observation Locality F.

1.7 Aplite dyke cutting granite. Observation Locality G.

1.8 Ripples within the Heavitree Quartzite. Observation Locality H.


1.1

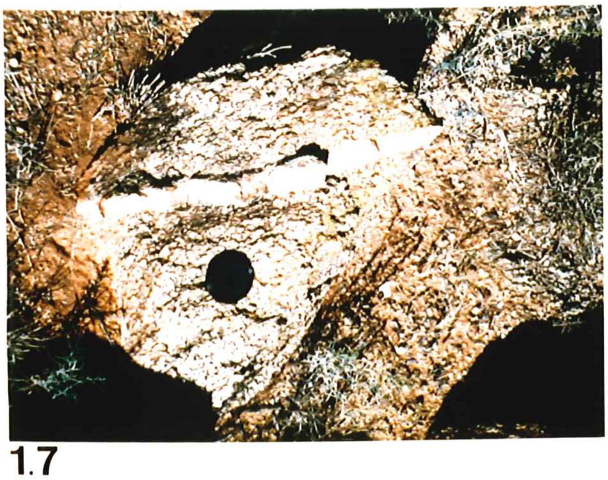

1.2


1.3


1.4


1.5


1.6


1.7


1.8

CHAPTER 3 : PETROGRAPHY

3.1 INTRODUCTION

The petrographic analysis of 20 thin and polished thin sections, with corresponding hand specimens, was undertaken in order to describe in detail a representative selection of the Arunta Inlier basement lithologies present in the study area. These descriptions represent a compilation of several slides of each lithology. Appendix 3 contains a more detailed description of individual hand specimens and thin sections.

3.2 TOMMYS GAP METAMORPHICS

3.2.1 MYLONITE

The quartz crystals in this lithology are anhedral. Biotite and muscovite grains are subhedral to euhedral and form a lepidoblastic foliation (plate 2-1).

Quartz, the most dominant mineral (85%), occurs as fine to medium elongate grains and exhibits undulose extinction. Grain boundaries range from straight to very irregular against like and different phases. Fracturing is quite common.

Muscovite is the main platey mineral (10%), with fine grains forming a well defined foliation throughout the slide.

Biotite is dispersed throughout the slide as fine grains and are parallel to the mineral alignment shown by all minerals. The biotite displays weak pleochroic colours ranging from pale brown to red brown.

Alkali feldspar is distinguished from plagioclase by its distinct cross hatch twinning. Both are fine grained, anhedral and appear in trace amounts.

Opaques are randomly distributed throughout the slide in trace amounts and exhibit very irregular grain boundaries. The larger grains contain inclusions and have a somewhat poikiloblastic texture.

3.2.2 CALC-SILICATE

The calc-silicate, in thin section, has a very brecciated appearance and consists mostly of actinolite (60%), and calcite and/or dolomite (35%) filling the interspaces (plate 2-2). Quartz, epidote, and opaques are minor phases.

Actinolite has been brecciated to a great extent along its cleavage planes, and is present as fine, anhedral to subhedral fragments. Outlines of remnant grains can be distinguished. Epidote is only slightly less brecciated than the actinolite and remnant subhedral to euhedral grains can be seen.

Fine grained, anhedral calcite and/or dolomite, which have distinct twinning and cleavage traces, occurs as a secondary phase. Plagioclase may be present as fine anhedral grains, but due to the highly brecciated nature of this lithology it is difficult to distinguish from calcite or dolomite which show similar twinning.

Quartz occurs as fine, anhedral grains which are fractured to varying degrees. Undulose extinction is shown by all quartz grains. Opaques are common as fine, anhedral grains.

3.2.3 QUARTZ-BIOTITE SCHIST

This grey-brown fine grained schist is composed of quartz (50-60%), biotite (30-35%), plagioclase (~5%), with minor apatite and opaques.

Quartz dominates this lithology and occurs as anhedral fine grains and exhibits undulose extinction. Biotite is present as fine, subhedral to euhedral grains and forms a well defined lepidoblastic foliation (plate 2-3). Pleochroism of the biotite grains ranges from straw yellow to red brown.

Plagioclase grains are anhedral and fine and display polysynthetic multiple twinning. Sericitization has occurred within a few of the plagioclase grains.

3.2.4 MARBLE

This lithology is predominantly calcite (90-95%), with minor epidote (plate 2-4).

Calcite occurs as fine to medium (0.2-2mm) anhedral grains which are rather interlocking. Cleavage planes intersect at oblique angles (approx. 45°) and multiple twinning is also present. Within some calcite grains, the twinning planes are slightly warped. Epidote is present as fine subhedral to anhedral grains, and easily distinguished due to their high birefringence.

3.2.5 ORTHOGABBRO

This lithology showed quite a variation in mineralogy, with the major minerals being actinolite (20-50%), chlorite (20-30%), plagioclase (5-40%), epidote (5-10%), biotite (~5%) and quartz (2-5%). Accessory minerals are opaques, muscovite, sphene and apatite (plate 2-5).

Actinolite is the most dominant mineral and occurs as fine to medium (.2-3mm), subhedral to anhedral, columnar to fibrous grains. They are green in colour and have 120° cleavage. Most grains are intergrown with rugged boundaries and show patchy interference colours. All grains show weak pleochroic colours ranging from yellow green to green and a few exhibit multiple twinning. Inclusions within the actinolite are epidote, sphene with pleochroic halos, plagioclase and quartz.

Chlorite occurs as fine to medium (.1-2.5mm) anhedral grains, intergrown with the actinolite and has weak pleochroic colours ranging from pale to deep green. The relationship between the chlorite and actinolite grains suggests that the chlorite is secondary after actinolite.

Plagioclase is present as fine grains which fill the interstice between actinolite and chlorite grains. All grains are anhedral and form a fine grained mosaic with quartz grains, suggesting partial recrystallisation. Sericitization has occurred to varying degrees in all grains, but on the whole almost completely replaces the plagioclase. Unaltered grains show multiple twinning.

Epidote occurs as subhedral to anhedral fine grains and are distinguished from actinolite by its higher birefringence and mottled appearance. It is generally found at the margins of actinolite grains, within the sericitization of the plagioclase. Some grains have a poikiloblastic texture.

Quartz grains are fine and anhedral. They only occur within the mosaic of recrystallised grains and show undulose extinction. Accessory minerals are opaques and sphene with pleochroic halos.

The actinolite is the result of retrograde greenschist facies metamorphism of a calcium rich pyroxene, most likely augite (Purvis pers. comm.). Assuming all the chlorite present in the rock resulted from the alteration of actinolite, then the original rock would have contained >50% pyroxene. This rock was called an orthogabbro due to the abundance and lack of initial pyroxene and olivine respectively.

The extraordinarily high actinolite and chlorite contents of sample 888-036 indicates it may have contained about 80% pyroxene. This suggests that this lithology may have resulted from a partially cumulative process with pyroxene grains crystallising and settling out of the magma.

3. 3 ATNARPA IGNEOUS COMPLEX

3. 3.1 DIORITE

The mineralogy of the diorite appears fairly constant with the major phases being hornblende (35-40%), plagioclase (35-45%), quartz (5-8%), epidote (8-10%) and biotite (2-5%). Minor potassium feldspar and muscovite is present. The only recognizable accesory minerals are sphene and opaques. The rock has a bimodal grainsize indicative of partial melting and recrystallisation.

Hornblende occurs as fine to medium (0.1-4mm), subhedral to anhedral grains which exhibit rugged grain boundaries. Sphene granules are present within the green hornblende grains, suggesting they have altered from a variety of brown hornblende (Heinrich 1982). Pleochroism is exhibited by all grains and ranges from straw yellow to green. Patchy interference colours is common amongst the larger hornblende grains and some are highly fractured. Chlorite alteration is complete in some grains.

Plagioclase is present as fine to medium (0.1-4.5mm), anhedral grains which exhibit characteristic polysynthetic twinning. Sericitization has occurred to a substantial degree in most of the larger grains whilst the fine recrystallised grains have little to no sericite alteration. Potassium feldspar is present only in minor amounts as fine anhedral grains with microcline cross hatch twinning.

Quartz grains are fine and anhedral. They occur within the fine grained recrystallised mosaic and exhibit undulose extinction.

Biotite has a close association with hornblende and is fine grained. Chlorite alteration has taken place to some extent. minor muscovite is also found with the biotite.

Epidote appears mostly within the sericite alteration of plagioclase as fine, subhedral to anhedral grains. They are a secondary phase and form a brightly coloured mosaic under cross polars.

3.3.2 TONALITE

The tonalite within the study area has a bimodal grainsize which suggests recrystallisation has occurred. Typical mineralogy is quartz (40-45%), plagioclase (30-35%), biotite (10-15%), epidote (5-10%) and minor amounts (0-5%) of alkali feldspar and hornblende (plate 2-6).

Quartz is the dominant phase and occurs as fine to medium (.02-2mm) anhedral grains with irregular boundaries. All grains exhibit undulose extinction and some of the medium sized grains are fractured.

Plagioclase grains are fine to medium (.1-3mm), subhedral to anhedral and have grain boundaries which range from straight to lobate. Multiple twinning is hard to recognize due to the amount of sericitization which has taken place, with some grains completely serictized. Few grains show Carlsbad twinning. Myrmelcitic texture is present in some grains with rod-like inclusions of quartz within the plagioclase. Quartz filled fractures are also present.

Biotite is the main ferromagnesian phase and occurs as fine to medium (.05-1.2mm) subhedral grains. Pleochroic colours range from straw yellow to a dark greenish brown. A well defined foliation is developed due to the preferred orientation of biotite grains (plate 2-7). Chlorite alteration is apparent in a small number of grains. Hornblende, when present, usually occurs in close association with the biotite as subhedral to anhedral, fine grains. Their pleochroism ranges from yellow green to deep green. Epidote is a secondary phase found in association with biotite and hornblende as subhedral to anhedral grains. Most grains have inclusions of quartz and apatite. Lamellar twinning is common.

Alkali feldspar occurs within the fine grained mosaic, formed by recrystallisation, as anhedral grains. Distinct microcline cross-hatch twinning is shown by all such grains.

Accessory minerals include fine, subhedral to euhedral muscovite and apatite and euhedral zircon (plate 2-8), all of which seem to be found in close proximity to the biotite.

3.3.3 GRANITE

All granite samples show some degree of recrystallisation and metamorphism. The mineralogy of the granite was quite consistent and typically contains fine to medium (.1-4mm) quartz

(30-40%), plagioclase (20-25%), potassium feldspar (20-30%), biotite (3-10%) and accessory magnetite, hematite, muscovite, sphene, zircon, apatite, epidote, corundum (plate 3-1) and hornblende. Hornblende is only present in appreciable amounts in sample 888-36 (plate 3-2).

Quartz grains are anhedral with rugged grain boundaries and quite often have a consertal texture. The fine grains form a mosaic with potassium feldspar within the recrystallised groundmass. All grains show undulose extinction.

Plagioclase grains are subhedral to anhedral and exhibit multiple twinning which is bent in a few grains. Carlsbad twins occur in a few grains also. Sericite alteration has taken place to varying extents in all grains, which is seen under plane polarised light as dusty cores.

Potassium feldspar is present as both microcline and orthoclase and are distinguished by the presence and absence of cross-hatch twinning respectively (plate 3-3). It occurs within the fine grained recrystallised groundmass and also as medium sized grains which are often fractured. Sericite alteration of potassium feldspar is only minor.

Biotite occurs as clusters of subhedral to euhedral grains and have pleochroic colours ranging from straw yellow to olive green/brown. Chlorite alteration has taken place on the rims of some grains (plate 3-4). Inclusions of epidote and quartz are common. Muscovite occurs in accessory amounts associated with the biotite. Epidote is also found in association with the biotite as euhedral to anhedral grains. These show high relief, have a mottled appearance and appear to be secondary. Allanite is one form of epidote present and shows distinctive zoning (plate 3-5).

Magnetite is the dominant opaque mineral and occurs as anhedral grains. In sample 888-26 most grains have a martite texture (plate 3-6) due to the replacement of magnetite by hematite along crystallographic preferred planes as a result of oxidation (Craig et al 1981).

Hornblende is mostly present in minor amounts but sample 888-31, which has mafic inclusions, contains approximately 15%.

3.3.4 HYDROTHERMAL VEINS

Epidote forms up to 95% of the hydrothermal veins (plate 3-7). It is present as fine to medium (.05-4mm) subhedral to euhedral grains, all of which show brilliant interference colours. Fracturing occurs within the grains to differing degrees.

Quartz occurs within the veins as fine, anhedral grains showing undulose extinction. Chlorite is also present in small amounts.

The hydrothermal veins appear to be the result of intruding fluids, hence are interpreted as being primary rather than the product of alteration of the country rock.

3.4 AMPHIBOLITE

The amphibolite is a fine grained rock with a minerology consisting of amphibole (70%), plagioclase (20%), quartz (5%) and minor amounts of potassium feldspar and epidote (plate 3-8). Accessory minerals include sphene, apatite and opaques.

Fine to medium grained (0.02-3mm), anhedral to subhedral amphibole is the dominant phase in this rock. Most amphibole grains are fine and form a fine grained mosaic suggesting recrystallisation has occurred. Some of the larger grains have a poikiloblastic texture due to inclusions of what appears to be secondary quartz. Pleochroic colours range from pale yellow/brown to deep green. Chlorite alteration has occurred within some amphibole grains.

Plagioclase grains are fine to medium (0.05-1.5mm) and anhedral. Multiple twinning is present and sericitization is common.

Quartz occurs as fine, anhedral grains. They are present within amphibole grains as well as in association with the fine grained plagioclase of the recrystallised matrix. All quartz grains exhibit undulose extinction.

Potassium feldspar is microcline and exhibits distinctive cross-hatched twinning. It occurs as fine, anhedral grains and has been slightly sericitized.

Epidote is present as fine anhedral grains which often have a poikiloblastic texture. It occurs mostly within the sericite alteration of plagioclase and potassium feldspar. All epidote grains show bright birefringence colours under cross polars.

PLATE 2 : MICROPHOTOGRAPHS

The following key for mineral identification is applicable for both microphotograph plates.

Q = Quartz
B = Biotite
P = Plagioclase
K = Potassium feldspar
E = Epidote
A = Actinolite
H = Hornblende
C = Chlorite
M = Muscovite
He= Hematite
Z = Zircon

2.1 Mylonite : elongated quartz grain and alignment of muscovite define the foliation. 888-4. X-polars. (X35 mag.)

2.2 Calc-silicate : brecciated actinolite and epidote within fine grained calcite/dolomite. 888-10. X-polars. (X35 mag.)

2.3 Quartz-biotite schist : foliation defined by biotite. 888-5. Plane polarised. (X35 mag.)

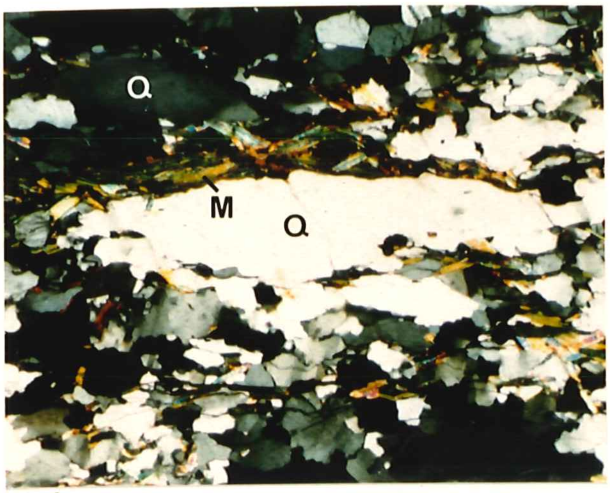
2.4 Marble : calcite showing twinning and cleavage traces. 888-8. X-polars. (X35 mag.)

2.5 Orthogabbro : typical mineralogy. Actinolite grain shows simple twin and plagioclase slightly sericitized. 888-76. X-polars. (X35 mag.)

2.6 Tonalite : typical mineralogy. Plagioclase exhibiting multiple and Carlsbad twinning and also sericitized. 888-20. X-polars. (X35 mag.)

2.7 Tonalite : lepidoblastic foliation developed by biotite. 888-22. Plane polarised. (X35 mag.)

2.8 Tonalite : zircon grain with a pleochroic halo. 888-25. Plane polarised. (X115 mag.)



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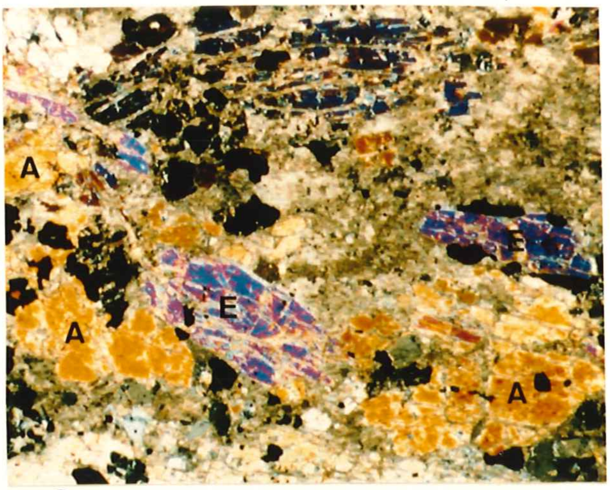

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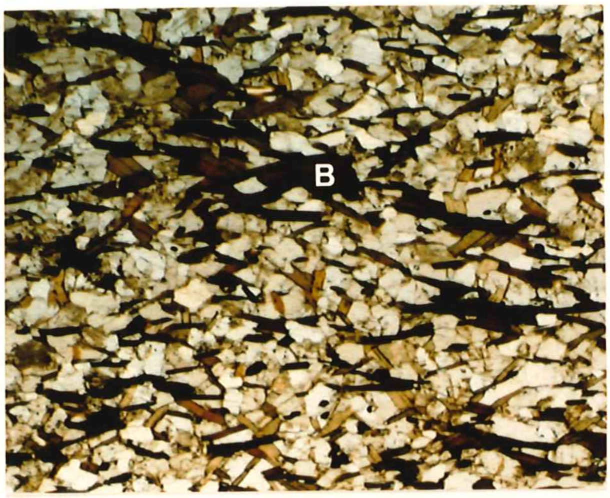

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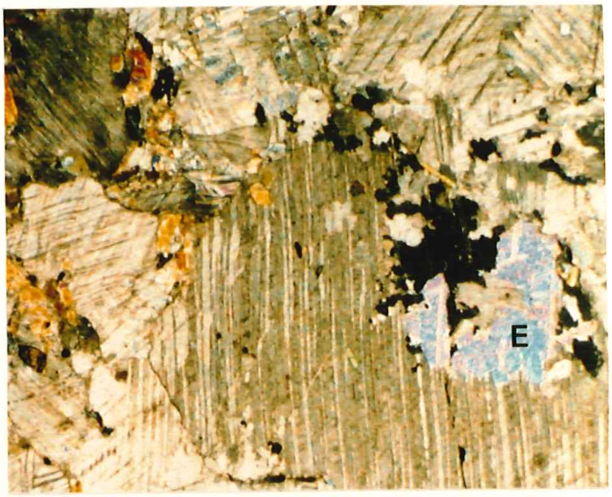

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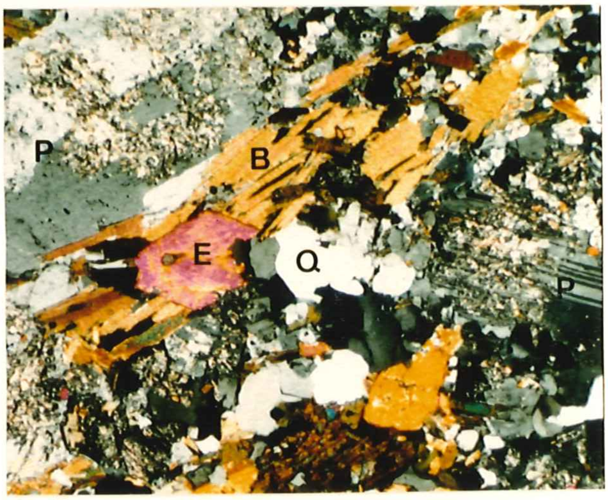

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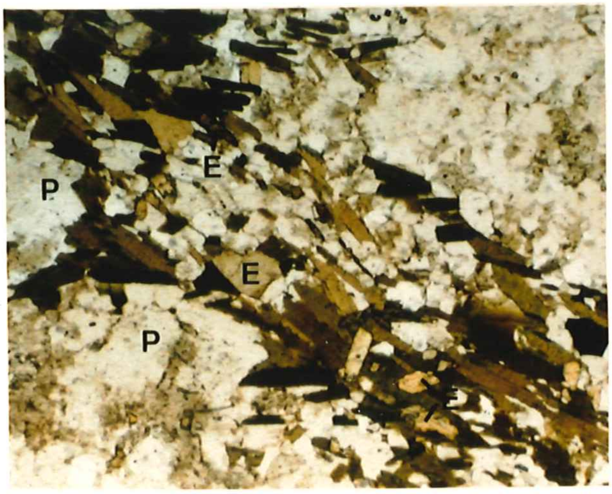

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2.8

PLATE 3 : MICROPHOTOGRAPHS

3.1 Granite : corundum within muscovite. Dark minerals are hematite and biotite. 888-26. Plane polarised. (X35 mag.)

3.2 Granite : hornblende containing fine sphene granules. 888-31. X-polars. (X35 mag.)

3.3 Granite : microcline (right) and orthoclase (left) cut by recrystallised vein. 888-26. X-polars. (X35 mag.)

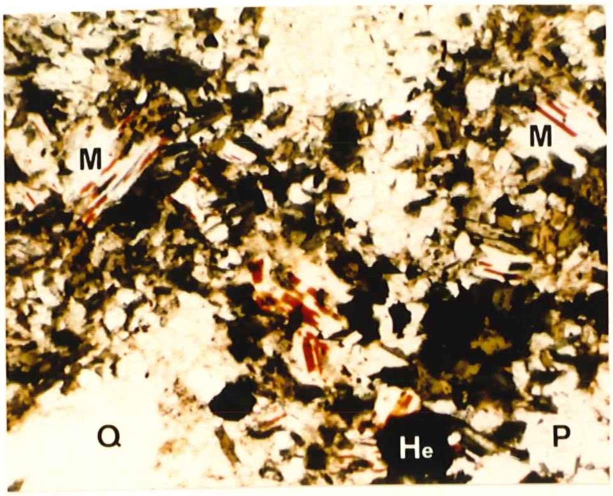
3.4 Granite : typical mineralogy. Note that biotite has slight chlorite alteration along grain boundaries and plagioclase has been sericitized. 888-71. X-polars. (X35 mag.)

3.5 Granite : allenite grain exhibiting distinctive zoning. 888-71. X-polars. (X35 mag.)

3.6 Granite : martite texture due to hematite replacing magnetite. Remnant magnetite crystallographic planes within fawn patches. 888-26. X-polars. (X35 mag.)

3.7 Hydrothermal vein. 888-35. X-polars. (X35 mag.)

3.8 Amphibolite : typical mineralogy. 888-81. Plane polarised. (X35 mag.)



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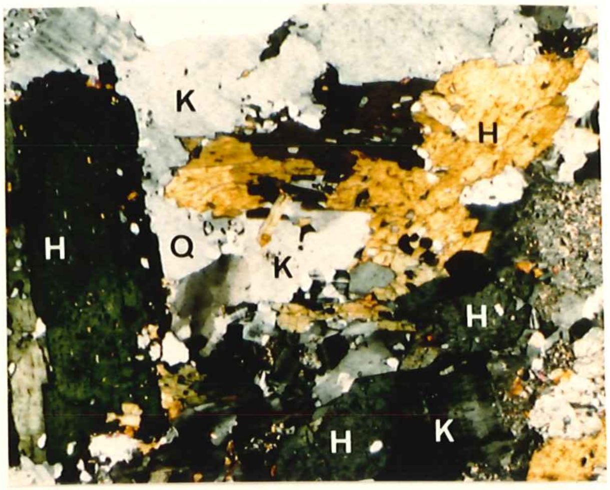

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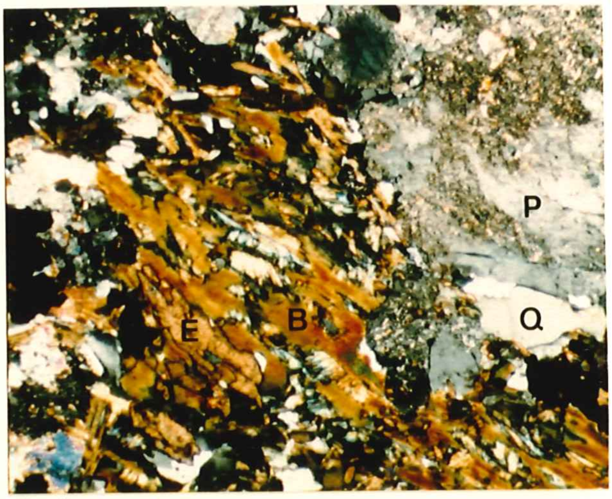

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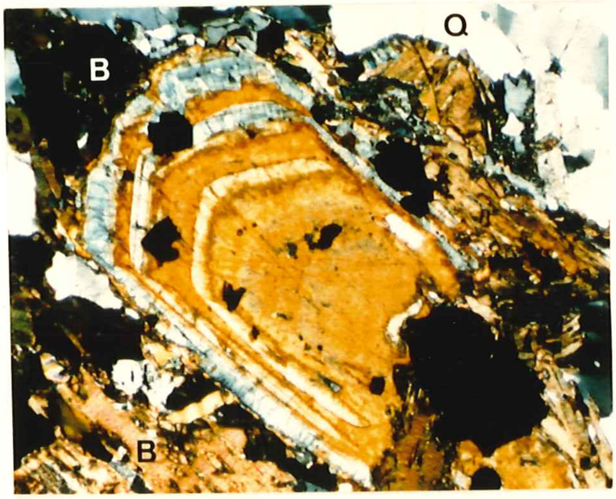

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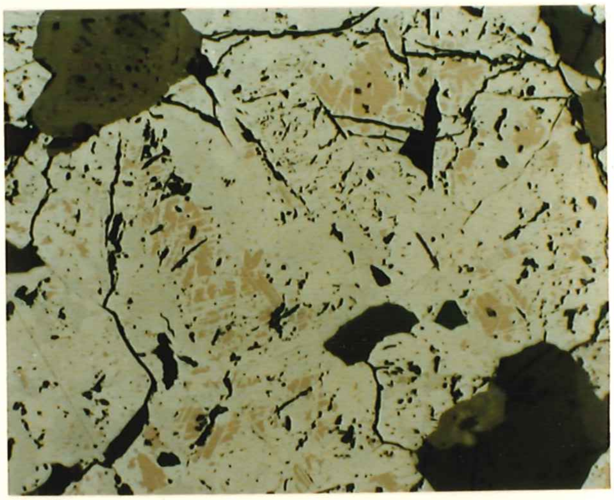

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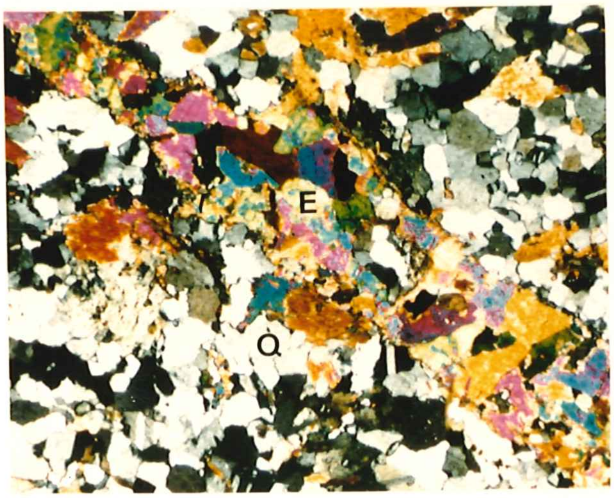

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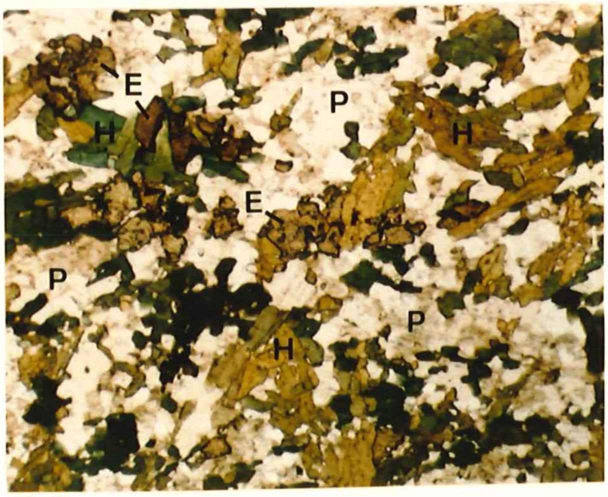


3.8

CHAPTER 4 : GEOCHEMISTRY

4.1 INTRODUCTION

Major element, and trace element data for the 25 samples analysed are presented in appendix 4 and geochemical procedures used are outlined in appendix 2. Appendix 1 contains a sample locality map. The geochemical evolution of the granitic rocks will be discussed assuming the analyses are truly representative of such processes although it is known that the area has been subsequently metamorphosed which may have had some effect on chemical distribution.

4.2 FRACTIONAL CRYSTALLISATION OR RESTITE UNMIXING?

In an igneous rock terrain which consists of a variety of different igneous rock types one must consider whether or not they have a related origin. Have they evolved from a homogeneous parent magma by the process of fractional crystallisation? Could they have resulted from varying degrees of unmixing of the high SiO_2 melt and restite components produced during a partial melting event? Or could these rocks have formed by a combination of these two processes? Or has the variation in rock types resulted from the mixing of two parent magmas to produce intermediate compositions?

The process of fractional crystallisation involves a magma whose first formed crystals are completely or partially prevented from reacting with the melt. By this process the melt composition continually changes and a suite of igneous rocks with different chemical compositions will be formed. The restite model proposed by White and Chappell (1977) is based on the ultrametamorphism of a source rock which produces a partial melt and solid residual material, the later being referred to as restite. Mixing and reaction between the melt and restite then produces a range of compositions.

By considering geochemical and petrographic characteristics of each rock type, it should be possible to determine which of the above processes best explains the origin of the igneous rocks in the Giles Creek Synform.

On Harker diagrams, curved trends are probably the result of some fractional crystallisation process whereas linear trends are readily produced by mixing or unmixing (White & Chappell, 1983). Petrographically, the following features would support the restite model;

1) Clinopyroxene is thought to be a common restite component and is found as cores in hornblende crystals.
2) Inclusions may well be unconsumed restite. Inclusions are usually mafic hornblende-rich types.
3) Calcic plagioclase cores surrounded by the precipitation of more sodic plagioclase. This is not necessarily a good distinguishing feature as it is also characteristic of fractional crystallisation.

The tonalite is the only rock type observed to contain mafic inclusions (plate 1-6) which may indicate that the tonalite was formed by restite unmixing. The granite appears to have no inclusions, which may be consistant with the restite model since more felsic magmas are those that have freed themselves of residual material (White & Chappell, 1983).

Petrographical analyses reveal that none of the rocks contain clinopyroxene cores in hornblende crystals. Calcic plagioclase cores within more sodic plagioclase crystals were not observed, however only microprobe analyses could determine this.

Straight line trends of the tonalites and granites shown by TiO_2, P_2O_5, V and Ni may support the theory that these rocks formed by restite unmixing, however straight line trends may also be the result of fractional crystallisation processes. Most of the Harker diagrams (Figures 2 - 25) show a slight curvilinear trend for the diorite, tonalite and granite which suggests that the chemistry is being dominated by fractional crystallisation processes.

On Harker diagrams there is a break in the SiO_2 range between the tonalites and granites. This implies that these two rock types have most likely come from separate magmas since a more continuous spectrum over the whole SiO_2 range (60 - 76%) would be expected if they were derived from the same parent magma. The large break in SiO_2 contents between the diorites and tonalites indicates that the diorite was derived from a different magma than the tonalite.

Of the major oxides, Al_2O_3, FeO, MgO and perhaps CaO, best illustrate the characteristic fractional crystallisation trends of the diorite, tonalite and granite. The Zr plot shows a slight increase followed by a rapid decrease with increasing SiO_2. The increasing Zr with SiO_2 stage could result from a mixing of two end members or fractional crystallisation without a zirconium mineral precipitating. The high SiO_2 stage with rapid Zr depletion is almost certainly the result of dominant fractional crystallisation with mineral zircon precipitating.

The orthogabbro has a mafic mineral content in excess of 60% and a cumulative texture, as revealed by petrological analyses. The large variations in content shown by MgO, Al_2O_3, Ni and Cr over the narrow SiO_2 range of the orthogabbro supports the theory that this rock type formed by cumulative processes, with Ca-rich pyroxene being the dominant mineral. The lack of analyses for the amphibolite means its origin is unclear.

4.3 DIORITE

The SiO_2 content of the diorite ranges from 51.91 to 55.77 per cent. The low number of analyses means that no clear trends are produced, but on Harker diagrams of a majority of the major oxides the diorite combines with the tonalite and granite to produce good curvilinear trends. All diorite samples have a mol $Al_2O_3/(Na_2O + K_2O + CaO)$ ratio less than 1.1 and a Na_2O content greater than 3.2% which makes them I-type granitoids under the classification of Chappell and White (1974).

The abundances of Al_2O_3 (17.25 - 20.05%), MgO (5.39 - 5.84%), CaO (7.54 - 9.87%), Fe_2O_3 (6.24 - 8.61%), Na_2O (3.46 - 5.36%) and K_2O (0.89 - 1.77%) are in accordance with the crystallisation of hornblende, biotite, plagioclase and quartz. P_2O_5 and TiO_2 are both low and as a result very little apatite and ilmenite is present in this rock.

The rare earth element contents of the diorite is quite low and, together with the low P_2O_5 and Zr, suggest that there is very little to no rare earth bearing minerals such as apatite and zircon. Petrography analyses reveal this is so.

The trace elements that are present in substantial amounts have been substituted into mineral lattices in place of major elements. The diorite has high V contents suggesting that magnetite is a common opaque mineral. Ba, Sr and Rb indicate the substantial amounts of plagioclase present in this rock.

4.4 TONALITE

The tonalites have a rather broad range of SiO_2, ranging from 63.03 to 72.48 per cent. Mol $Al_2O_3/(Na_2O + K_2O + CaO)$ ratios are < 1.1, all samples except 888-55 and 888-73 have normative corundum and contain greater than 3.2% Na_2O which means that the tonalites, under the classification of Chappell and White (1974), are I-type granitoids.

Harker diagrams show that the major oxides Al_2O_3 (13.83 - 16.44%), Fe_2O_3 (1.34 - 5.67%), MnO (0.05 - 0.08%), MgO (0.74 - 2.07%) and CaO (2.59 - 5.05%) have relatively good curvilinear trends decreasing with increasing SiO_2. This is in accordance with fractional crystallisation of plagioclase, biotite and minor hornblende.

Na_2O and K_2O, which are mobile, don't show good trends but they do remain fairly constant over the SiO_2 range. This suggests that at the dominant later stages during recrystallisation, they both had even contents in the precipitating crystals, thus destroying any initial fractional crystallisation trend.

The decreasing trends of P_2O_5 and TiO_2 most likely represent the fractional crystallisation of apatite and ilmenite respectively. Some TiO_2, however, may also be present in biotite and hornblende since it can proxy for Al in these minerals' lattice.

Of the trace elements, only Sc, V, Sr, and Y show very good decreasing trends with increasing SiO_2. Nd, Nb, Rb, Ni and Zr show poor trends, whilst Ga, La, Ce and Ba show no trends at all. Since there are no apparent veins in the tonalite samples, the scattering shown by some trace elements is interpreted not to be due to mobilisation during partial melting. Hence the tonalite samples are assumed to have been part of a closed system during low grade metamorphism, and any scatter of the trace elements on the Harker diagrams is interpreted to be due to uneven distribution of these elements within the tonalite. Scattering may also be due to the slight variation in mafic mineral abundance.

V contents indicate magnetite is an opaque mineral present in the tonalite. The Sr, Ba and Rb contents are in accordance with the amount of plagioclase. The lack of mafic minerals present in this rock is due to the low Fe and Mg contents of the precipitating magma and is also reflected by low levels of Ni, Cr and Sc.

4.5 GRANITE

The granite has an SiO_2 content ranging from 74.52% to 76.55% (sample 888-031 has an SiO_2 content of 64.50% but contains mafic contaminants). All samples have a mol $Al_2O_3/(Na_2O + K_2O + CaO)$ ratio < 1.1, contain normative corundum and all but one (888-074) have a Na_2O content greater than 3.2%, making them I-types under the classification of Chappell and White (1974).

On the Harker diagrams, Al_2O_3 (12.54 - 16.01%), FeO (0.90 - 3.99%), MgO (0.01 - 2.14%), CaO (0.28 - 4.62%), Na_2O (3.35 - 4.77%), P_2O_5 (0.02 - 0.14%) and TiO_2 (0.11 - 0.51%) all show decreasing trends as SiO_2 increases. The granites have a higher SiO_2 content than the tonalites as expected but have a lower abundance of all other major oxides indicating they evolved from a more differentiated magma than the tonalites. Harker diagrams of the major oxides (except perhaps Na_2O and K_2O) all show clear curvilinear trends connecting the tonalites and granites, suggesting that perhaps they both resulted from the same magma by fractional crystallisation.

The only major oxide to show an increase with increasing SiO_2 content is K_2O. Over the SiO_2 range of the granites, the K_2O content increases by a factor of two. This indicates that low K-bearing minerals are being precipitated early and the evolving magma is becoming enriched in K_2O. The granites with lowest SiO_2 contents most likely have plagioclase feldspar containing greater amounts of Na_2O and as fractionation progressed, the melt became depleted in Na_2O after being incorporated into plagioclase, and the alkali feldspars took in more K_2O which essentially remained in the melt whilst earlier minerals were being fractionated.

CaO and P_2O_5 are most likely being incorporated into apatite. Apatite is the principle carrier of rare earth elements in most igneous rocks (Moore et al 1982) and the decreasing trends of La, Ce, Nd and Y with increasing SiO_2 suggests that they are, in fact, also incorporated into apatite.

TiO_2 and V show decreasing trends, suggesting that magnetite and ilmenite fractionation took place. Na_2O was most likely removed from the melt by being incorporated mostly into plagioclase and alkali feldspars and to a lesser extent, hornblende.

Rb, which can proxy for potassium, increases three fold with increasing SiO_2 and most likely had the same fractionation history as K_2O.

A rapid drop in Zr concentration with increasing SiO_2 content indicates fractional crystallisation of zircon.

4.6 ORTHOGABBRO

This rock group contains characteristic SiO_2 content of 50-55% and relatively high Fe_2O_3 (7.11 - 9.87%) and MgO (9.03 - 16.49%) which reflects the abundance of ferromagnesian minerals present. On the Harker diagrams MgO, Fe_2O_3 and CaO (10.73 - 15.94%) show complex relationships, with only MgO showing a curvilinear trend increasing as SiO_2 increases.

This MgO trend is mirrored by Ni and Cr which are known to proxy for Mg in early forming crystals. Fe_2O_3 and CaO tend to form clusters, but if anything, show a slight increase with increasing SiO_2.

Al_2O_3 (5.65%-16.04%) shows two distinct groups of analyses suggesting there may be two different mineralogies. Petrographical analyses indicates that the lower three samples are those which contain very little plagioclase, are rich in actinolite and chlorite and were formed by cumulative processes. The upper three samples have a higher abundance of plagioclase and are less cumulative in nature.

The high MgO, Ni (89-403ppm) and Cr (157-1137ppm) reflects a high abundance of initial pyroxene (now actinolite and chlorite). High CaO contents suggests that the pyroxene was Ca-rich, most likely augite. CIPW norm calculations for this rock show that it consists of up to 60 per cent pyroxene (Diopside and Hypersthene). Sr, which can proxy for Ca, shows a very broad range in abundances, with the Sr content being highest in samples containing considerable amounts of plagioclase. Hence, it appears Sr is proxying for Ca in the plagioclase rather than in augite.

Fe_2O_3 analyses plot relatively close together and don't show a spread like MgO, indicating that there were equal quantities of Fe_2O_3 in the precipitating minerals and residual melt. This suggests that magnetite or ilmenite are not present in this rock.

Mg# (Mg/Mg + Fe) for the orthogabbro ranges from 74 to 83 which is extremely high and indicates magmatic differentiation was minimal.

The rare earth elements La, Ce, Nd and Y all show reasonably low contents which is in accordance with their incompatible nature.

Sample 888-077 has anomalously high contents of most trace elements, the reason for which, is not clear.

4.7 AMPHIBOLITE

The two amphibolites analysed have low SiO_2 contents averaging 49.44 per cent and since there are only two samples, not much information regarding the origin of this rock type can be determined.

Major oxides, which have reasonably high abundances, include Al_2O_3 (13.29%), Fe_2O_3 (15.91%), MgO (6.35%), CaO (9.0%) and TiO_2 (1.5%). Hornblende, which makes up to 70 per cent of the rock, would contain the bulk of these major oxides, with smaller amounts being present in plagioclase, alkali feldspar, epidote and sericite, all to varying degrees. The high TiO_2 content suggests that magnetite and ilmenite have not been residual minerals in the amphibolite source region.

The relatively low levels of Na_2O (2.24%) and K_2O (1.5%) is characteristic of a basaltic magma. However, Ni, which can proxy for Mg in pyroxenes and olivines, is quite low, and together with the lack of Cr, suggests that the amphibolites are not cumulates from a basaltic magma.

Mg# calculated for the amphibolites average 53, which indicates they resulted from a slightly differentiated magma, hence Ni and Cr may have been removed from the magma by the first formed crystals and the amphibolite has precipitated from a Ni and Cr depleted basaltic magma.

CIPW norm calculations for the amphibolites reveal a free quartz content of up to 10 per cent, while petrological analyses show approximately 5 per cent. This suggests that either the amphibolite or plagioclase present has a low SiO_2 content. Anorthite is the most common calcic plagioclase found in basalts and typically has a SiO_2 content of 43 per cent whilst basaltic hornblende contains about 45 per cent SiO_2.

4.8 COMPARISON WITH THE MOUNT ISA INLIER

The Kalkadoon Batholith, located within the Mt. Isa Inlier, contains granite and tonalite that have a similar geochemistry to those of the Atnarpa Igneous Complex. The similarities are shown in Table 1. The only significant difference is in the abundance of Ba, Rb and Sr, which, according to work done on the relationship between these elements in granitic rocks by El Bouseily and El Sokkary (1975), suggests that the Kalkadoon Batholith is more differentiated than the Atnarpa Igneous Complex (Figure 26).

The BMR, in their April 1987 Research Newsletter, have produced primordial mantle normalised geochemical patterns for a range of igneous rocks. They have grouped together rocks of similar ages in an attempt to show the changes in Proterozoic granitoid compositions with time. Using the plot which has a time interval of 1870-1840 m.y., the granite and tonalite from the Atnarpa Igneous Complex plot very close to data from the Kalkadoon Batholith (Figure 27). This further emphasizes the similarities between the two igneous suites.

TABLE 1. Kalkadoon Batholith compared with the Atnarpa Igneous Complex.

	GRANITE		TONALITE	
	Kalkadoon*	Atnarpa	Kalkadoon*	Atnarpa
SiO_2	75.62	75.34	63.87	66.55
TiO_2	0.11	0.15	0.66	0.49
Al_2O_3	12.60	13.02	16.25	15.72
FeO (tot.)	1.26	1.31	4.93	3.64
MnO	0.03	0.02	0.07	0.06
MgO	0.32	0.25	1.50	1.54
CaO	1.03	1.17	4.12	4.12
Na_2O	2.64	3.69	2.93	4.31
K_2O	5.39	4.26	3.35	2.47
P_2O_5	0.03	0.04	0.17	0.14
Ba	261	704	956	703
Rb	221	111	143	75
Sr	83	156	305	379
Pb	44	12	28	12.6
U	7	5	3	4
Zr	105	103	257	159
Nb	8	6	12	5.4
Y	17	11	29	13.2
La	38	49	66	40
Ce	76	76	120	60
Nd	34	24	53	22
Sc	5	3	9	9.7
V	4	12	55	74
Ni	2	5	7	11
Ga	14	15	18	19

* Data from Wyborn and Page (1983).

The following key applies to all Harker diagrams (Fig.2-25).

X Diorite
▯ Tonalite
▮ Granite
+ Orthogabbro
▭ Amphibolite

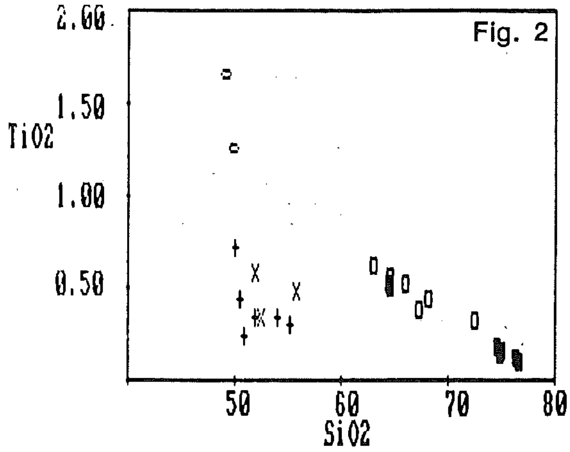


Fig. 2

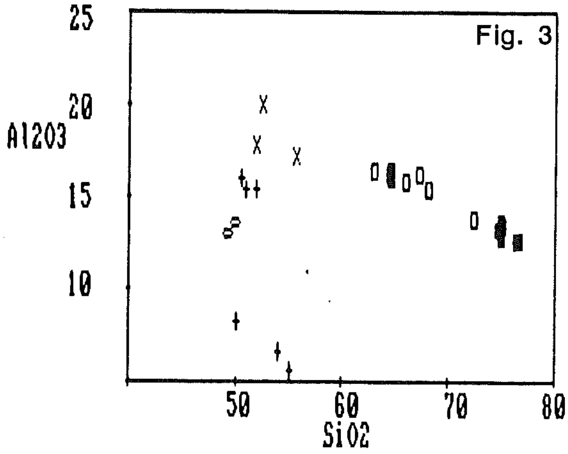


Fig. 3

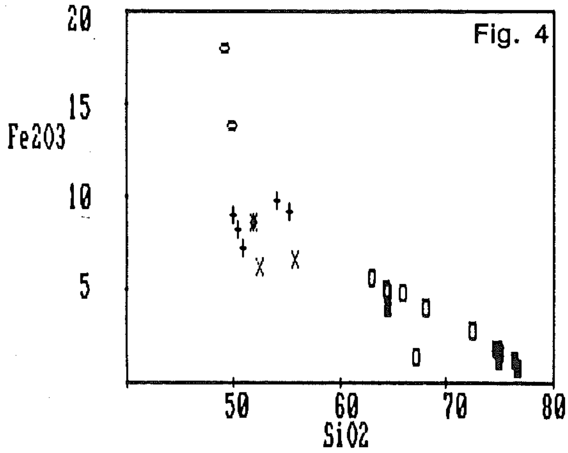


Fig. 4

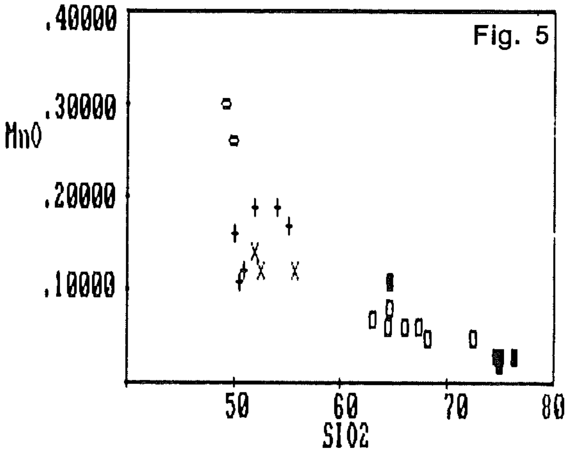


Fig. 5

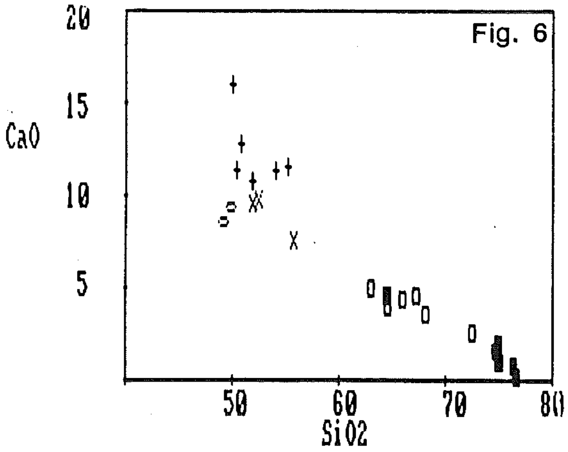


Fig. 6

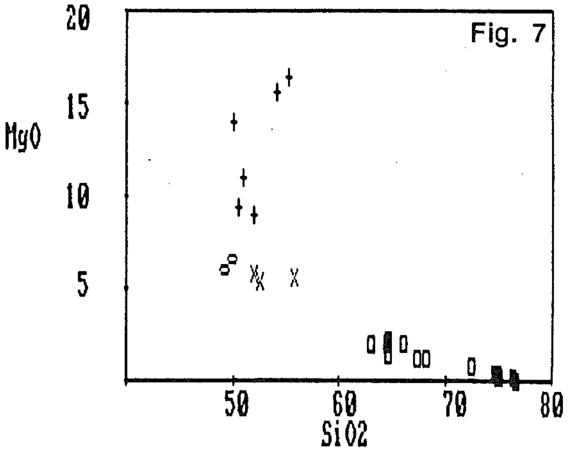
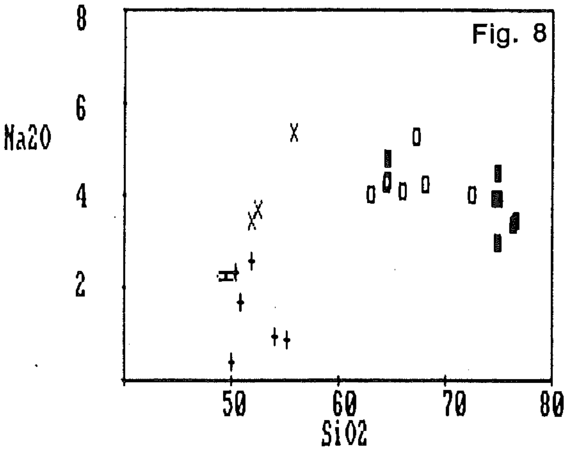


Fig. 7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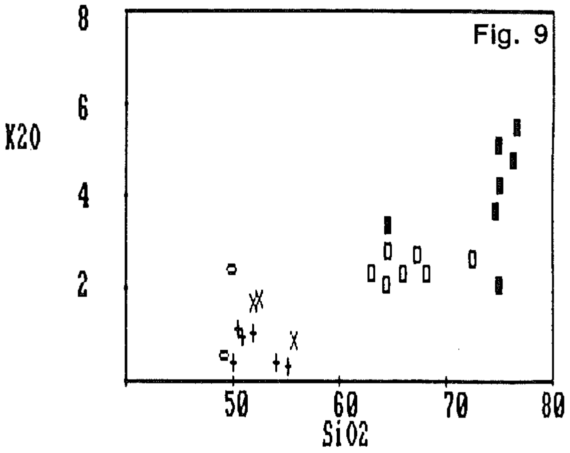
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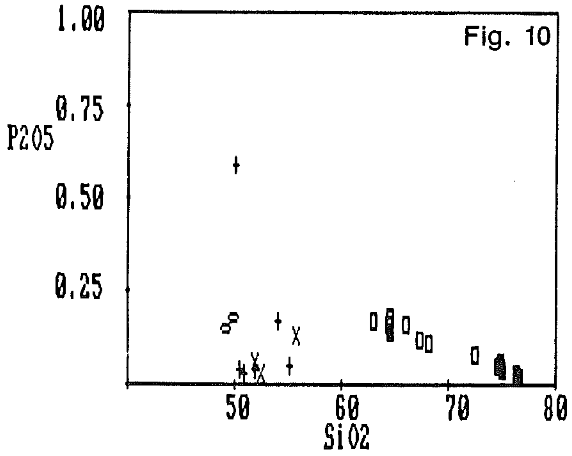
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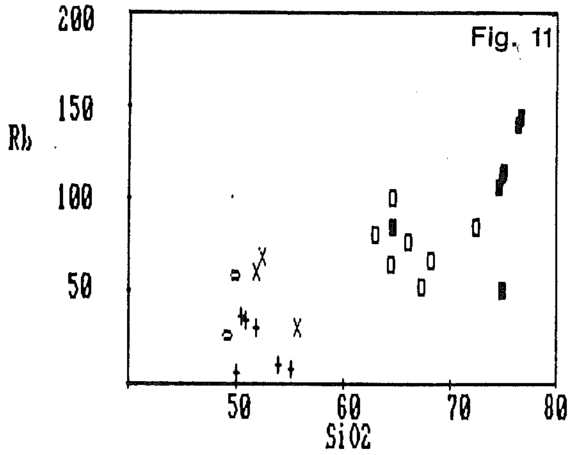
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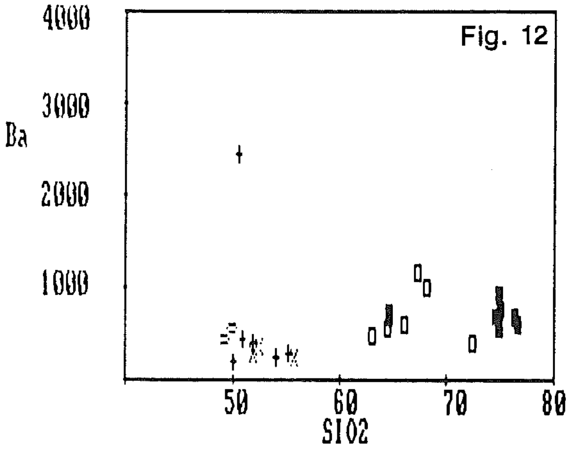
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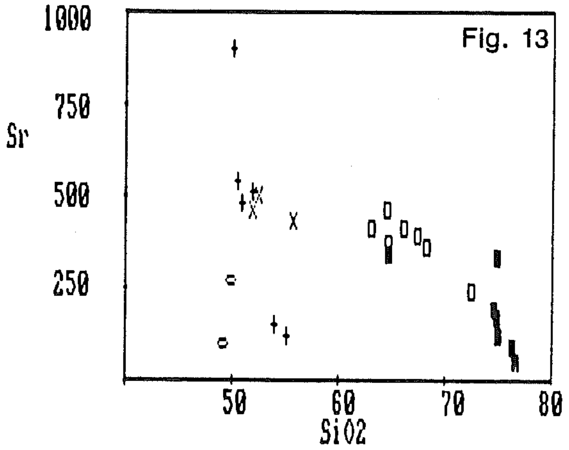
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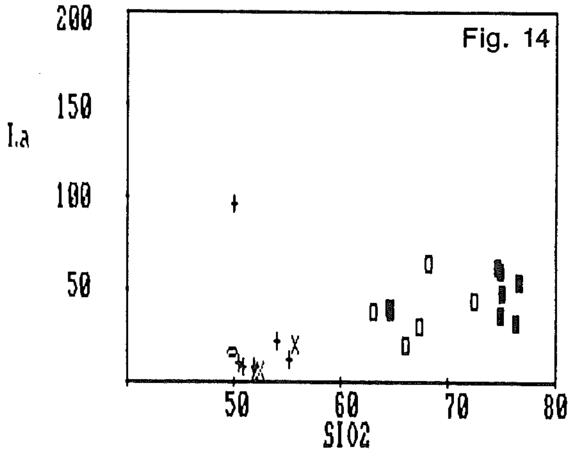
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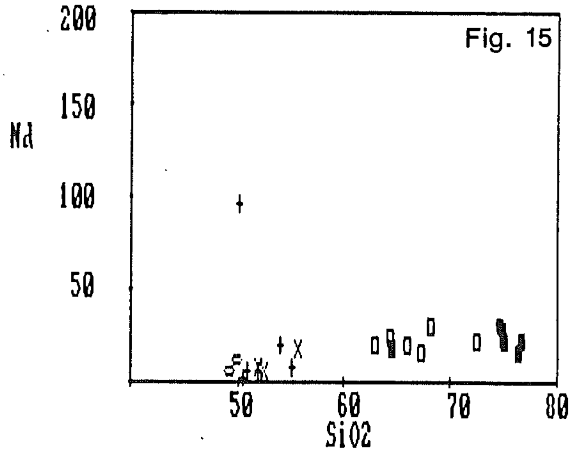
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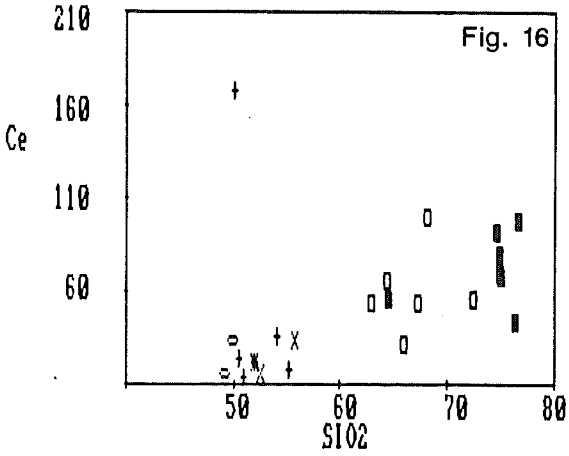
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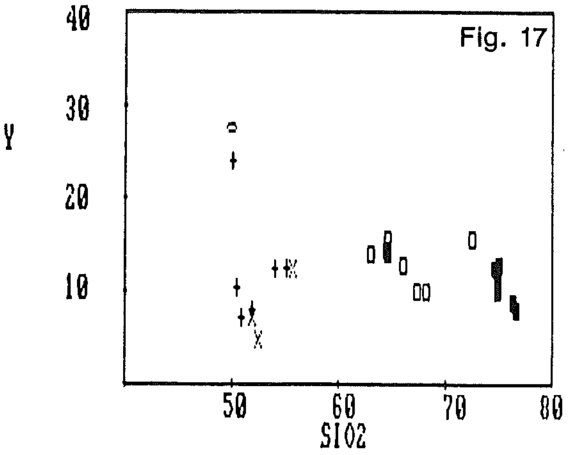
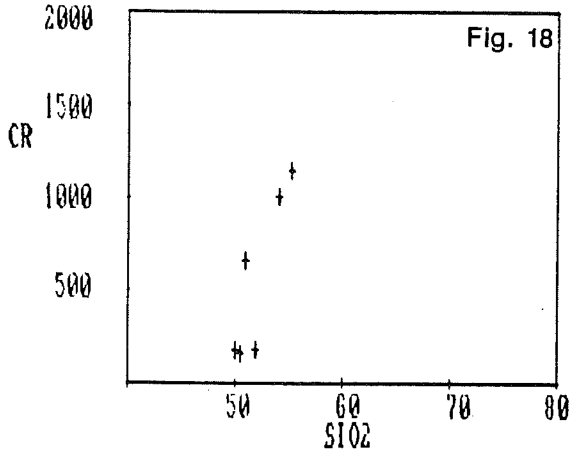


Fig. 17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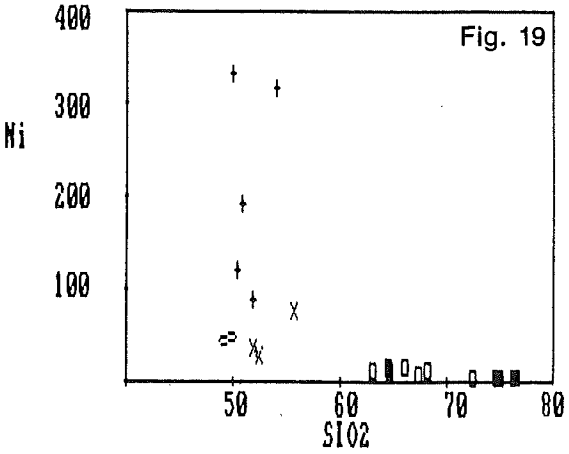
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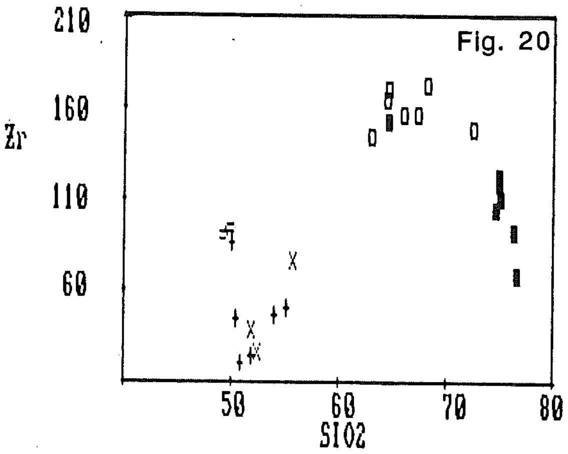
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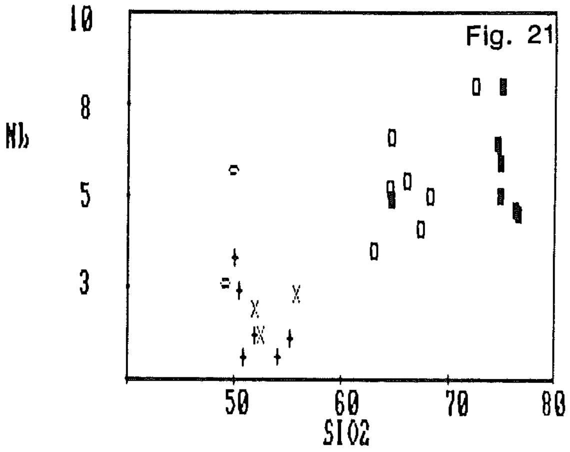
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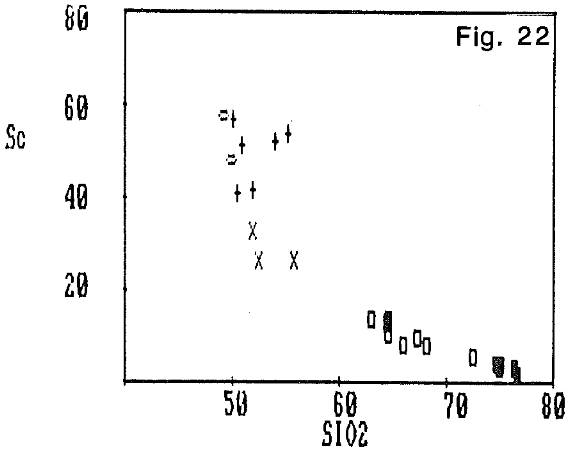
Fig. 22

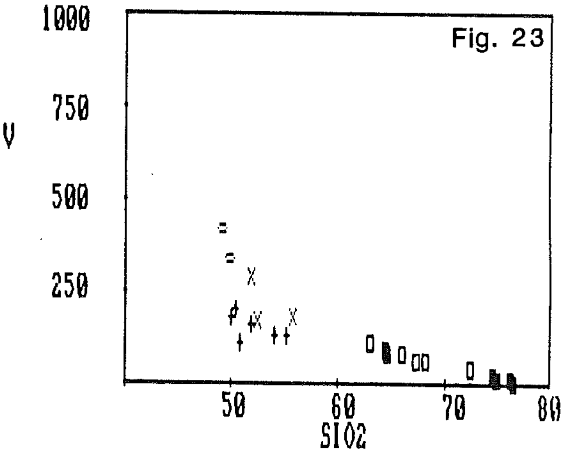
Fig. 23

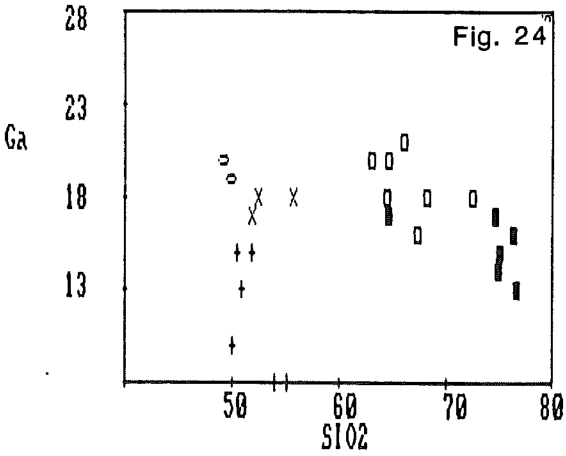
Fig. 24

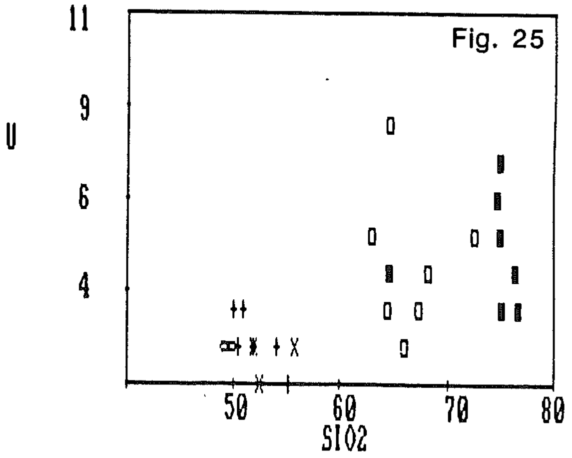
Fig. 25

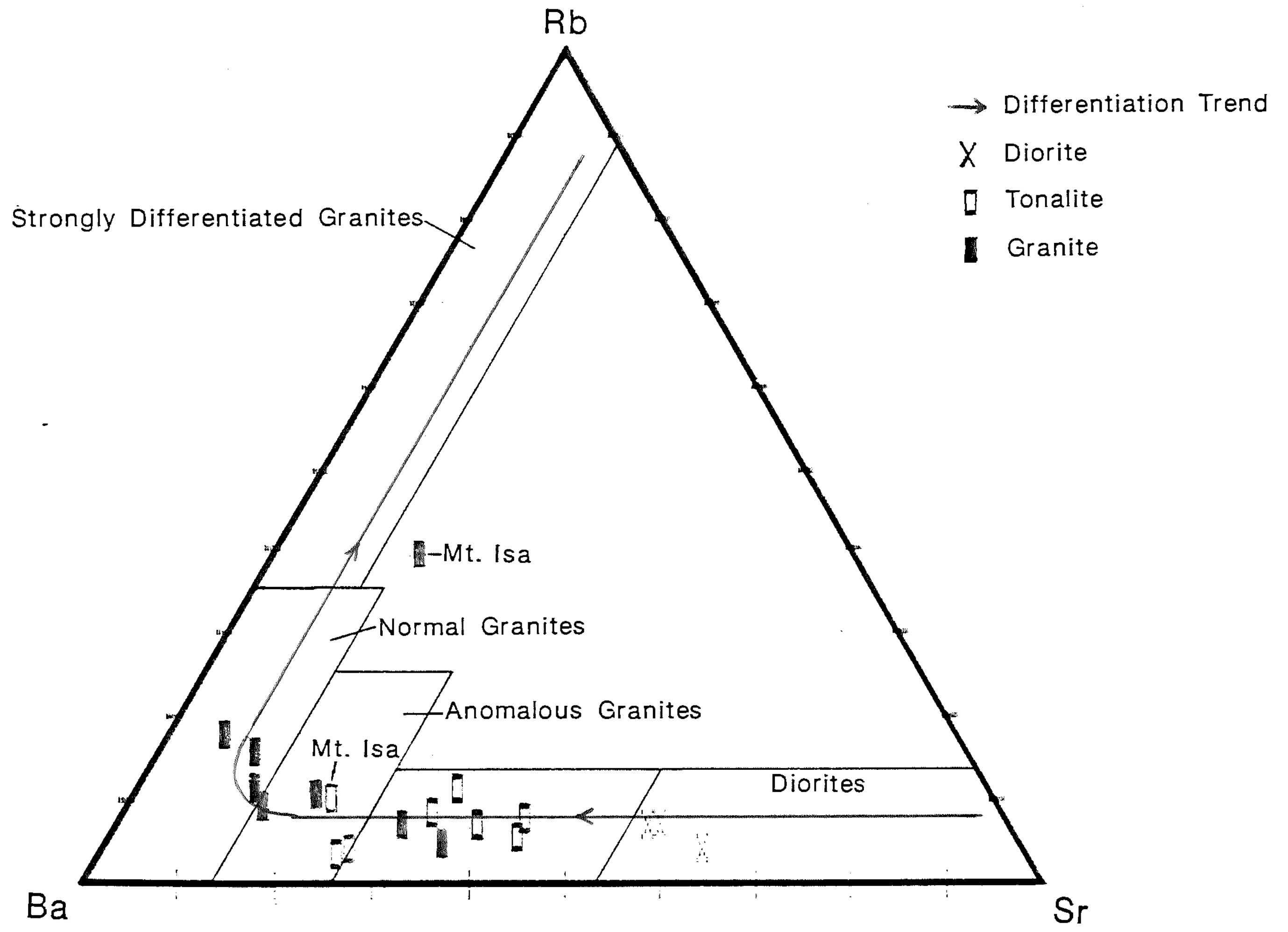

Fig. 26. The relation between Rb, Ba and Sr in Mt. Isa (marked) and Arunta (unmarked) intrusives. (El Bouseily & El Sokkary 1975.)

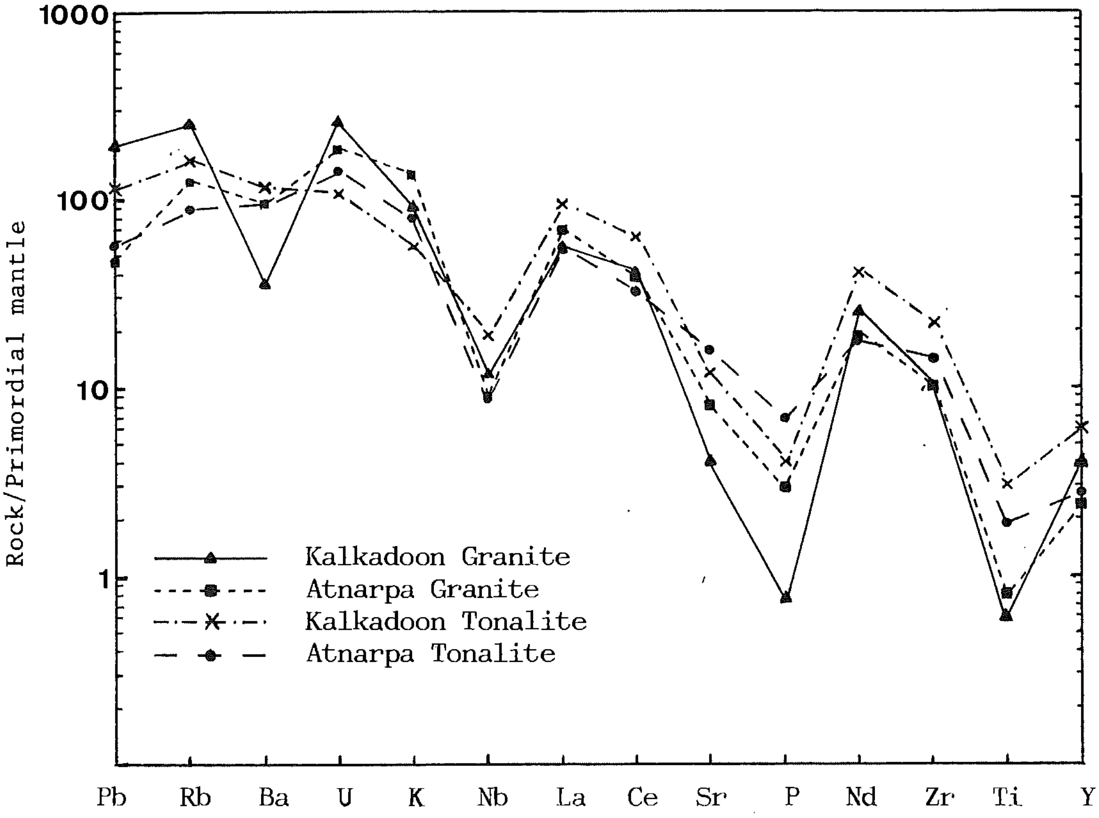

Fig. 27. Primordial-mantle-normalised geochemical patterns.

CHAPTER 5 : GEOCHRONOLOGY

5.1 INTRODUCTION

The U-Pb decay scheme involves two radioactive parent isotopes of uranium, ^{238}U and ^{235}U which both have half - lives which fall into the range of geologic time.

$$^{238}U \longrightarrow {}^{206}Pb \; ; \; \text{half-life } T = 4468 \text{ Ma}$$
$$^{235}U \longrightarrow {}^{207}Pb \; ; \; \text{half-life } T = 704 \text{ Ma}$$

The spontaneous decay of these two parent isotopes enable an age determination to be made.

Zircon is a U-Pb bearing mineral, which has been shown to be usefull for age determination work on the tonalite. Its abundance was realized by studying thin sections and X-ray fluorescence analysis of the rock powder which revealed a Zr concentration of greater than 150ppm.

5.2 REASONS FOR DATING

Previous dating on granitic rocks intruded into two subdivisions of the Lower Proterozoic in the Northern Territory using Rb-Sr total rock and K-Ar methods show well grouped ages averaging 1440 and 1630 Ma (Hurley et al 1961). However, these Proterozoic rocks have undergone widespread post-emplacement metamorphism and deformation on at least one occassion which may have caused significant isotopic disturbances to these systems. Hence these ages most likely represent periods of metamorphism rather than the times of primary magmatic crystallisation.

Age determination of the Atnarpa Igneous Complex Granite from the Giles Creek Synform has been carried out by Black and others (1983) using Rb-Sr total rock isochrons and was found to be 1651 +/- 47 million years old. Dating of the Atnarpa Igneous Complex Tonalite was conducted to determine its age relationship with the granite and whether the U-Pb system has been reset or disturbed by metamorphism. Field relationships between the tonalite and granite suggest that the tonalite is the older of the two.

5.3 SAMPLING AND ANALYTICAL PROCEDURES

Approximately 35kg of fresh, unweathered tonalite, representative of the tonalite within the study area, was collected for geochronological analysis. A granite sample was also collected for geochronological analysis but since it had already been dated by Black and others (1983), and had a lower zirconium content, the tonalite was preferred.

Analytical procedures for the extraction of zircons from the tonalite and sample preparation prior to analysis on the mass spectrometer are outlined in Appendix 5.

The zircons are clear and deep pink/brown coloured, euhedral crystals. They contain many translucent cavities and inclusions and sparse opaque inclusions. Many zircons displayed a surface frosting which was partially removed by abrasion. Euhedral internal zoning was exhibited by many grains.

Six fractions of different size and magnetic properties were chosen to obtain a maximum spread on the concordia diagram and consequently an accurate age.

5.4 RESULTS

The U-Pb isotopic data for the six zircon fractions are plotted on the concordia diagram in figure 28. The fractions are variably discordant with $^{207}Pb/^{206}Pb$ ages ranging from 1676 m.y. to 1808 m.y. and $^{206}Pb/^{238}U$ ages ranging from 1259 m.y. to 1544 m.y. This relatively good spread of points produce a fairly linear discordia on the $^{206}Pb/^{238}U$ v $^{207}Pb/^{235}U$ "Concordia" diagram, which indicates the pattern is dominated by two events in time. An appropriate regression (Ludwig, 1980) through these points produces an upper intercept of 1863 +/- 31 m.y., which would be interpreted as representing the age of crystallisation. Generally, no geological meaning is attributed to the secondary age, defined by the lower intercept, which frequently range between 600 m.y. and 0 m.y. (Gebauer & Grunenfelder). However, the lower intercept age in this case of 421 +/- 81 m.y. may well represent the Alice Springs Orogeny, which occurred during Late Devonian - Carboniferous time.

The data has a MSWD of 63.55 which is much higher than that expected due to errors in analytical precedures, hence the simple two stage pattern is slightly biased by other geological aspects such as variable lead loss at an intermediate time or the presence of older inherited pre-magma zircon grains.

If only data points 1, 3 and 6, which are least likely to contain inherited older grains, are plotted on the concordia diagram the upper intercept gives an age of 1853 Ma. Since this age is only slightly younger than that determined using all six points, it suggests that if inherited zircon grains are present, they are, in this instance, only causing a small "older" bias to the rock crystallisation age determination.

5.5 COMPARISON WITH OTHER ARUNTA INLIER DATES

Black and others (1983) have determined numerous ages for various igneous and metamorphic events within the Arunta Inlier using Rb-Sr total rock isochrons.

The earliest event recognized in the Arunta Inlier is the Strangways Event. This is a major granulite facies metamorphic event, which Black and others (1983) have calculated Rb-Sr ages for several samples to be about 1800 m.y.

Metamorphic and granitic rocks formed during or affected by the Aileron Event have produced Rb-Sr ages in the range 1700-1650 m.y. The granite from the Atnarpa Igneous Complex is one of the granitic rocks used for this age determination by Black and others (1983).

The U-Pb age for the tonalite of the Atnarpa Igneous Complex of 1863 +/- 31 m.y. is older than all Rb-Sr ages calculed for the Arunta Inlier. Since the tonalite lacks characteristic granulite facies minerals such as clinopyroxene, it appears that the Rb-Sr age for the Strangways Event is too young, and the Rb-Sr isotopic system has been disturbed.

5.6 COMPARISON WITH MOUNT ISA INLIER

The age of 1863 +33/-27 m.y. for the tonalite of the Atnarpa Igneous Complex is remarkably similar to the U-Pb age for the Kalkadoon Granodiorite of 1862 +27/-21 m.y. determined by Page (1978). Wyborn and Page (1983) conducted a further age determination of the Kalkadoon Granodiorite which produced an intersection age of 1856 +11/-9 m.y.

Wyborn and Page (1983) also dated the Ewen Batholith, which is part of the Mount Isa Inlier also, using the U-Pb zircon method. However, low U concentrations and very high initial common Pb gave rise to large uncertainties which did not define a clear discordia array. However, the data indicated that the Ewen zircon isotopic system was initiated between about 1820 m.y. and 1860 m.y.

Rb-Sr data of Wyborn and Page (1983) on the Kalkadoon and Ewen Batholiths indicate that enhanced and prolonged metamorphic disturbances have affected this isotopic system and ages are upto 20 per cent younger than the emplacement age. If the same metamorphic conditions are assumed for the Arunta Inlier, which is almost certain, then the Rb-Sr age for the granite determined by Black and others (1983) to be 1651+/-47 m.y., may not represent the emplacement age. Hence the granite, may in fact be much closer to the tonalite in age. Only a U-Pb age determination on the granite can eliminate any doubt on this matter.

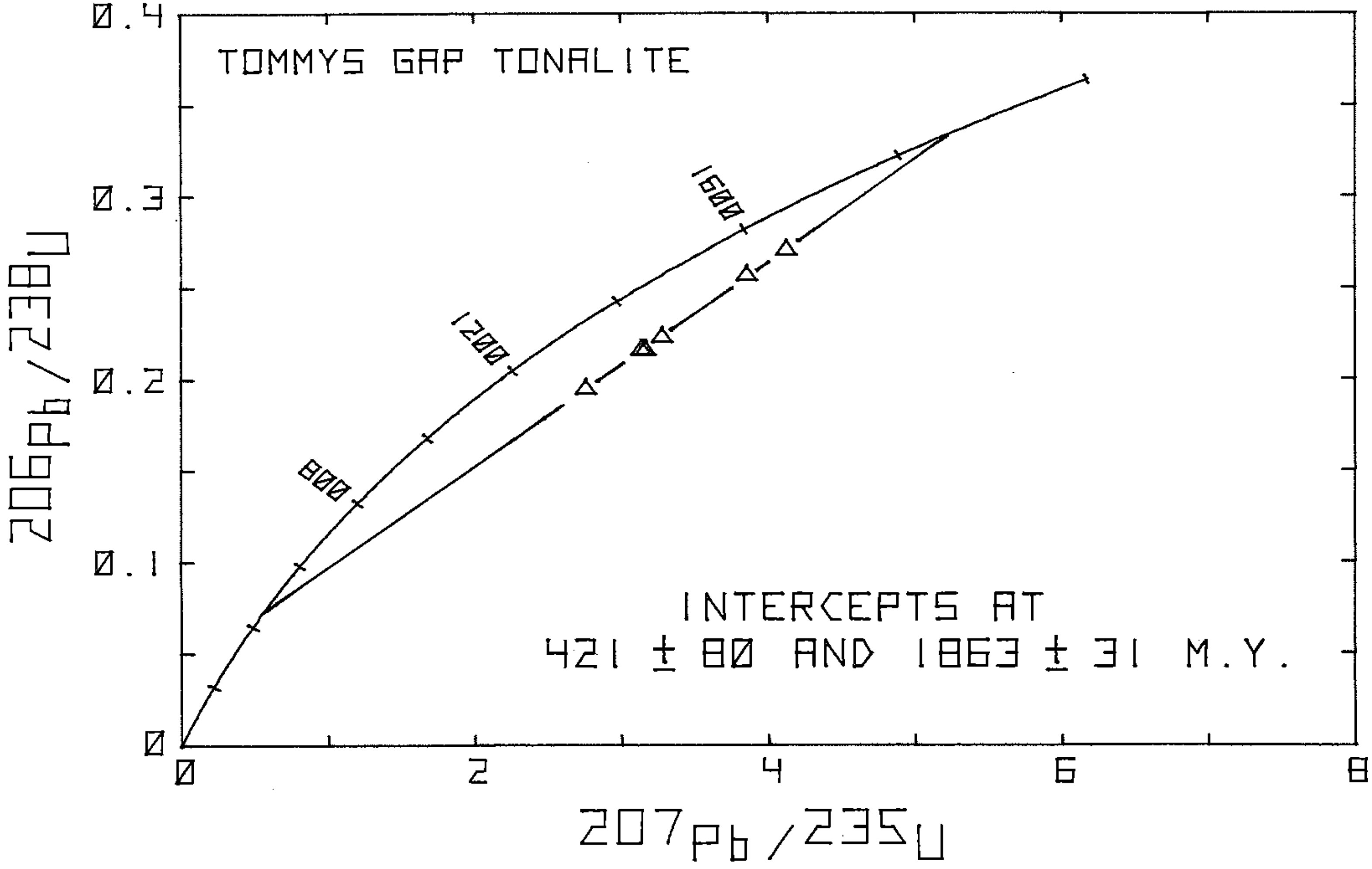

Fig. 28. Concordia diagram showing data points of six zircon populations from the Atnarpa Tonalite.

CHAPTER 6 : CONCLUSIONS

U-Pb zircon data show that the tonalite of the Atnarpa Igneous Complex was emplaced within the Arunta Inlier and crystallised 1863 +/- 31 m.y. ago.

Geochemical and geochronological similarities between the Arunta Inlier and Mount Isa Inlier intrusive bodies supports the theory of Wyborn and Page (1983) that during the period 1900 - 2100 m.y., in the Proterozoic of Northern Australia, a significant mantle differentiation event took place, during which large volumes of material were accreted to the base of the crust in these areas.

Post emplacement metamorphism and deformation has caused significant textural and mineralogical changes in the Atnarpa Igneous Complex. The basement rocks of the Arunta Inlier, prior to magma emplacement, had been metamorphosed to upper amphibolite to granulite facies (Shaw et al 1984a). On magma emplacement, the country rocks suffered contact metamorphism. During the Alice Springs Orogeny, retrograde greenschist facies metamorphism affected all rocks in the Giles Creek Synform.

ACKNOWLEDGEMENTS

I wish to thank Dr. Pat James for inspiring me to undertake the Honours course and Dr. John Cooper for organizing and supervising my project throughout the year. Ding Puquan was most helpful in the field and to him I extend my full appreciation.

David Bruce, whose assistance with geochronological techniques involving the use of the mass spectrometer and other isotope chemistry apparatus, was invaluable.

Drs. Vic Gostin, Graham Mortimer and Alan Purvis contributed with helpful discussion and advice.

I am grateful to the technical staff of the Geology Department for their help during the year. In particular, Geoff Trevellyan and Wayne Mussared for thin sectioning; Evert Bleys and Rick Barrett for photography; Phil McDuie and John Stanley for their help with whole rock and trace element analyses; John Willoughby for help with computing and Fleur DeLaine for her help with drafting.

Many thanks go to my fellow colleages who have made 1987 a year to remember. I hope the bond of friendship developed over the past year will be with us as we enter our professional careers.

Finally, I wish to thank my parents for their continued financial support and encouragement throughout my years at University and Caroline for her patience and understanding during the past year.

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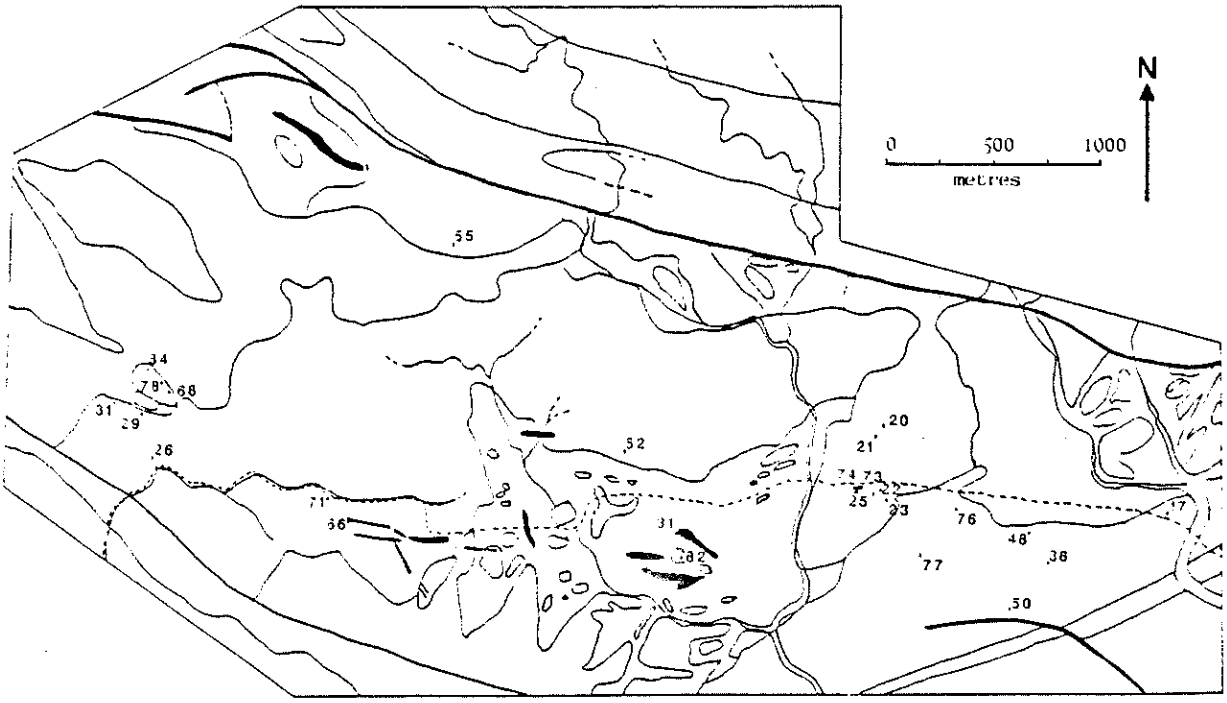
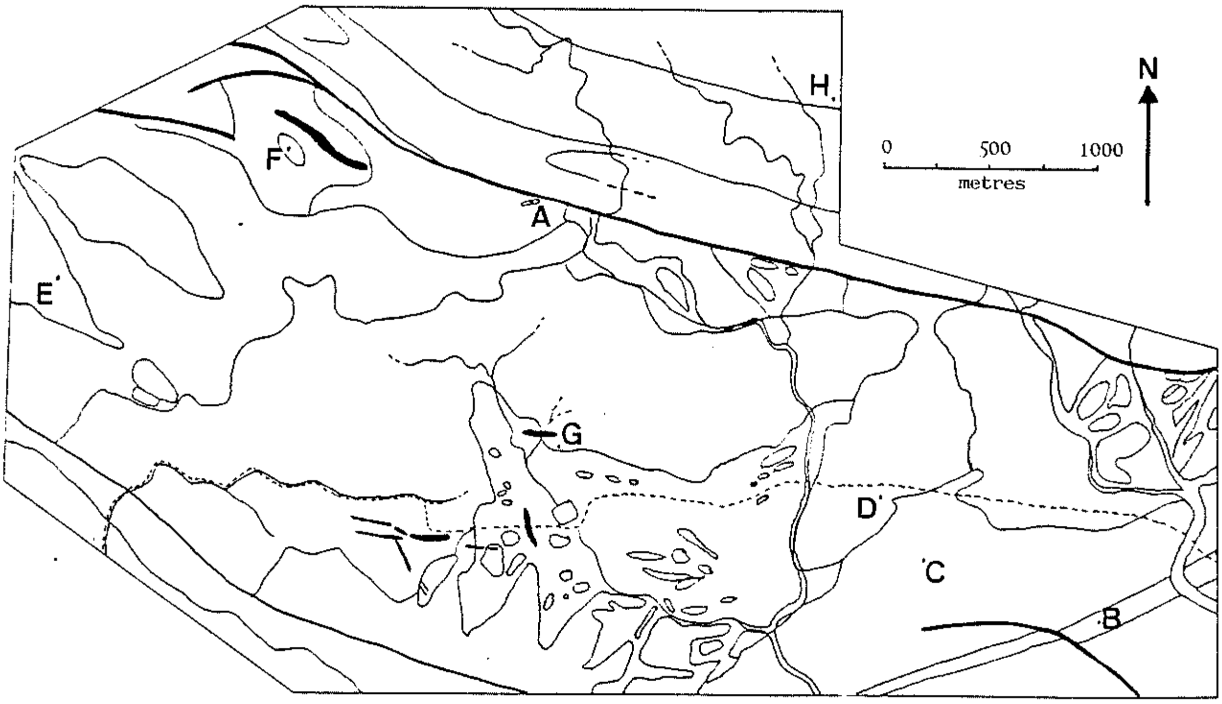
APPENDIX 1 : SAMPLE AND OBSERVATION LOCALITY MAPS

SAMPLE LOCALITY MAP



OBSERVATION LOCALITY MAP



APPENDIX 2 : ANALYTICAL PROCEDURES

SAMPLE PREPARATION AND ANALYSIS

1) Samples were trimmed of weathered material and crushed using a jaw crusher.

2) The crushed samples were finely powdered in the Siebtechnik tungsten carbide mill.

3) Major element oxides were analysed with the Siemens XRF using fused buttons of the samples. The powdered sample was ignited to a temperature of 960°C to drive off volatiles and the loss on ignition subsequently calculated. The fused buttons were prepared by fusing a mixture of the following:
    (a) .02gm of $NaNO_3$
    (b) .28gm of sample ignited to 960°C
    (c) 1.5gm of flux.

4) Trace element concentrations of Rb, Sr, Ba, Y, Zr, Nb, Sc, V, Ni, Cr, La, Ce, Nd, Ga, Pb and U were determined using X-ray fluorescence spectrometry on pressed pellets of the powdered samples, backed by boric acid powder.

5) Sodium concentrations were determined for each sample by digesting approximately 60mg of ignited sample in a teflon beaker containing hydrofluoric acid (10ml) and sulfuric acid (2ml). The mixture was heated overnight and the resultant solution diluted to 100ml with distilled water. The sodium concentration of the solution, and hence the sample, was then determined using atomic absorption spectrometry.

APPENDIX 3

THIN SECTION DESCRIPTIONS

MYLONITE

888-4

Hand specimen

A mylonite, very rich in quartz, with all grains showing a distinct preferred orientation. Grainsize is mostly fine to medium with a few coarse quartz phenocrysts.

Thin section

All crystals, except biotite and muscovite which form a lepidoblastic foliation, are anhedral. Biotite and muscovite are subhedral to euhedral.

Quartz, the most dominant mineral in the slide, occurs as fine to medium (.05 - 3mm) elongate grains and exhibits undulose extinction. Grain boundaries are straight to very irregular against similar and different phases. Fracturing is common.

Muscovite is the dominant platey mineral with fine grains forming a well defined foliation throughout the slide.

Biotite is dispersed throughout the slide as fine grains and are aligned parallel to the foliation shown by other minerals in the slide. The biotite is weakly pleochroic (light brown - red brown).

Alkali feldspar is distinguished from plagioclase by its cross - hatch twinning. Both are fine grained.

Opaques are randomly distributed throughout the slide and exhibit very irregular grain boundaries. The larger grains contain inclusions and appear somewhat poikiloblastic.

QUARTZ-BIOTITE SCHIST

888-5

Hand Specimen

A fine grained grey rock with mica grains producing a well defined lepidoblastic foliation.

Thin Section

This lithology is a fine grained, equigranular rock.

Biotite occurs as fine subhedral to euhedral grains and forms a well defined lepidoblastic foliation. Pleochroism ranges from straw yellow to red brown.

The dominant phase in this lithology is quartz. It occurs as anhedral fine grains and exhibits undulose extinction.

Plagioclase grains are anhedral and fine and show multiple twinning. Sericitization has occurred within a few of the plagioclase grains.

Opaques and apatite are present in accessory amounts.

MARBLE

888-8

Hand Specimen

A grey, fine to medium, equigranular marble.

Thin Section

Calcite is the dominant phase (85%) and occurs as fine to medium (0.2-2mm) anhedral grains. Cleavage planes intersect at oblique angles (approx. 45°) and multiple twinning is also present. Within some grains the twinning planes are slightly warped.

Epidote (10%) is present as fine subhedral to anhedral grains.

Opaques are present in accessory amounts.

CALC-SILICATE

888-12

Hand Specimen

A massive medium to coarse grained rock, grey in colour with a green tinge.

Thin Section

The calc-silicate has a very brecciated appearance and consists mostly of actinolite (60%), and calcite and/or dolomite (35%) filling the interspaces. Quartz, epidote, and opaques are minor phases.

Actinolite has been brecciated to a great extent along its cleavage planes, and is present as fine, anhedral to subhedral fragments. Outlines of remnant grains can be distinguished. Epidote is only slightly less brecciated than the actinolite and remnant subhedral to euhedral grains can be seen.

Fine grained, anhedral calcite and/or dolomite, which have distinct twinning and cleavage traces, occurs as a secondary phase. Plagioclase may be present as fine anhedral grains, but due to the highly brecciated nature of this lithology it is difficult to distinguish from calcite or dolomite which show similar twinning.

Quartz occurs as fine, anhedral grains which are fractured to varying degrees. Undulose extinction is shown by all quartz grains. Opaques are common as fine, anhedral grains.

ORTHOGABBRO

888-	17	36	48	76
Actinolite	35	50	20	30
Chlorite	25	30	20	25
Plagioclase	30	5	40	25
Epidote	3	5	10	8
Biotite	5	-	5	-
Quartz	2	5	tr	8
Opaques	tr	tr	tr	tr
Muscovite	tr	tr	tr	tr
Sphene	tr	tr	tr	tr

888-17

Hand Specimen

Medium grained equigranular rock with a green appearance.

Thin Section

Actinolite occurs as fine to medium (0.5-3mm) anhedral to subhedral grains which are green in colour and show 120° cleavage. Grain boundaries are very irregular. Actinolite grains are thought to be the result of pyroxene alteration and they themselves have been partially altered to chlorite.

Plagioclase grains have been mostly altered to sericite. They tend to be mainly interstitial amongst actinolite and chlorite.

Chlorite grains occur with actinolite and are the continued alteration of pyroxene. They are fine to medium and anhedral.

Biotite is present as fine subhedral grains amongst the plagioclase. They show a weak pleochroism of straw brown to green brown.

Epidote grains are fine and anhedral within the actinolite.

Quartz grains are fine and anhedral and exhibit undulose extinction.

888-36

Hand Specimen

This dark green mafic rock contains mostly fine to medium pyroxene and minor quartz or feldspar. It is massive with no fabric at all.

Thin Section

Actinolite occurs as fine to medium (0.2-3mm), subhedral to anhedral, columnar to fibrous grains. A few grains exhibit multiple twinning. All grains show weak pleochroic colours of yellow green to green.

Chlorite occurs as an alteration product of actinolite. Grains are fine to medium (0.2-1.5mm), green and anhedral.

Plagioclase appears as fine anhedral grains which have undergone almost complete alteration to sericite.

Quartz occurs as anhedral, fine (0.05-0.6mm) grains. They are isolated grains in between the actinolite grains and show undulose extinction.

Epidote is present as subhedral fine grains (0.1-0.5mm) and are distinguished from actinolite by its higher interference colours and mottled appearance.

888-48

Hand Specimen

A dark green massive rock consisting primarily of pyroxene or plagioclase and quartz.

Thin Section

Actinolite occurs as fine to medium (0.1-2mm) anhedral grains. Most grains are intergrown and show patchy interference colours. Grain boundaries are rugged. Inclusions are numerous and are mostly sphene.

Chlorite grains are fine to medium (0.1-1.8mm) anhadral grains. Pleochroism is pale to deep green.

Plagioclase has been almost completely altered to sericite. Within the altered patches other minerals such as epidote and muscovite are present.

Biotite is present as fine anhedral to subhedral grains which show weak pleochroic colours of pale straw brown to brown. They occur as clusters and show no preferred orientation.

Epidote grains are fine and very irregular, often poikiloblastic in appearance. They are generally found at the margins of actinolite grains, within the altered plagioclase.

888-76

Hand Specimen

A dark green massive rock consisting of pyroxene, quartz and plagioclase.

Thin Section

Actinolite grains are fine to medium (0.1-2mm) and anhedral. All grains have rugged boundaries and contain inclusions which include epidote, sphene, plagioclase and quartz. Some grains show multiple twinning.

Chlorite occurs as fine to medium (0.1-2.5mm) anhedral grains, intergrown with the actinolite.

Plagioclase is present as fine grains which fill the interstice between actinolite and chlorite grains. Approximately one third of the plagioclase has been sericitized. All grains are anhedral and form a fine grained mosaic with quartz grains, suggesting partial recrystallisation. Unaltered grains show multiple twinning.

Quartz is present as fine grains within the mosaic of recrystallised grains and exhibits undulose extinction.

Epidote occurs as fine, anhedral grains, generally adjacent to actinolite and chlorite, but within the sericite.

GRANITE

888-	26	29	31	71
Quartz	30	40	30	35
Plagioclase	25	20	25	20
Alkali feldspar	30	30	20	30
Biotite	5	3	tr	8
Hornblende	2	-	15	-
Epidote	-	tr	3	5
Muscovite	1	3	-	tr
Zircon	-	tr	tr	-
Sphene	-	-	tr	-
Apatite	tr	tr	tr	tr
Rutile	-	tr	-	-
Corundum	tr	-	-	-
Opaques	2	tr	2	1

888-26

Hand Specimen

A massive coarse to medium grained granite with a primary mineral composition of biotite, potassium feldspar and quartz.

Thin Section

This slide exhibits bimodal grainsize, suggesting recrystallisation has occurred.

Quartz occurs as fine to medium (0.1-2.5mm), anhedral grains. The fine grains form a mosaic with potassium feldspar and sericite within the recrystallised groundmass. Grain boundaries between quartz grains show consertal texture.

Potassium feldspar grains are fine to medium (0.1-3.5mm) anhedral grains. Microcline and orthoclase are distinguished by the presence and lack of cross-hatched twinning respectively.

Plagioclase occurs as fine to medium (0.2-4mm), anhedral grains which show multiple twinning.

Sericite is present as fine laths within the potassium feldspar and plagioclase. It is an alteration product of the feldspars.

Biotite grains are fine (0.05-0.3mm), anhedral to subhedral and occur in clusters. Pleochroism is straw yellow to dark olive green.

Magnetite is the dominant opaque and occurs as fine to medium anhedral grains. Most grains have a martite texture due to the

replacement of magnetite by hematite along crystallographically preferred planes as a result of oxidation (Craig et al 1981).

Minor amounts of fine grained, anhedral hornblende.

Muscovite occurs in association with the biotite as fine to medium (0.1-2mm) subhedral grains.

Accessory minerals include rutile in association with the magnetite and hematite, corundum in association with muscovite and apatite is ubiquitus throughout the slide.

888-029

Hand specimen

A massive grey and pink speckled granite with a coarse grained equigranular texture.

Thin section

This is a recrystallized rock with a bimodal grainsize.

Quartz appears as aggregates of fine to medium (.25 - 2mm) anhedral grains. Grain boundaries are sutured with other quartz grains and irregular to curved with potassium feldspar. Some grains are fractured, while all have undulose extinction.

Potassium feldspar consists of fine to medium (.2 - 4mm) anhedral grains. Most grains exhibit a well defined microcline cross-hatched or "tartan" multiple twinning, while a few show little or no twinning and are most likely orthoclase. Minor amounts have been altered to sericite within the recrystallized groundmass. Some of the larger grains exhibit fractures which are filled with recrystallized fine grained quartz and potassium feldspar.

Plagioclase occurs as fine to medium (.2 - 3mm), subhedral to anhedral, grains which show varying degrees of sericitization.

Biotite occurs as fine grained aggregates. Individual grains are subhedral to euhedral and are mildly pleochroic (yellow/green to olive green). Some grains show alteration to chlorite.

Muscovite occurs in association with the biotite as fine anhedral grains.

Accessory minerals are zircon within biotite, epidote, apatite, opaques and rutile

888-031

Hand specimen

A massive, medium grained rock with a tan and black speckled appearance. Black mineral is hornblende while the light coloured phase is mostly quartz and alkali feldspar.

Thin section

Quartz grains are anhedral and fine to medium (.1 - 1.2mm). Grain boundaries are straight to irregular with both like and different phases. Undulose extinction is shown by all grains.

Alkali feldspar occurs as fine to medium grains (.2 - 2mm). They are anhedral and show little to no alteration. The medium size grains show hazy or no twinning whilst the finer grains show distinctive cross-hatched twinning.

Plagioclase has mostly been altered to sericite but many relict grains still exhibit Carlsbad twinning. Grains are subhedral to anhedral and range from fine to medium (.2 - 2mm). Within the sericitization of the plagioclase grains are other fine grains such as sphene, zircon, apatite and epidote.

Hornblende occurs as fine to medium (.1 - 3mm) grains which are green under plane polarised light. Pleochroism ranges from deep green to light brown. They are subhedral to anhedral with irregular grain boundaries and show characteristic 120^{o} cleavage. All grains contain inclusions and give some grains a poikiloblastic texture. Inclusions include quartz, sphene, apatite, zircon and epidote, some of which have pleochroic halos. A few grains exhibit simple twinning.

Quartz grains are anhedral and fine to medium (.1 - 1.2mm) in size. Grain boundaries are straight to irregular with both like and different phases. Undulose extinction is shown by all grains.

Epidote occurs as subhedral to euhedral, fine to medium grains. The fine grains are found within the alteration of plagioclase, and as inclusions in hornblende. All grains appear to be secondary.

Opaques are fine grained and most likely magnetite

Accessory minerals are zircon, sphene and apatite.

888-71

Hand Specimen

A medium, equigranular granite. Potassium feldspar, plagioclase, quartz and biotite are the major minerals.

Thin Section

Quartz grains are anhedral, fine to medium (0.2-3mm) and show undulose extinction. Consertal texture is present, with grain boundaries being quite rugged.

Potassium feldspar is present as microcline and orthoclase. Grains range from fine to coarse (0.2-6.5mm). Sericite alteration has taken place to varying extents in all but some of the finer grains. Microcline shows cross-hatch twinning whilst orthoclase has no twinning.

Plagioclase occurs as fine to medium (0.2-4mm) anhedral to subhedral grains. Multiple twinning is shown by all grains and Carlsbad twinning is seen in a few grains. Sericite alteration is present in most grains. Twins are warped/bent in a few grains.

Biotite occurs as clusters of fine to medium (0.1-1mm) subhedral to euhedral grains. Inclusions of epidote and quartz are common. Pleochroic colours range from straw yellow to olive green.

Epidote grains show high relief and are euhedral to anhedral. These appear to be secondary and are found in association with the biotite. Grainsize is fine to medium (0.1-4mm). Allanite is common and shows distinctive zoning.

Opaques occur in accessory amounts and are most likely magnetite. they are found in close association with biotite. Other accessory minerals include muscovite and apatite.

TONALITE

888-	21	22	25	82
Quartz	45	40	45	45
Plagioclase	30	30	35	25
Biotite	15	10	10	12
Alkali feldspar	-	3	5	
Epidote	5	10	tr	
Hornblende	3	-	-	-
Muscovite	-	tr	tr	2
Zircon	tr	tr	tr	tr
Apatite	tr	tr	tr	tr

888-021

Hand specimen

This is a medium grained rock with a black and white speckled appearance, consisting of quartz, plagioclase, biotite and hornblende. It exhibits a very slight preferred orientation of biotite and hornblende grains.

Thin section

There is a large range in grain size (~.02 - 2mm) which tends to suggest this rock has undergone partial recrystallization.

Quartz is fine grained (.02 - 1mm) and anhedral with curved to irregular grain boundaries against plagioclase and irregular to sutured boundaries with like grains. All grains have undulose extinction.

Plagioclase is anhedral to subhedral with distinct to hazy multiple twinning present and sericitization occurring in some grains. In some cases the entire grain has been altered to sericite. Grainsize is fine to medium (.1 - 2mm) with grain boundaries ranging from straight and curved to lobate.

Biotite is fine to medium grained (.05 - 1.2mm) occurring at random throughout the slide and are partially orientated to the foliation plane. Pleochroic colours range from pale yellow to greenish brown.

Hornblende occurs in close association with the biotite as subhedral to anhedral, fine grains (.02 - .8mm). Their pleochroism ranges from yellow green to deep green.

Epidote is associated with hornblende and biotite as subhedral to anhedral grains of medium size (.2 - 1mm). Many grains have inclusions of quartz and apatite. Lamellar twinning is common.

Sericite replaces plagioclase as very fine grained (< 0.01mm) aggregates.

Accessory minerals include apatite, zircon and opaques.

888-022

Hand specimen

A medium grained tonalite consisting of quartz, plagioclase, biotite and possibly hornblende. There is a fairly well defined preferred orientation of the biotite grains.

Thin section

Quartz is anhedral with undulose extinction and grain boundaries are curved to lobate against other phases. Grain size ranges from fine to medium (.05 - 1.5mm). Some grains are fractured.

Plagioclase shows poor multiple twinning and is mostly altered to sericite. Grainsize is fine, although there are patches of sericite up to 2mm which may have originally been medium grain sized plagioclase. Grain boundaries are often hidden due to sericite alteration but are mostly straight or curved.

Alkali feldspar is distinguished by cross-hatch twinning and occurs as fine (.2 - .5mm) anhedral grains.

Biotite is subhedral, fine to medium grained (.1 - 1.2mm) and strongly pleochroic (pale straw yellow to greenish brown). A weak foliation is developed due to the preferred orientation of biotite.

Epidote occurs as euhedral to anhedral fine to medium grains (0.2-1mm) and is closely associated with biotite. Quartz and apatite inclusions are numerous.

Opaques are most likely magnetite.

Sericite occurs as fine fibres and appears to be a replacement/alteration product of plagioclase. The outlines of relict plagioclase grains can be seen within the sericite.

Accessory minerals are zircon and apatite. Traces of muscovite occur in association with biotite.

888-025

Hand specimen

This medium grained tonalite has a primary mineral assemblage of quartz, plagioclase and biotite. The quartz and plagioclase have a slight green tinge suggesting the rock has been partially altered and/or recrystallized. There is a slight preferred orientation shown by the biotite.

Thin section

Quartz occurs as fine to medium (.02 - 2mm) anhedral grains with grain boundaries being rounded to sutured with all other phases. The fine grains have a granoblastic texture, surrounding the larger medium grains. All grains exhibit undulose extinction and some of the medium sized grains are fractured.

Plagioclase grains are fine to medium (.1-3mm), subhedral to anhedral and have straight to curved grain boundaries with other phases. Few grains have cores altered to sericite, others are entirely altered. Some plagioclase grains show myrmekitic texture with rod-like inclusions of quartz. Grains exhibit both multiple and Carlsbad twinning. Few grains have quartz recrystallized within fractures.

Alkali feldspar are fine to medium (.3 -1mm), anhedral to subhedral grains showing distinctive cross-hatched twinning.

Sericite occurs as fine grained laths within plagioclase.

Biotite is the main ferromagnesian phase and occurs as fine (.05 - .8mm) subhedral grains with strong pleochroism (straw yellow - greenish brown). Contains small inclusions with pleochroic haloes.

Minor mineral assemblages include fine, subhedral to euhedral epidote and muscovite and euhedral zircon and apatite, all closely associated with biotite.

888-082

Hand specimen

A grey, weakly foliated rock with a speckled appearance. Major minerals are quartz, plagioclase and biotite.

Thin section

This slide has a bimodal grain size suggesting recrystallization.

Plagioclase occurs as either partially or completely sericitized fine to medium (.2 - 2.5mm) grains. All grains are anhedral and have irregular grain boundaries. Polysynthetic twinning is distinct to hazy in most grains. Sericitization is pronounced and gives the plagioclase grains dusty cores under plane polarised light.

Quartz is fine to medium (0.2-3mm) and occurs as anhedral grains. All grains exhibit undulose extinction.

Biotite is the main ferromagnesian phase and occurs as fine to medium (0.05-1.3mm) subhedral grains. Pleochroic colours range from straw yellow to olive brown. Chlorite alteration has occurred to some extent.

Epidote has a close association with the biotite as anhedral to euhedral fine grains (0.1-0.75mm). Twinning occurs in a few grains. Inclusions are ubiquitus in most grains and produce a poikiloblastic texture.

Muscovite occurs as anhedral, fine grains in association with the biotite.

DIORITE

888-	78	84
Hornblende	35	40
Plagioclase	45	35
Quartz	8	5
Epidote	8	10
Biotite	2	5
Sphene	tr	tr

888-78

Hand Specimen

A massive medium to coarse grained rock consisting of hornblende, plagioclase and quartz.

Thin Section

Hornblende grains are fine to medium (0.1-4mm) and subhedral to anhedral. They are green in colour and exhibit pleochroic colours ranging from straw yellow to green. Some grains are completely altered to chlorite. Simple twinning is common as are patchy interference colours. Secondary sphene granules are numerous within the hornblende.

Plagioclase occurs as fine to medium (0.1-4.5mm) anhedral grains and are almost completely sericitized. Multiple twinning is present in all grains. Minor potassium feldspar is distinguished by its distinctive cross hatch twinning.

Quartz grains are anhedral, fine and exhibit undulose extinction. They occur primarily in a recrystallised groundmass.

Epidote occurs as fine grains which range from anhedral to subhedral. They occur mostly within the sericite alteration of the plagioclase.

888-84

Hand Specimen

A massive coarse to medium grained rock consisting of hornblende, plagioclase and quartz. Fractures are present.

Thin Section

Hornblende grains are fine to medium (0.1-3.5mm) and anhedral to subhedral. Simple twins are common and patchy interference colours exist. Chlorite alteration occurs to a significant degree. Pleochroic colours range from straw yellow to olive green. Sphene is present within the hornblende grains as secondary granules.

Plagioclase occurs as fine, anhedral grains within the recrystallised groundmass. Multiple twinning is present in all grains and substantial sericite alteration has occurred.

Quartz is present as fine anhedral grains which exhibit undulose extinction and occurs mostly within the recrystallised groundmass.

Biotite has a close association with the hornblende. It occurs as fine anhedral to subhedral grains and is chloritized to some extent. Minor muscovite is associated with the biotite.

Epidote forms a brightly coloured fine grained mosaic under cross polars. It is found mostly within the sericite alteration of plagioclase.

AMPHIBOLITE

888-	66	81
Amphibole	70	70
Plagioclase	20	20
Quartz	5	5
Potassium feldspar	tr	2
Opaques	5	tr
Epidote	tr	2
Sphene	tr	tr

888-66

Hand Specimen

A fine grained black rock with white speckles.

Thin Section

Amphibole occurs as fine, anhedral to subhedral grains. They have a poikiloblastic texture. Pleochroic colours range from straw yellow to deep green.

Plagioclase grains are anhedral and have been sericitized to a certain extent. Twinning is present in all grains.

Quartz is present as fine, anhedral grains which exhibit undulose extinction.

Opaques have been mostly altered to hematite and have a red/brown coloured rim.

888-81

Hand Specimen

A black, massive, fine grained rock with white speckles.

Thin Section

Amphibole occurs as fine to medium (0.02-3mm) anhedral to subhedral grains. They have a poikiloblastic texture and have been altered to varying degrees. Pleochroic colours range from light brown to dark green.

Plagioclase grains are fine, anhedral and exhibit multiple twinning. Sericite alteration has taken place.

Quartz grains are fine, anhedral and exhibit undulose extinction.

Potassium feldspar has microcline twinning and minor sericite alteration. Grains are fine and anhedral.

Epidote occurs as fine, anhedral to subhedral grains and has a poikiloblastic texture. It occurs mostly within the sericite alteration of the plagioclase and potassium feldspar.

HYDROTHERMAL VEINS

888-37

Hand specimen

A light coloured rock, possibly a tonalite, with a green vein showing diffuse edges and potassium alteration of the parent rock.

Thin section

Epidote (90%) forms most of the vein. Grains are anhedral and have interlocking boundaries. Grainsize is fine to medium (0.05 - 1.5mm). There are a few remnant grains of the original rock are altered.

Quartz (5%) is fine grained and anhedral within the vein.

Along the contacts of the vein within the country rock the plagioclase has been almost completely altered.

Biotite grains of the original rock have been altered to chlorite.

Alkali-feldspar is less altered than the plagioclase.

888-35

Hand specimen

This is a fine to medium grained acidic rock which has a green, fracture fill, hydrothermal vein, about 4-5mm wide.

Thin section

Epidote (98%) is the dominant mineral within the vein and consists of both medium (up to 4mm) subhedral to euhedral grains and fine (as small as 0.05mm) subhedral to anhedral grains. Grains are fractured to differing degrees and exhibit bright birefringence colours.

Quartz occurs within the vein as fine anhedral grains.

The grains of the country rock surrounding the vein show little to no sign of alteration.

APPENDIX 4

MAJOR, TRACE ELEMENT AND NORMATIVE WHOLE ROCK COMPOSITIONS

	Diorite			Amphibolite	
	888-68	888-78	888-84	888-66	888-81
Major elements (wt%)					
SiO_2	55.77	52.39	51.91	49.09	49.79
TiO_2	0.48	0.35	0.59	1.66	1.26
Al_2O_3	17.25	20.05	17.73	13.01	13.57
Fe_2O_3	6.69	6.24	8.61	18.07	13.75
MnO	0.12	0.12	0.14	0.30	0.26
MgO	5.60	5.39	5.84	5.96	6.67
CaO	7.54	9.87	9.52	8.59	9.41
Na_2O	5.36	3.68	3.46	2.24	2.23
K_2O	0.89	1.77	1.72	0.58	2.42
P_2O_5	0.13	0.03	0.06	0.15	0.18
Total	99.83	99.89	99.58	99.65	99.54
Trace elements (ppm)					
Rb	31	69	60	25.5	58
Sr	431	504	456	105	266
Ba	231	346	294	436	573
Y	12.4	4.7	7.2	43	27.6
Zr	77	26.5	38	91	95
Nb	2.3	1.2	1.9	2.6	5.7
Sc	26.1	26.8	33	58	48
V	185	166	292	425	342
Ni	76	29	36	45	49
Cr	144	<5	<5	<5	146
La	21	6	5	<2	17
Ce	35	16	23	17	35
Nd	19	7	8	7	12
Ga	18	18	17	20	19
Pb	14	9	8	4	7
U	2	1	2	2	2
CIPW norms					
Il	1.41	1.03	0.39	5.19	3.78
Mt	1.51	1.39	1.93	4.32	3.16
Or	4.79	9.50	9.27	3.32	13.28
Ab	27.21	18.61	17.57	12.07	11.53
An	29.62	39.17	33.82	29.14	24.48
Di	9.24	11.55	14.60	16.33	22.46
Hy	9.42	8.88	9.74	16.84	12.48
Q	15.90	9.74	10.07	10.66	6.95

Orthogabbro

	888-17	888-36	888-48	888-50	888-76	888-77
Major elements (wt%)						
SiO_2	50.41	55.21	50.90	54.07	51.88	50.02
TiO_2	0.44	0.30	0.25	0.35	0.35	0.72
Al_2O_3	16.04	5.65	15.40	6.68	15.35	8.13
Fe_2O_3	8.21	9.21	7.11	9.87	8.70	9.05
MnO	0.11	0.17	0.12	0.19	0.19	0.16
MgO	9.47	16.49	10.99	15.62	9.03	14.07
CaO	11.41	11.57	12.82	11.33	10.73	15.94
Na_2O	2.31	0.89	1.71	0.96	2.57	0.39
K_2O	1.15	0.35	0.96	0.42	1.02	0.41
P_2O_5	0.04	0.05	0.03	0.17	0.04	0.59
Total	99.59	99.89	100.29	99.66	99.86	99.48
Trace elements (ppm)						
Rb	37	7.9	34	9.5	30	5.2
Sr	538	121	476	154	511	904
Ba	2452	276	452	248	392	202
Y	10.3	12.6	7.4	12.6	8.0	24.2
Zr	45	51	19.4	46	23.8	86
Nb	2.4	1.1	0.6	0.6	1.2	3.3
Sc	41	54	51	52	42	57
V	197	128	115	132	162	176
Ni	122	403	194	317	89	331
Cr	157	1137	670	993	178	184
La	11	12	9	23	8	97
Ce	25	19	15	37	22	169
Nd	3	9	6	20	7	96
Ga	15	8	13	8	15	10
Pb	6	1	6	2	8	58
U	2	1	3	2	2	3
CIPW norms						
Il	1.30	0.89	0.73	1.05	1.04	2.01
Mt	1.85	2.09	1.58	2.27	1.98	1.94
Or	6.22	1.91	5.13	2.31	5.55	2.10
Ab	11.78	4.57	8.61	4.97	13.18	1.88
An	34.04	12.01	34.00	14.56	32.00	18.75
Di	23.53	43.83	29.51	40.84	22.32	53.84
Hy	11.95	16.81	11.46	17.18	12.35	9.10
Q	8.13	16.90	8.59	15.43	10.61	8.45

Granite

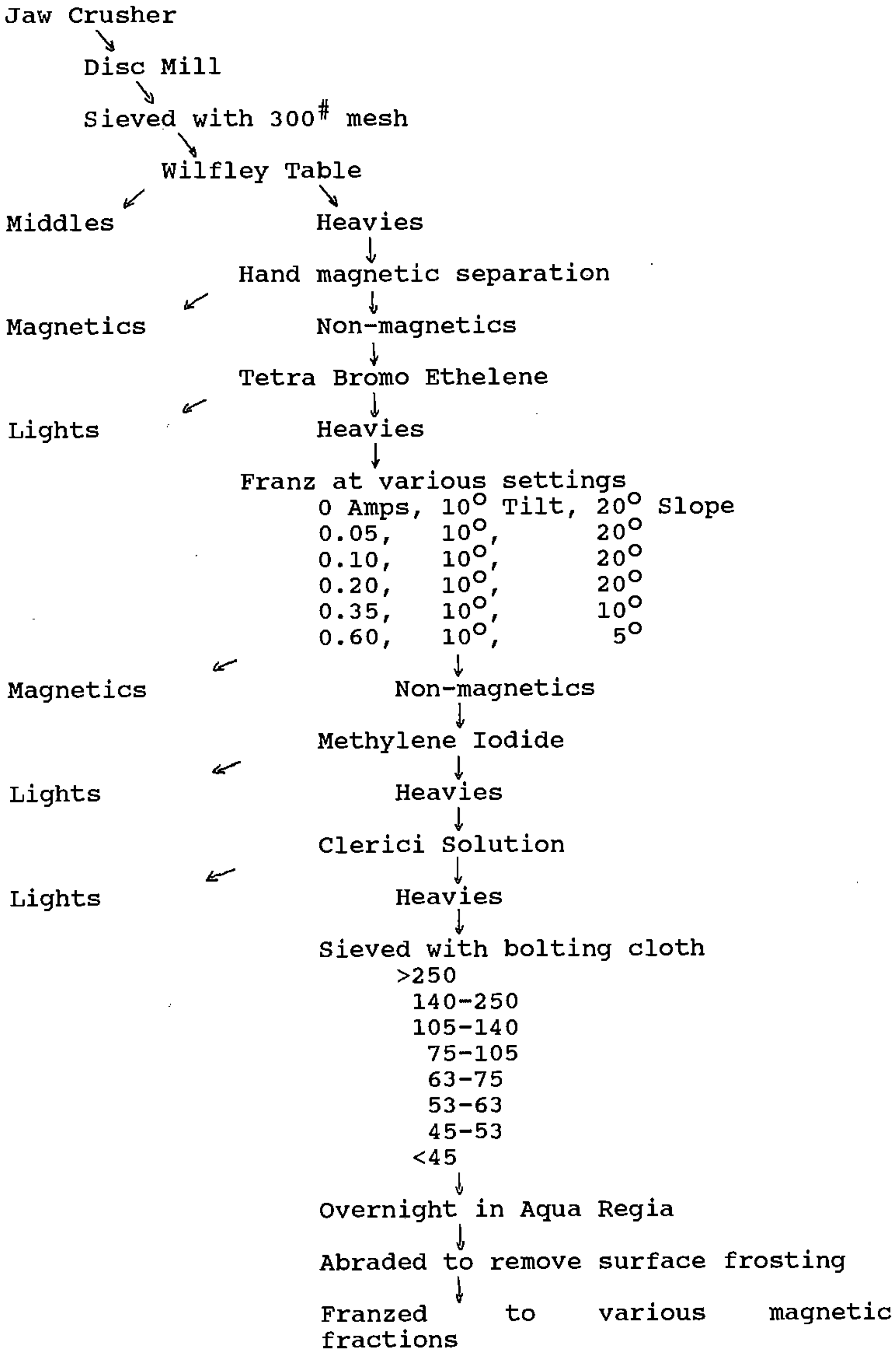
	888-23	888-26	888-29	888-31	888-52	888-71	888-74
Major elements (wt%)							
SiO_2	74.82	74.98	76.30	64.50	76.55	74.52	74.87
TiO_2	0.17	0.16	0.12	0.51	0.11	0.19	0.15
Al_2O_3	13.51	13.47	12.54	16.01	12.61	13.13	12.84
Fe_2O_3	1.87	1.62	1.28	3.99	0.90	1.83	1.23
MnO	0.02	0.03	0.03	0.11	<0.01	0.03	0.02
MgO	0.34	0.28	0.26	2.14	0.01	0.31	0.28
CaO	2.10	1.03	0.88	4.62	0.28	1.69	1.04
Na_2O	4.49	3.94	3.35	4.77	3.47	3.89	2.99
K_2O	2.12	4.27	4.83	3.33	5.52	3.66	5.13
P_2O_5	0.06	0.04	0.03	0.14	0.02	0.05	0.06
Total	99.50	99.82	99.62	100.12	99.47	99.30	98.61
Trace elements (ppm)							
Rb	50	114	140	84	144	106	112
Sr	332	120	90	342	49	187	169
Ba	578	756	661	735	619	694	915
Y	10	12.7	9	14	8.1	12.6	11.2
Zr	123	111	92	153	68	104	118
Nb	5	8	4.6	4.9	4.5	6.4	5.9
Sc	3.8	3.8	3.5	13.7	1.8	4.1	3.0
V	15	15	9	85	3	20	11
Ni	6	6	5	13	3	3	5
Cr	<5	<5	<5	<5	<5	<5	<5
La	60	49	32	38	54	63	37
Ce	71	68	44	57	98	93	80
Nd	29	23	17	18	22	30	24
Ga	14	15	16	17	13	17	14
Pb	11	12	11	2	10	13	13
U	5	3	4	4	3	6	7
CIPW norm							
Il	0.45	0.42	0.31	1.43	0.29	0.50	0.39
Mt	0.38	0.32	0.26	0.86	0.18	0.36	0.24
Or	10.24	20.50	23.18	17.07	26.29	17.74	24.59
Ab	20.44	17.83	15.15	23.05	15.57	17.76	13.51
An	10.14	4.95	4.22	20.28	1.33	8.19	4.99
Di	nd	nd	nd	2.83	nd	nd	nd
Hy	1.49	1.27	1.05	4.33	0.50	1.43	1.02
C	4.78	5.64	4.58	nd	5.35	3.91	4.64
Q	51.35	48.70	50.70	29.77	49.86	49.18	49.06

Tonalite

	888-20	888-21	888-22	888-25	888-55	888-73	888-82
Major elements (wt%)							
SiO_2	66.04	64.43	64.53	72.48	67.22	63.06	68.09
TiO_2	0.52	0.53	0.57	0.33	0.38	0.63	0.44
Al_2O_3	15.71	16.41	16.44	13.83	16.27	16.33	15.34
Fe_2O_3	4.72	4.95	4.85	2.85	1.34	5.67	3.97
MnO	0.06	0.06	0.08	0.05	0.06	0.07	0.05
MgO	2.00	2.07	1.48	0.74	1.29	2.04	1.18
CaO	4.36	4.58	4.04	2.59	4.61	5.05	3.64
Na_2O	4.06	4.27	4.30	4.03	5.32	3.99	4.23
K_2O	2.33	2.09	2.84	2.62	2.73	2.29	2.36
P_2O_5	0.16	0.16	0.18	0.08	0.12	0.17	0.11
Total	99.96	99.28	99.31	99.60	99.34	99.30	99.41
Trace elements (ppm)							
Rb	76	65	101	85	52	80	66
Sr	412	461	374	241	395	409	360
Ba	616	571	699	405	1146	489	996
Y	13	14.6	15.5	15.5	10.1	14	10
Zr	157	165	171	149	156	145	173
Nb	5.4	5.2	6.6	8	4.1	3.5	5
Sc	7.9	12.6	10.4	5.8	9.5	13.4	8.4
V	84	89	80	36	59	108	62
Ni	15	17	7	5	8	13	12
Cr	<5	<5	<5	<5	<5	<5	<5
La	21	41	40	45	31	39	65
Ce	33	66	56	57	55	55	100
Nd	20	25	19	23	16	21	31
Ga	21	18	20	18	16	20	18
Pb	8	10	11	11	30	8	10
U	2	3	8	5	3	5	4
CIPW norms							
Il	1.46	1.49	1.59	0.89	1.04	1.79	1.21
Mt	1.00	1.07	1.04	0.59	0.27	1.24	0.84
Or	11.94	10.76	14.46	12.86	13.62	11.91	11.83
Ab	19.61	20.71	20.63	18.64	25.02	19.56	19.99
An	22.34	23.58	20.57	12.71	20.51	26.13	18.27
Di	nd	nd	nd	nd	2.13	0.11	nd
Hy	5.31	5.57	4.71	2.52	1.62	6.00	3.77
C	1.13	1.17	2.28	3.60	nd	nd	2.69
Q	36.58	34.32	33.42	47.46	34.90	31.89	40.36

APPENDIX 5

GEOCHRONOLOGICAL TECHNIQUES



Jaw Crusher

Disc Mill

Sieved with 300# mesh

Wilfley Table

Middles

Heavies

Hand magnetic separation

Magnetics

Non-magnetics

Tetra Bromo Ethelene

Lights

Heavies

Franz at various settings

0 Amps, 10° Tilt, 20° Slope
0.05, 10°, 20°
0.10, 10°, 20°
0.20, 10°, 20°
0.35, 10°, 10°
0.60, 10°, 5°

Magnetics

Non-magnetics

Methylene Iodide

Lights

Heavies

Clerici Solution

Lights

Heavies

Sieved with bolting cloth

>250
140-250
105-140
75-105
63-75
53-63
45-53
<45

Overnight in Aqua Regia

Abraded to remove surface frosting

Franzed to various magnetic fractions

Six of the above magnetic and size fractions were choosen so as to give as wide a range in size and magnetic susceptibility as possible.

Each fraction was purified by hand picking.

Up to nine milligrams of each fraction was dissolved under pressure in a mixture of HF and HNO_3 at 220°C for one week.

Each of the six solutions was then divided into two fractions and a mixed U/Pb spike was added to one of these.

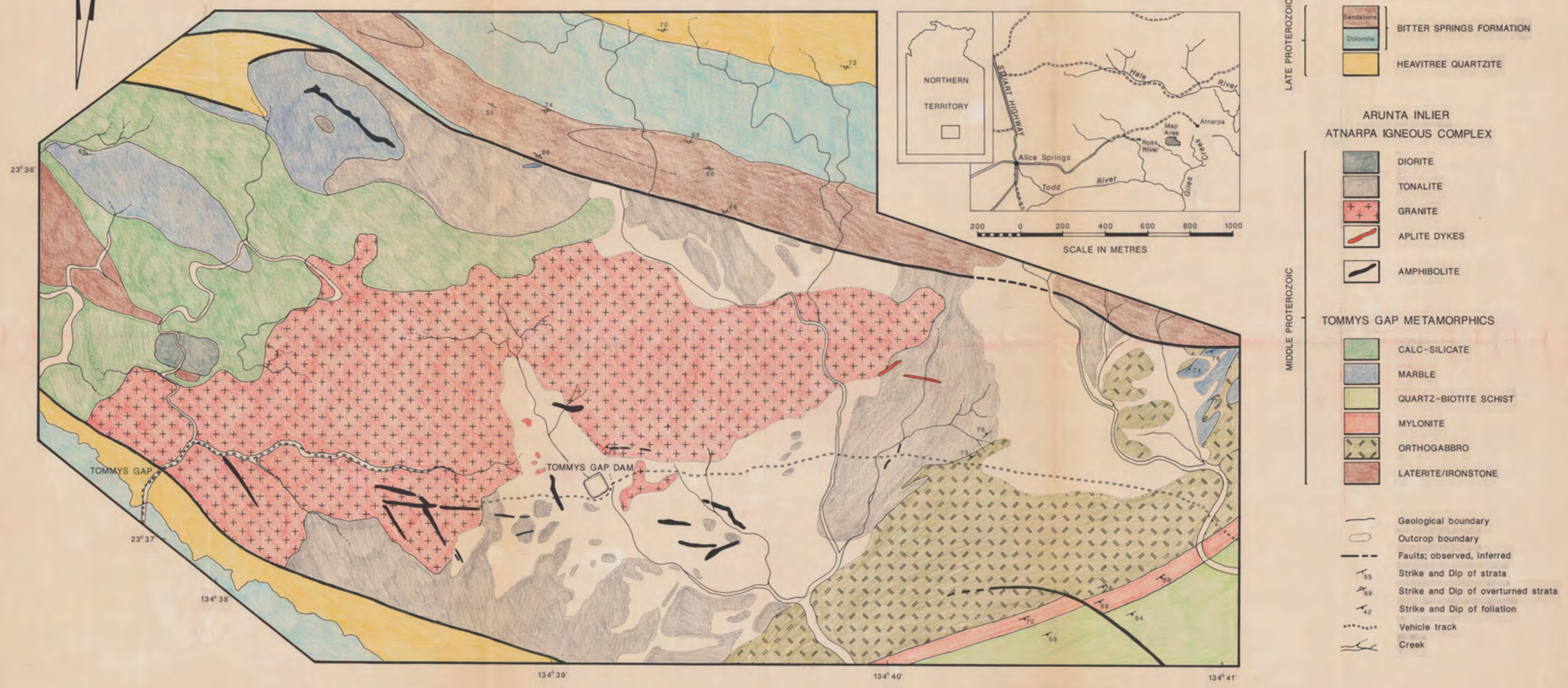
The spiked and unspiked fractions were run through ion exchange columns and the Pb, Pb-spiked and U-spiked fractions collected.

Pb and Pb-spiked fractions were loaded onto rhenium filament beads and U-spiked fractions were loaded onto tantalum filament beads and analysed on the mass spectrometer.

Zircon fraction	Size (microns)	Magnetic response	Weight (mg)	U (ppm)	Pb (ppm)	206Pb 204Pb	206Pb 208Pb	206Pb 238U	207Pb 235U	207Pb 206Pb	Apparent ages (Ma)		
											206Pb 238U	207Pb 235U	207Pb 206Pb
1	142 - 250	NM 1	5.2	754	213	2634	6.801	0.2567	3.855	0.10891	1473	1604	1781
2A	105 - 142	NM -1	4.9	671	195	4680	7.914	0.2706	4.125	0.11057	1544	1659	1809
3A	75 - 105	NM -1	8.0	1368	290	1899	7.729	0.1947	2.761	0.10285	1147	1345	1676
4A	63 - 75	M 2	6.8	1036	245	5601	8.383	0.2228	3.280	0.10678	1296	1476	1745
5A	53 - 63	M 2	9.8	1215	279	5240	8.340	0.2159	3.165	0.10640	1259	1449	1739
6A	45 - 53	M 2	3.7	1209	279	3851	8.328	0.2160	3.139	0.10541	1261	1442	1721

TABLE 2 : U - Pb isotopic analyses of zircon fractions separated from the Tommys Gap Dam tonalite sample 888-025 (J.A.C. 87/1). Under "Magnetic response" M = magnetic, NM = non-magnetic, and the digit represents degrees dip of the Franz separator magnet with 1.8 amps magnet current. The 206Pb/204Pb ratio is as measured. The other isotope ratios include radiogenic lead only.

GEOLOGY OF THE TOMMYS GAP DAM AREA, SOUTHERN ARUNTA INLIER, CENTRAL AUSTRALIA



Brett G. Sando 1987