GEOLOGICAL SURVEY
OF
WESTERN AUSTRALIA

REPORT 9

CONTRIBUTIONS TO THE GEOLOGY OF THE EASTERN GOLDFIELDS PROVINCE OF THE YILGARN BLOCK

by W.G. Libby
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FOREWORD

The four papers in this Report cover various aspects of the petrography of felsic igneous rocks of the Eastern Goldfields Province. Each paper is restricted in scope, but together they touch on a wide range of problems within the felsic igneous spectrum.

Three of the papers include discussion of granitoid rock. This reflects an increasing awareness that the geological framework of the Eastern Goldfields cannot be understood through study of the greenstone belts alone. On the other hand, felsites and alkaline rocks from the greenstone belts are considered in two of the papers.

Mildly alkaline rocks are the subject of two of the papers. To my knowledge these rocks have not previously been described as a coherent suite in the Eastern Goldfields. The potential economic and petrogenetic significance of the suite justifies their study at the expense of more abundant material.

The Eastern Goldfields Province continues to be a major contributor to the mineral wealth of Western Australia. The petrogenetic studies presented here should aid the effort to understand the rocks of the area and assist in the development of this wealth.

J.H. Lord
DIRECTOR

7th August, 1978

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TEXTURE OF FELSITE

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by

W.G. Libby

ABSTRACT

Porphyritic acid to intermediate pyroclastic deposits, flows and hypabyssal intrusions are common in parts of the Eastern Goldfields Province.

Groundmass textures are varied, but abundant micropoikilitic texture and rare relict perlitic texture indicate devitrification and suggest that a substantial part of the felsite suite was emplaced at or near the surface of the ground.

Recrystallization has affected all felsites in the area but ranges in intensity from delicate, with preservation of such details as perlitic cracks, to intense, with development of a secondary coarse mosaic groundmass.

INTRODUCTION

The Geological Survey of Western Australia prepared geological maps of much of the Eastern Goldfields Province of Western Australia between 1963 and 1974. Samples of felsite, as well as other rocks, were collected during this work, and thin sections were prepared. Information from these thin sections has been used in the mapping of individual sheets. The present paper brings together thin-section data on felsites throughout the province. The area of study, geological framework of the Yilgarn Block, and location of map sheets discussed are shown in Figures 1 and 2 of the accompanying paper on granitic rocks of the area (Libby, 1978a).

Textural relations are emphasized because the textural assemblage is rich, and promises to provide clues to the origins of the rock. A textural approach also complements a recent chemical study of the composition of felsites in the northern portion of the Eastern Goldfields Province by Davy (1977).

INTRUSIVE, EXTRUSIVE AND HYPABYSSAL ROCKS

Most accounts of felsites in the Eastern Goldfields Province describe the bodies as large concordant sheets or small, clearly discordant dykes. Neither field relations nor petrography have determined in all cases, whether the sheets are sills or flows. There has even been disagreement as to whether certain sheets are sheared felsite bodies or oligomictic conglomerate. In the face of such uncertainty, attempts to classify felsites on mode of emplacement were abandoned for this report as being more likely to add to confusion than to clarify relationships.

Petrographic criteria have been suggested for distinguishing hypabyssal intrusions from flows. In a section attributed in part to Trendall, Turek (1966, p.A-9) suggested that "... extrusive rocks are characterized by predominance of small corroded quartz phenocrysts and by spherulitic and allied structures of the matrix, while intrusive have larger and more abundant feldspar phenocrysts in an even quartz-feldspar mosaic of the matrix". These tentative criteria could not be checked during the study so were not used.

It seems likely that felsites in the collections represent several types of emplacement: fully intrusive sills and dykes, dykes and less regular intrusive masses associated with vents and/or rifts, lava flows, and, possibly, pyroclastic and sedimentary emplacement.

USE OF TERMS

The rocks studied in this section conform to the definition of "felsite" by Gary and others (1972, p.256). According to this source, a felsite is, "A light-colored, fine-grained extrusive or hypabyssal rock with or without phenocrysts and composed chiefly of quartz and feldspar ..." The term should not be used when a more precise name can be found, but is useful for the varied suite considered here.

The use of "porphyry" follows the recommendations of Trendall (1964, p.46-50), and accordingly, "porphyrite" is not used. Following the argument of Joplin (1964, p.3), the porphyritic aspect of a rock is usually indicated by an adjectival modifier prefixed to the name of the compositionally equivalent even-grained volcanic or plutonic rock. "Porphyry" is used only in reference to other works or where a more precise term would be awkward or misleading.

For a rock to be porphyritic, some single constituent mineral must have at least two distinctly different common sizes; that is, the size distribution of some single mineral must be bimodal. The rock is hiatal (Johannsen, 1939, p.216) in that one or more gaps exist in the size-frequency distribution of grains. In contrast, an inequigranular rock in which the size of grains varies gradually or in a continuous series is seriate (Johannsen, 1939, p.233). "Vitrophyric" is preferred to "porphyritic" where discrete grains are set in a groundmass which is glassy and not devitrified, but "porphyritic" is used for a hiatal rock in which relatively coarse grains are set in a devitrified groundmass.

The grain size of a porphyritic rock, for the purpose of classification, is determined by the coarseness of the groundmass phase, regardless of the proportion of phenocrysts and groundmass. Thus a rock with 90 per cent phenocrysts (of, for example, potassium feldspar and quartz) in an aphanitic matrix is a porphyritic rhyolite, despite the preponderance of coarse grains. However, only igneous textures are considered; a crushed granite is not a rhyolite.

REFERENCE TO SAMPLES

Throughout the text samples are identified by their Geological Survey field sample number followed by the name of the 1:250 000 map sheet covering the area from which they were collected. An exception from Baja California is described in the text. The Australian Transverse Mercator yard grid location for each sample mentioned in the text is listed in the Appendix.

PREVIOUS STUDIES

Felsic volcanic and porphyritic rocks of the Eastern Goldfields Province have been studied in detail by Trendall (1964), O'Beirne (1968), and Davy (1977). In addition to discussion of the propriety of the terms "porphyry" and "porphyrite", Trendall considered problems of alteration of porphyries and their association with conglomerates. The development of oscillatory zoning in plagioclase, and the failure of phenocrysts to straddle the boundary between clasts and matrix suggested that conglomerates are clastic derivatives of associated porphyries, and that porphyries have not been derived from sedimentary rocks by porphyritization. O'Beirne classified the porphyries, determined the physical conditions of their emplacement, found that, in general, they are not directly related to associated granite, and found pseudo-igneous porphyroids at Widgiemooltha, Wongi Dam, and in the Mandilla and Wanda Wanda Beds. Sodic felsic rocks were emplaced over a long period throughout the Kalgoorlie succession; both extrusive and intrusive porphyritic rocks are present, and all the porphyries in the area are older than "internal" granitic rocks, where "internal" granites are discrete granitoid plutons within greenstone belts. Gold appears to O'Beirne to be spatially and genetically related to the porphyritic sodic rhyolite, but details of the relationship remain for further studies.

Trendall (1964) considered the earlier literature on nomenclature, and O'Beirne (1968) reviewed other early literature on porphyritic rocks of the Eastern Goldfields Province.

Davy's study of the bedrock chemistry of the Leonora, Laverton and Archaean portion ofthe Rason 1:250 000 sheets includes an extended treatment of the chemical aspects of fine-grained felsic rock.

In some areas (Ford Run Plateau, Leonora sheet) Davy found similarities between acid volcanic rocks, hypabyssal intrusives, and nearby "biotite" granite such as to suggest a related origin. Elsewhere (Rutter Soak and Yamarna on the Rason sheet) there is little chemical relation between granitoid rock and nearby volcanic or hypabyssal rock.

In some areas (Rutter Soak) acid volcanic rocks vary widely in composition from ultrapotassic rhyolite to andesite; however, in other areas (Yamarna), the compositional range is small. In general, dacite is the characteristic composition throughout the three sheets.

Wherever enough varied data were available to plot a trend on an AFM diagram the rock suites were found to be calc-alkaline; however, there is a gap due to lack of rocks of intermediate composition.

PETROGRAPHY OF COMMON FELSITES

Three categories of felsite are discussed separately: andesite, alkaline felsite and quartz-bearing felsites without obvious alkaline affinities. For ease of reference the latter are called common felsites. These are the predominant fine-grained felsic rock of the Eastern Goldfields Province, corresponding in large part to the rock called porphyry in this work and the work of various other authors. The andesites are considered later in this report and alkaline felsites are treated together with granitic alkaline rock in a separate report in this publication (Libby, 1978b).

The general petrographic characteristics of the porphyries have been briefly summarized by Trendall (1964, p.48 and 49).

MINERALOGY

Petrographic identification of matrix minerals of small grain size is not reliable and the data of O'Beirne (1968, p.292) suggest that phenocrysts are not a reliable guide to the bulk mineralogical composition of these rocks. Still, recognition of minerals imposes constraints on the bulk composition.

MAJOR FELSIC MINERALS

Quartz

Rounded and embayed quartz phenocrysts (Plates I and III) are common and quartz is also abundant in the matrix of rocks with granular groundmass. It may also be abundant in rocks with micrographic texture, but the groundmass grains are commonly too fine for identification in such rocks. Only rarely is feldspar not a phenocryst phase but in samples 38307 (Leonora) and 15504 (Edjudina) quartz is present and feldspar phenocrysts excluded.

Feldspar

Plagioclase phenocrysts (Plates II, III and IV) are prominent in most samples of common felsite. The plagioclase phenocrysts tend to be homogeneous and albitic but there are exceptions. Normative plagioclase up to 30 per cent anorthite was found by O'Beirne (1968) and a-normal extinction angles on plagioclase in a hornblende dacite in the present study suggest zoning up to 25 or 30 per cent anorthite. Oligoclase and andesine commonly have euhedral, oscillatory zoning (sample 32719, Leonora). Zoned plagioclase, that is, plagioclase more calcic than albite, is most commonly associated with primary hornblende, but in samples 20979A and B (Menzies) it is associated with secondary red biotite. Plagioclase is very weakly zoned in a rhyodacite (sample 15501, Edjudina), and, in some samples, zoning appears only in differential concentrations of alteration products (samples 29962, Laverton and 24808, Edjudina; illustrated in Plate IV). Plagioclase commonly is severely altered to sericite or sericite plus saussuritic epidote. Saussuritization indicates that much of the rock which contains albite crystallized with a more calcic plagioclase.

The plagioclase phenocrysts normally are euhedral (Plates II, III and IV) but in a few samples (15514A, Edjudina) phenocrysts are rounded, apparently as a result of resorption in magma or reaction with the matrix. Mechanical rounding of phenocrysts is characteristic of the sheared rocks. In some samples, phenocrysts are glomeroporphyritic (sample 32717, Leonora). Where the matrix is coarsely granular (sample 37803, Laverton) grain margins are irregular in detail but retain their general euhedral shape. Rarely (as in sample 38127, Laverton), plagioclase is surrounded by a granophyric intergrowth of quartz and plagioclase.

Some samples carry phenocrysts of potassium feldspar. In a few of these the phenocrysts have well-developed microcline "M" twinning (samples 17645A, Menzies and 24808, Edjudina) but more commonly twinning is not obvious or is missing (sample 37805, Laverton). Thus potassium feldspar may be present in samples where it was not recognized, especially where alteration has been severe.

In a few samples (9101 and 9102, Kalgoorlie) microcline forms very coarse euhedral phenocrysts, too large for estimation of size in normal thin sections.

Rarely (sample 32717, Leonora), potassium feldspar is associated with zoned plagioclase and hornblende; and, also rarely, plagioclase is intergrown with and surrounded by potassium feldspar (sample 37805, Laverton).

Thus, potassium feldspar, though persistent, seems distinctly subordinate to sodic plagioclase in the phenocryst assemblage of the common felsites. However, as it tends to crystallize late, it may be more abundant in the matrix.

MAJOR MAFIC MINERALS

Biotite

This is the usual mafic mineral in the common felsite but it can only rarely be shown to be primary. In two samples (38308, Leonora and 37820, Laverton) large, euhedral phenocrysts of biotite accompany feldspar phenocrysts. In some samples biotite phenocrysts are chloritized (sample 20926, Kurnalpi) or altered to aggregates of biotite, epidote, and felsics (sample 9102, Kalgoorlie). More commonly, biotite has a clearly hornfelsic habit (sample 24808, Edjudina; illustrated in Plate VIII). Hornfelsic biotite is best developed in rocks with microgranular texture, discussed later. Igneous biotite may be recrystallized even where plagioclase phenocrysts retain their euhedral shape and oscillatory zoning (samples 20979A and B, Menzies).

In rocks showing textural response to stress biotite tends to be reconstituted into multitudinous fine flakes (samples 13143 and 40860, Widgiemooltha and 37810, Laverton). Rarely (sample 37814, Laverton) biotite has been replaced by prehnite as well as chlorite.

The colour of biotite most commonly is medium brown, but grey-brown, dark olive-brown, dusky olive-green and bright fox-red are all developed, probably in secondary biotite.

Amphibole

Amphibole is less abundant in the common felsite than in intermediate porphyries, but euhedral hornblende occurs as a primary phase in several samples, accompanied in sample 32717 (Leonora) by quartz, plagioclase, potassium feldspar and biotite phenocrysts, in sample 32719 (Leonora) by quartz and plagioclase phenocrysts, and in sample 38127 (Laverton) by plagioclase and partly-granophyric quartz. Primary amphibole phenocrysts have been replaced by chlorite in a few samples (9103, Kalgoorlie; 20926, Kurnalpi). Hornblende is seriate in sample 32799 (Leonora). Secondary amphibole and biotite are abundant in a devitrified vitrophyre, sample 8886B (Menzies).

Chlorite

The most common mafic mineral is chlorite which has replaced much of the secondary as well as primary biotite and some hornblende.

Other minerals

Secondary clinopyroxene and garnet along with epidote and prehnite indicate substantial metamorphism of sample 39802 (Leonora).

MINOR AND SECONDARY MINERALS

Colourless mica

Although colourless mica is abundant in many samples there is no evidence for peraluminous magmas. The colourless mica seems entirely secondary. Normally it is concentrated in plagioclase grains. It is invariably associated with chlorite, epidote, carbonate or secondary biotite and in all but one sample (20919, Kurnalpi) the colourless mica is in rocks with a granular groundmass.

In sample 20919 phenocrysts of quartz and feldspar are set in a microsymplectic matrix of incipient spherulites. Here, the coarser muscovite seems to have replaced mafic minerals, possibly biotite; the finer grains range from more-or-less discrete grains to radiating aggregates and irregular, cryptocrystalline wisps. Sericitic alteration of plagioclase is common, but most of the colourless mica is intergranular. Again, none of the colourless mica seems primary.

Carbonate

Secondary carbonate is common in many samples, becoming prominent in some (samples 38659, Kurnalpi and 15522, Edjudina, and the breccia, sample 38660, Kurnalpi). Where carbonate is abundant it forms amoeboid masses replacing parts of both matrix and phenocrysts. Less commonly it occupies veins. Some of the veins seem to be, at least partly, of replacement origin. The veins die out abruptly and irregularly, they may have irregular margins, and include patches of matrix.

Other minerals

Sphene is common in the hornblende-bearing rocks (sample 32717, Leonora). In some samples apatite is coarse enough to be recognized. Magnetite, hematite and ilmenite are common. Fluorite is abundant in a few samples (for example, sample 8887, Menzies).

A few common felsites have been metamorphosed at high grade. Sample 17645A (Menzies) contains garnet and sample 39802 (Leonora) contains clino-pyroxene and garnet as well as epidote and prehnite. Sample 37814 (Laverton) also has prehnite and contains minor pumpellyite.

TEXTURES

Typical common felsite is a simple porphyry with euhedral or partially absorbed phenocrysts in a groundmass which is granular, patchy or micrograndphyric. Examples are shown in Plates I, II, III and IV. However, other textures are common. Many samples are sheared, showing various stages of development of mylonitic texture (Plates V, VI and VII). Some are glomeroporphyritic and some are breccias. A few samples are even grained. Generally, however, a coarse phase and a groundmass phase can be readily distinguished or the rock is seriate, ranging regularly from fine to coarse. In this discussion the terms "matrix" and "groundmass" are used interchangeably.

GROUNDMASS TEXTURES

It seems certain that most or all of the present groundmass texture was developed after the rock cooled below through the solidus temperatures. In some cases the texture has been grossly altered, as in the sheared and metamorphosed samples. More commonly the general texture is one of sub-solidus crystallization, that is, devitrification. The term "devitrification" has been used in the literature in various senses. As early as 1903 Sollas criticised the use of "devitrification" by Bonney and Parkinson (1903) for textures which "... might be due to direct crystallization from molten magma". Commonly no critical distinction is made between crystallization at solidus temperatures and early devitrification from a supercooled glass.

After thoughtful consideration of the problem, Lofgren (1971a, p.111) used "devitrification" to describe crystallization below the thermodynamic solidus temperature. Crystallization below the solidus temperature but above the glass transition temperature was included in "devitrification" because of the difficulty in recognizing the glass transition temperature; textures formed above this temperature are similar to those formed below it. The groundmass of most samples can be described under one of five headings: microcrystalline (Plates IX, X and XI), microsymplectic (Plates XII to XX), orb (Plates XXIX and XXX), microgranular (Plates XXI, XXII and XXIII) or microlitic (Plate XXIV). All but the last two textures seem to be associated with devitrification. The three devitrification textures and the microgranular texture seem intergradational.

The devitrification textures seem to be included in the "micropoikilitic" texture of Reed (1895). "Micropoikilitic" has been retained in a restricted sense but was rejected as a general term for the devitrification textures in this work because it does not logically seem to include the vermicular and granophyric intergrowths of microsymplectic texture. Johannsen (1939, p.234) defined "symplectic" as "A texture in which two different minerals are intimately interlaced, embracing thus the pegmatitic, granophyric, poikilitic, ophitic, basiophitic, etc., textures". The microsymplectic textures in the felsites of the Eastern Goldfields Province have the form characteristic of the symplectites of Johannsen, but the diameter of aggregates of intergrown grains is rarely greater than 0.8 mm. Where aggregates are coarser than this the component textures (granophyric, pegmatitic, etc.) are described individually.

Microcrystalline texture

Felsites of the Eastern Goldfields Province commonly have an even groundmass of very fine grain size, about 0.015 mm. This is microcrystalline texture, illustrated in Plates IX and X. Grains are sutured or intertwined in a complex manner. Where intertwining of grains becomes more complex microcrystalline texture grades into microsymplectic texture (Plate XI). If on the other hand, the grain size increases with simplification of grain boundaries, microcrystalline texture approaches microgranular texture. As grain size decreases the texture becomes cryptocrystalline but true cryptocrystalline groundmass texture is rare. Samples 7900 C, K and L (Kalgoorlie), 37805 (Laverton), 17645B (Menzies) and 9102 (Kalgoorlie), among others, have typical microcrystalline groundmass; samples 32719 and 32722 (Leonora) are gradational to microsymplectic texture; and samples 11645A and B (Menzies), and patches in sample 11053

(Kurnalpi) are transitional to microgranular texture.

The origin of microcrystalline texture is not clear. It does not seem to have been found by Lofgren (1971a) among the products of artificially induced devitrification. Probably it is related to the cryptocrystalline texture of various authors (Reed, 1895).

Microsymplectic texture

Very fine aggregates of intergrown felsic minerals are typical of the felsites of the Eastern Goldfields Province. Microsymplectic texture refers to these intergrowths which occur in aggregates seldom more than 0.8 mm in diameter. Microsymplectic texture includes at least three textures which can be more specifically named: "micropoikilitic", "vermicular-granophyric" and "micrographic". All of these textures are "patchy" in that they are difficult to recognize in plain light, but between crossed polarizers elements within aggregates are seen to have either a dominant orientation or a radiating pattern. Most samples with these textures are incipiently spherulitic.

Micropoikilitic (snowflake) texture describes rocks in which individual mineral elements in the microsymplectic aggregates tend to be equidimensional. A texture apparently similar to this was named "snowflake texture" by Snyder (1962). A rounded or irregular single grain, normally quartz, encloses other grains which are effectively equidimensional. There are at least two types of micropoikilitic texture. In the first, enclosed grains, though very small can be easily resolved by a petrographic microscope. The second consists of indistinct quartz patches blurred by inclusions which appear as points under the petrographic microscope. Micropoikilitic texture is illustrated in Plates XII to XV.

Resolvable micropoikilitic texture is normally not well developed and is characteristic of small grain aggregates which are transitional to microgranular texture (see Plate XII).

Fine micropoikilitic texture, or "patchy" texture, refers to dusty patches of quartz, generally smaller than 0.8 mm in diameter. The patches have indistinct margins which, together with dustiness, gives them a blurred appearance between crossed polaroid filters. Unless individual patches are surrounded by material expelled during crystallization (orb texture), adjacent patches are very difficult to distinguish from matrix or from each other under plain light, though the patchiness is evident between crossed polaroids. Fine micropoikilitic texture is illustrated in Plates XIII, XIV and XV.

The mineral of the patches often, possibly invariably, is quartz. Patches of this type are common in descriptions of devitrified natural glass. Reed (1895, p.166-67) described quartz patches in detail in a discussion of micropoikilitic texture. He included with micropoikilitic texture, quartz patches which contain "... cryptocrystalline, or 'dusty' material ...".

Micropoikilitic patches rarely form a continuous pavement in the thin sections studied, but occur individually or in clusters, separated by other textures such as the interstitial microgranular texture in sample 38307 (Leonora) and 15514A and B (Edjudina).

Fine micropoikilitic texture grades into microgranular texture. Some rocks have three-tiered textures with coarse phenocrysts, fine-grained micropoikilitic patches, and interstitial, very minutely granular, almost cryptocrystalline patches (sample 15514A, Edjudina). A small proportion of samples with fine micropoikilitic texture have microlites as well. Probably these rocks have been devitrified from a porphyritic and microlitic vitrophyre.

There are many examples of micropoikilitic texture in the thin sections studied. Fine micropoikilitic texture is represented by sample 32722 (Edjudina). Coarse micropoikilitic texture is developed in sample 9101 (Kalgoorlie), Plate XII. Sample 8885B (Menzies) is similar, but has a microlitic element as well. Micropoikilitic patches are more fully developed in samples 32799 (Leonora), 39018 (Laverton) and 15527 (Edjudina). Resolvable micropoikilitic patches are relatively large (0.75 mm) and unusually well developed in sample 6523 (Widgiemooltha). Scattered resolvable micropoikilitic patches in the microgranular groundmass of sample 37810 (Laverton) seem associated with metamorphic recrystallization.

In sample 9130A (Kalgoorlie) the coarse host to the poikilitic inclusions has a fibrous tendency, transitional to microspherulitic texture.

In sample 9153 (Kalgoorlie) two or more phases are very intimately intergrown so that the distinction between host and inclusions is lost, yet there are elements which retain an approach to parallel extinction. In this sample micropoikilitic texture is much like vermicular-granophyric texture without appreciable elongation of any mineral.

Vermicular-granophyric texture is a form of microsymplectite represented by aggregates of intergrown vermiform grains of felsic minerals, similar to the quartz of myrmekite.

In detail the grains are sinuous, distinguishing the texture from micrographic texture where the grains are rod-like or angular. The vermiform grains appear to pinch and swell, but this may be due to weaving of the "worms" in and out of the plane of the thin section. Bundles of "worms" tend to be roughly parallel, forming groups within single aggregates. Groups of parallel "worms" are joined, forming sectors which give the aggregate an overall radiating appearance. Thus the vermicular-granophyric aggregates in large part probably are incipient spherulites. Sample 32797 (Leonora) is a good example of most of these features. In this and in other samples the "worms" are locally ordered to form micrographic texture. Elsewhere in the sample there are sheaf-like aggregates of the type described by Lofgren (1971a) as incipient spherulites (Plate XVII). Parts of sample 17263 (Menzies), Plate XVI, resemble the spherulitic texture illustrated by Lofgren (1971a) in his Figure 3A.

In sample 15514C (Edjudina) intergrowth is cryptocrystalline and is recognized mainly by radial extinction of very small aggregates. The groundmass of sample 20919 (Kurnalpi) is both microlitic and vermicular-granophyric. The granophyric aggregates are radiating and relatively coarse, about 0.5 mm, but the intergrown rods are very fine. Sample 30800 (Laverton) also has vermicular-granophyric texture superimposed on a microlitic fabric (Plate XVIII).

Micrographic texture is similar to vermicular-granophyric except that the intergrown grains are angular. The two textures are gradational and may be present in the same thin section, for example, samples 32797 (Leonora) and 25033 (Edjudina). Micrographic texture is illustrated in Plates XIX and XX.

Most vermicular-granophyric and micrographic aggregates have an incipient spherulitic form. Some are similar to those illustrated by Lofgren (1971a), Figure 3A. Rarely, as in sample 8889 (Menzies), the margins or resorbed centres of potassium feldspar grains are partly symplectic. In this sample the texture strongly suggests that intergrowth developed subsequent to crystallization as a partial replacement of the phenocrysts rather than as an overgrowth. In other samples, granophyre apparently nucleated on phenocrysts and grew outward. Where the intergrowth has nucleated on a phenocryst or microlite, one phase of the granophyre may be in optical continuity with the host (sample 15532, Edjudina).

Some samples have a three-tiered structure which may consist of phenocrysts, microlites and granophyre; in other samples phenocrysts and granophyre lie in a microcrystalline groundmass.

Vermicular-granophyric and micrographic textures are rare in rocks with appreciable planar cataclasis although vermicular-granophyric texture is weakly developed in at least one sheared sample (38135, Laverton).

Orb texture

Lofgren (1-71a, p.118-19) named and described as orb texture the spheroidal domains relatively devoid of globulites. Globulites, in turn, were defined (Lofgren, 1971a, p.115) as tiny, even-spaced bubbles and crystalline blebs, 0.5 to 5 microns in diameter. The globulites appear as opaque dust particles under transmitted light. They commonly are concentrated at the margins of the globulite-free orbs. Presumably the orbs are free of globulites due to exclusion during devitrification.

Orb-like textures are common in the felsites of the Eastern Goldfields Province; but excluded material coarse enough for rough identification is present as well as globulites. Presumably some of the excluded globulites have recrystallized into coarser grains in response to metamorphism. Orb-like textures are developed in micropoikilitic and microsymplectic rocks (sample 32798, Leonora). Minerals rimming the orbs include chlorite (sample 15514A, Edjudina), sericite (samples 38307 and 32798, Leonora and 25034, Edjudina), biotite (sample 8894, Menzies and 15514C, Edjudina) and biotite plus hornblende (sample 8886B, Menzies). This final sample is unusual, as the orbs are very large, about 4.5 mm in diameter, and enclose relict perlitic cracks and axiolites. Plates XXIX and XXX illustrate orb texture in the Eastern Goldfields Province.

Microgranular texture

This texture refers to a groundmass which is essentially equigranular, and is made up of discrete felsic grains. It is gradational to microcrystalline texture from which it is distinguished by coarser grain size and less interlocking of grains. Although grains may be sutured they are not intimately intergrown. The grain size is coarser than about 0.05 mm. The texture is shown on Plates XXI, XXII and XXIII.

Samples with microgranular texture have a hornfelsic aspect. Felsic minerals, biotite, chlorite, colourless mica and carbonate are common, and amphibole and epidote are less abundant. In rocks lacking strong foliation the mafic minerals and muscovite, especially the micas, tend to be irregular and sutured, with apophyses extending, like the pseudopodia of an amoeba, between grains of felsic minerals. This is a hornfelsic texture suggesting static metamorphic recrystallization. Sample 24808 (Edjudina, Plates XIII and XXI) is microgranular with felsic blebs in the margins of phenocrysts and with hornfelsic, symplectic biotite.

Microgranular texture is typical also of foliated rocks, Plate XXIII. Rarely, microgranular texture is patchy, with areas 1 to 4 mm in diameter which are coarser than surrounding material; these areas seem monomineralic and may be the relicts of recrystallized phenocrysts. Grain shapes and size distribution in a few samples give the rock a clastic appearance; along with phenocrysts, this texture suggests crystal tuff. In a few cases microgranular texture may be due to selective recrystallization of a granitic rock, preserving feldspar grains and giving the rock a pseudoporphyritic texture; however, the great majority of samples seem clearly to be truly porphyritic.

The regular association of microgranular texture with metamorphic mineral assemblages, the association with metamorphic textures in mafic minerals, and the association with deformed rocks suggest that microgranular texture commonly is a result of metamorphic recrystallization.

Microlitic texture

The microlites in felsites of the Eastern Goldfields Province are very small, euhedral feldspar grains commonly, if not always, plagioclase. They are seldom the sole textural element in the groundmass of the rock but commonly are abundant (sample 8885B, Menzies). In some samples (6884 and 20919, Kurnalpi and 32798, Leonora) the microlites are set in a microsymplectic matrix, whereas in others (7900P, Kalgoorlie) they are in a microgranular matrix, or (samples 38647, 11050 and 20926, Kurnalpi) they are in a micropoikilitic matrix. Sample 20919 with a microsymplectic matrix is illustrated in Plate 6D. Samples containing microlites seldom have quartz phenocrysts, although microsymplectite and, rarely, visible quartz in the groundmass show that microlitic rock need not be quartz-free. The best development of microlites is in rocks of intermediate composition. Some care is needed in assigning a rock this texture as lathlike twinning in grains which are in fact irregular can simulate microlitic texture.

The simplest explanation of microlitic texture seems to be that phenocrysts and a few groundmass feldspar grains crystallized before the remainder of the rock was chilled to a glass. After chilling devitrification continued with the formation of micropoikilitic and microsymplectic textures. In some samples microlites are encased in microsymplectite. In others well-formed microlites are crystallographically continuous with pools of feldspar which in turn give way to poorly developed microsymplectite.

GRANOPHYRIC TEXTURE

Granophyric texture, by definition, is coarser than vermicular-granophyric or other microsymplectic textures described above. Well-developed granophyre was found only in one sample (7900E, Kalgoorlie). Somewhat more commonly, granophyre appears as patches enclosed in another texture. In sample 17263 (Menzies) granophyric patches are set in microsymplectite; in sample 38121 (Laverton, Plate XXV) granophyric patches are set in an otherwise coarse-grained adamellite.

SPHERULITIC TEXTURE

A single rock, sample 32793 (Leonora), Plate XXVI, has fully developed, coarse spherulites. The spherulites are of uniform diameter, about 3.5 mm. They consist of radiating, almost submicroscopic, branching and intergrown blades of felsic minerals. Rarely, growth seems to have been periodic forming concentric growth rings, the rhythmic structure described by Mourant (1932, p.232-237). In some places the margins of the spherulites are sharp, against either other spherulites or matrix; elsewhere, adjacent spherulites are intergrown in a complex manner. The matrix is made up of patchy to granular quartz and feldspar, minutely granular, unresolvable material, and very small partially to completely developed spherulites. A few quartz and feldspar phenocrysts are scattered through the rock.

MICROSTRUCTURES

PERLITIC STRUCTURE

At least two samples (8886B, Menzies and 11020, Kurnalpi) have features which can be reasonably interpreted as relict perlitic cracks (Plates XXXI and XXXII). In both cases the felsic groundmass texture associated with the relict perlitic cracks has fine micropoikilitic (patchy) texture. This association probably indicates devitrification from solidified glass. Sample 11020 seems to be a breccia, some fragments of which are microlitic and may have been holocrystalline at the time of emplacement. The groundmass and probably some fragments were glassy. Some of the best perlitic structure seems to be in fragments.

SHARD STRUCTURE

In a few porphyritic rocks (sample 37818, Laverton, Plate XXVII) one can believe that a relict shard structure has been preserved through devitrification and minor metamorphic recrystallization. This rock is established as igneous by euhedral plagioclase, probably combination-twinned (Ross, 1957) in a synneusis relationship (Johannsen, 1939, p.234).

BRECCIA STRUCTURE

Several samples consist of fragments of assorted rock types in a more-or-less uniform matrix. Probably these are flow or intrusive breccias. Those described probably are not tectonic breccias or conglomerates. In sample 32792 (Leonora) fragments of various sizes are set in a heterogeneous matrix. Quartz grains are broken but some feldspar grains are euhedral. The rock probably was a crystal-lithic tuff. Sample 38684B (Laverton) is tightly packed with coarse fragments differing in texture but with a uniform plagioclase-rich, quartz-free aspect. Sample 39029 (Laverton) is also packed with fragments, but they are of medium grain size. The rock is a quartz andesite. Quartz is rare but primary hornblende is common. Sample 9130C (Kalgoorlie) is an oligomictic breccia with plagioclase, including a few relatively coarse microlites, set in a matrix transitional from fine micropoikilitic (patchy) to microgranular and microgranophyric. Fragments and groundmass are difficult to distinguish but the latter may be richer in biotite.

Sample 38660 (Kurnalpi) consists mainly of very coarse, rounded fragments of porphyry in a largely carbonated matrix. Phenocrysts are plagioclase and quartz. In one fragment abundant blocky phenocrysts of a mafic mineral have been pseudomorphed by chlorite. The matrix within fragments normally is granular but in one case there are abundant microlites. A final breccia, sample 11052 (Kurnalpi) probably is a crystal tuff. Many of the coarse grains of feldspar are euhedral, but finer grained quartz and feldspar seem to be fragmental. Other breccias have been described in the section on perlitic structure.

CATACLASTIC FOLIATION

Little evidence was seen suggesting fluxion structure due to flow in a viscous, consolidating magma. Many rocks are foliated, but this foliation seems to be tectonic, superimposed on the rock after cooling. In almost all cases secondary minerals, including mica, amphibole, sericite, and patches of carbonate, have been oriented. In all cases where these minerals, other than sericite, are involved in the foliation the groundmass has a granular texture and quartz phenocrysts have been elongated. The quartz has been either converted into aggregates of sutured or polygonized grains or, at least, severely strained. On the other hand, rocks with sericitic mica tend to have a very fine-grained groundmass, largely of the micrographophyric type, and quartz which is unstrained or weakly strained. Plate V illustrates the sericitized mylonitic rocks and Plates VI, VII and VIII illustrate the more granular type of blastomylonitic porphyry.

In sample 15522 (Edjudina) carbonate occupies the strain-shadow area at the tails of many feldspar phenocrysts; chlorite and quartz occupy the same position adjacent to hematite which probably is pseudomorphous after pyrite.

Although post-crystallization deformation seems responsible for most of the directed fabric in these rocks, textures in many are not clear and flow effects could be present.

PETROGENESIS

Uncertainty concerning physical and chemical conditions within and on the surface of the earth in early Precambrian time as well as the length of time that rocks have been vulnerable to physical and chemical alteration make the interpretation of petrogenesis of Archaean rocks less certain than similar interpretation of more recent rocks. The uncertainty is compounded in volcanic rocks by their susceptibility to textural change and their sensitivity to conditions both within the earth and at the surface. However, bulk changes in chemical composition should be detectable petrographically and many Archaean volcanic rocks have little petrographic evidence of gross metasomatic alteration. Chemical analyses of more than 100 felsites in the Leonora, Laverton and Rason sheet areas by Davy (1977) can be interpreted in the same manner as modern felsites. Anomalies appear only in a few high values for Na and where there is clear petrographic evidence of weathering or silicification.

RECOGNITION OF ACID VOLCANIC ROCKS

Probably the most generally used petrographic criterion for the recognition of a volcanic or shallow hypabyssal origin of an acid rock is a fine-grained, porphyritic texture. Some uncertainty is introduced by similar textures due to marginal chilling of small, shallow stocks and the development of pseudoporphyries by selective tectonic granulation of quartz in a quartz-rich granitic rock. Generally the latter problem is overcome if the samples in question lack planar structure, have phenocrysts of quartz as well as feldspar and if phenocrysts are embayed (samples 9102, Kalgoorlie, Plate III; 41484C, Edjudina; and 37805, Laverton). Well-embayed phenocrysts of quartz from sample 15504 (Edjudina) are shown in Plate I.

Criteria other than porphyritic texture would be more convincing and would be useful if they were recognized often and with confidence. Shard structure and perlitic cracks have been described above but are not common, probably because they are particularly susceptible to destruction during devitrification and later recrystallization. Plate XXVIII illustrates destruction of shard structure during progressive devitrification of a Phanerozoic vitrophyre from Baja California, Mexico.

INTERPRETATION OF GROUNDMASS TEXTURES

Micropoikilitic (or snowflake) texture is generally recognized as a common texture in rocks that have been glassy. However, there are uncertainties as to whether the texture developed directly from glass without an intervening microcrystalline or cryptocrystalline stage, and whether the texture can be relied upon as an indicator of former glassy state.

A sample (133 A-58) from Baja California, Mexico, on loan from the Department of Geology, San Diego State University, seems to establish that micropoikilitic texture can develop from a glassy rock (Plate XXVIII). Patches with micropoikilitic texture, about 1 cm in diameter, constitute about 20 per cent of this Phanerozoic felsic porphyritic tuffaceous rock. The matrix consists of well-developed shards, strongly oriented by flattening and possibly by flow. Everywhere except in the micropoikilitic patches the shards have been devitrified to cryptocrystalline felsic material and opaques which apparently are hydrous iron-oxide. The relict pattern of shards gradually disappears into the centre of micropoikilitic patches. It seems clear, then, that micropoikilitic texture can develop, directly or indirectly, from a felsic glassy rock. Incidentally, these relations show that the development of micropoikilitic texture is effective in obliterating evidence of shards and primary structure, possibly explaining the rarity of these textures in rocks of the Eastern Goldfields.

The glassy origin of a rock with micropoikilitic texture is also demonstrated by a rock from the Eastern Goldfields Province, sample 8886 (Menzies), Plates XV and XXXI. Here a rock with relict perlitic cracks has micropoikilitic texture.

These examples have shown that some rocks which now have micropoikilitic texture were once glassy. Reed (1895, p.167) in a discussion of the rocks around Fishguard, Pembrokeshire, thought that this texture was developed after "normal", even-grained devitrification.

He traced a series of stages from rocks with simple microlitic or cryptocrystalline groundmass to those with a fully developed micropoikilitic mosaic. He thought that introduction of silica in micropoikilitic rocks was suggested by quartz veins, vesicles, etc. He drew an analogy with mosaic textures in slates subject to contact metamorphism and suggested that the degree of development of micropoikilitic texture correlated with the size and nearness of "intrusive masses".

Following this line of argument, micropoikilitic texture should be considered a product of recrystallization rather than devitrification. However, Geijer (1913) thought that approximate eutectic composition of the groundmass in many cases favoured development of micropoikilitic texture by direct crystallization from a melt or, possibly, by devitrification of glass during its original cooling phase either by reheating or by action of volcanic vapours.

Anderson (1969) described further examples of snowflake (micropoikilitic) texture and suggested that the texture may be diagnostic of densely welded ash-flow tuff. However, Green (1970) showed that Keweenawan flows with snowflake texture are massive and uniform with a frothy top "... clearly implying the presence of a fluid lava and not a pyroclastic origin".

Lofgren (1971a) has developed micropoikilitic textures in the laboratory from natural glass fluxed with various alkali salts and hydroxides in runs of a few days duration. He concluded that "... micropoikilitic quartz may be a good indication of a former glassy state". In these runs, even if micropoikilitic texture followed cryptocrystalline devitrification, both processes occurred during the same thermal event. In fact, it seems likely that micropoikilitic texture developed directly from glass. The best micropoikilitic textures generated by Lofgren developed between 400 and 650°C.

Torske (1975) suggested that some, if not all, snowflake texture is generated from quartz-rich and feldspar-rich domains which separated from homogeneous glass by metastable fluid immiscibility below the solidus temperature but prior to crystallization. Subsequent crystallization froze the snowflake pattern in the relation we now see. The "micrograno-phyric" snowflake textures of Torske seem particularly similar to the micropoikilitic texture of the Eastern Goldfields Province.

In summary, micropoikilitic (snowflake) texture clearly can develop from rocks which at some time were glassy. This is the thread of consistency through all of the papers cited. Most of the investigators suggest or assume that the texture forms only in rocks which were glassy. This would be necessary if the metastable exsolved quartz- and feldspar-rich glassy phases described by Torske are prerequisite to the development of snowflakes.

Thus a glassy phase in the history of many of the felsites of the Eastern Goldfields Province seems likely.

Micrographic and vermicular-granophyric textures described in this work seem to be similar to the spherulitic texture of Lofgren (1971a, p.116-117). These textures seem to be incipient forms of the true spherulites of the type sample 32793 (Leonora). Clear sheaf-like forms described by Lofgren as embryonic spherulites are rare in the Eastern Goldfields Province but a few examples were seen (sample 32797, Leonora, Plate XVII). Forms similar to Lofgren's Figure 3a, however, are common (Plates XVI and XXIX). Interfering sheafs of this type were generated by Lofgren (1971b, p.5636) between 400 and 650°C. These results may give some idea of the physical conditions of devitrification in the Eastern Goldfields Province - if the rock types are comparable and the alkali-rich solutions of the experimental runs did not give spurious results.

CHEMISTRY

The chemistry of the felsites has been studied by Davy (1977) in the Leonora, Laverton and Rason sheet areas and by O'Beirne (1968) throughout a broad area around Kalgoorlie. Average composition of three andesites has been reported by Williams and others (1971).

Davy analyzed more than 100 fine-grained felsic rocks, concluding that many, if not all, suites in the area are calc-alkaline, though the composition of individual rocks ranges widely, from ultrapotassic rhyolite to andesite. Some individual suites have a broad compositional range whereas others are compositionally compact. In most areas of felsic rock dacite is characteristic.

Acid and basic rocks from some areas plotted in a continuous series on an AFM diagram, generating chemical trends which seem clearly coherent; though, as usual, rocks of intermediate composition are sparse. Also, in a few areas, spatially associated volcanic rocks, hypabyssal intrusives, and granitic rocks are chemically similar and may be genetically related, but in most areas fine-grained felsic rocks are quite dissimilar to nearby granitoids. Where similarities exist they are usually between rhyolitic porphyries and nearby adamellites.

O'Beirne (1968) found that none of the porphyries which he studied, with the possible exception of minor intrusive porphyritic microcline-albite-quartz rhyolites, were related to the "internal granites" of the Eastern Goldfields Province. "Internal granites" are the discrete granitic plutons within greenstone belts and are contrasted with the seas of granitoid and gneissic rock between greenstone belts which constitute the "external granites" (Sofoulis, 1963, p.10).

Phenocrysts of all porphyries reported by O'Beirne were interpreted to have crystallized between 700 and 900°C. The phenocrysts of the intrusive porphyritic quartz-albite sodic rhyolite were considered to have crystallized between 1 500 and 3 500 kg/cm^2, and those of the intrusive microcline-quartz-albite rhyolites and the extrusive potassic rhyolite, at pressures above 3 500 kg/cm^2.

In general, the proportions of feldspars and quartz in phenocrysts studied by O'Beirne bore little relation to chemical composition, leading to the conclusion that the type and proportion of various minerals in the phenocryst assemblage varied with physical rather than chemical conditions. The composition of the rock apparently can not be estimated from the phenocryst assemblage.

FIELD RELATIONSHIPS

According to Trendall (1964) the porphyries of the Pilbara and Yilgarn Blocks are mainly elongate, planar, concordant bodies, tens of metres thick, which may variously be dykes, sills or flows. Honman (1913) reported that the porphyries of Binduli could be traced for 24 miles (39 km) with little change in thickness.

Gradation of porphyry into granite was reported by Honman (1917) in the Yerilla District and Clarke (1921) at St Ives, but McMath (1950), during the Coolgardie resurvey, considered that the porphyry grading into granite in the Coolgardie area was fundamentally different to the thick porphyry bodies which were continuous for many miles. A tendency for the composition of porphyry at any locality to approach the composition of enclosing rock at that locality was reported by several geologists (Matheson, 1948; McMath, 1950; and Ward, 1951) of the Coolgardie re-survey who considered that the relationship demonstrated assimilation of country rock by porphyry. Clarke (1921), again at St Ives, found "... some remarkable gradations from porphyry to greenstone (probably a result of digestion of the greenstone by the porphyry) ...".

Relations such as the transition from greenstone to porphyry may have led to the theory of "porphyritization" suggested by Sofoulis and Bock (1962, p.11) as an origin for porphyry. Trendall found no petrographic evidence to support porphyritization, but O'Beirne (1968, p.251-271) later interpreted rocks at Widgiemooltha from the Mandilla and Wanda Wanda Beds to be products of porphyritization. "Ghost" pebbles and relict layering in rocks containing megacrysts resembling phenocrysts were cited as evidence of porphyritization. O'Beirne proposed, however, an igneous origin for most of the porphyries which he described.

In 1964 Trendall noted the association of oligomictic conglomerate with porphyry. Horwitz and others (1967) considered this relationship at length, concluding that the oligomictic conglomerates were derived directly from the porphyry. Williams (1970, p.14) is more explicit: "They (oligomictic conglomerates) are thought to be the product of direct deposition of pyroclastic material in water admixed with erosion products derived from the upbuilding acid igneous pile".

Volcanic centres, producing piles of acid rock, have been proposed for parts of the Laverton (Gower, 1974), Kurnalpi (Williams, 1970) and Edjudina (Williams and others, 1971) sheets. Perhaps re-interpretation of sheets mapped earlier would result in the discovery of similar centres of acid volcanic activity in other areas.

SUMMARY OF PETROGENESIS

Porphyritic felsites are common in the Eastern Goldfields Province. Although a few of these rocks may have originated by "porphyritization" of enclosing rocks, the majority are of igneous origin. At least two habits are seen, large concordant or nearly-concordant sheets, and smaller, discordant bosses and dykes. The discordant bodies seem clearly intrusive; some concordant bodies may be sills and some may be flows. Evidence for sills is seen in the slight discordance and bifurcating nature of some "concordant" bodies. Evidence for extrusion includes rare perlitic cracks and shards. Common micropoikilitic and microspherulitic textures probably signify wide development of glassy matrix, suggesting volcanic origin for many more of the felsites. General felsic volcanism is implied by the widespread association of porphyry and oligomictic conglomerate, explained as quasi-contemporaneous erosion of a growing pile of acid rocks. While petrographic criteria alone may not distinguish *in situ* flows from acid volcanic clasts in an agglomerate or conglomerate, the existence of flow-derived rock can be established.

Most major porphyry bodies seem chemically unrelated to adjacent granitoids but there may be a few exceptions. Rarely, in the data from Laverton-Leonora, rhyolitic porphyry is chemically similar to nearby adamellite and, farther south, minor bodies have been reported to grade in field appearance from porphyry to granitoid. However, even these few minor exceptions may be explained differently. Chemical similarities can be fortuitous and, as porphyry bodies pass from one enclosing unit to another, they have been reported to approach the composition of the local host.

This effect has been attributed to assimilation of country rock by the porphyry. If this compositional convergence is extreme it could give the appearance of mechanical gradation into enclosing rock.

The temperature of emplacement is not clear, but O'Beirne (1968) has suggested the phenocrysts crystallized between 700 and 900°C in most types of porphyritic felsites which he studied. Final devitrification may have been near the interval 400 to 650°C within which Lofgren experimentally obtained devitrification textures similar to those in many of the felsites in the Eastern Goldfields Province.

Conditions of emplacement and subsequent alteration of the felsic volcanic and hypabyssal rocks are gradually being clarified but little information is available on the origin of the magma. The origin of this magma is of particular interest in view of the suggestions by Davy (1977) and O'Beirne (1968) that the porphyritic felsites are, at least in large part, not related to spatially-associated granitoidal rock; though other data from Davy suggest that in some areas granitoids, hypabyssal intrusive rocks and extrusives may be related.

ROCKS OF INTERMEDIATE COMPOSITION

Most of the rocks which have been discussed contain quartz phenocrysts. In addition a few without quartz phenocrysts have abundant recognizable quartz in the matrix. These rocks probably range in composition from rhyolite to dacite. In other rocks, not specifically discussed, quartz is absent among the phenocrysts and either absent or not recognizable in the matrix. Where the matrix is coarse effective absence of quartz from the rock can be confirmed.

For this study, rocks in the andesitic compositional field and in the field of dacite near andesite are considered to be of intermediate composition. The original plagioclase composition would be calcic oligoclase to andesine, quartz would be near 20 per cent or less and potassium feldspar would be subordinate to plagioclase.

O'Beirne (1968, p.292) has shown that the phenocryst assemblage cannot be used to estimate the chemical composition of porphyries of the Eastern

Goldfields Province. Thus feldspar porphyries with a matrix in which constituent minerals cannot be identified cannot be classified optically either as acid or intermediate. The criteria for intermediate rocks used here are:

(1) plagioclase is abundant and quartz and potassium feldspar are minor or absent in a rock in which they would be recognized;
(2) hornblende is common; or,
(3) epidote is abundant and apparently is derived from plagioclase in the rock.

In the last two cases, quartz and potassium feldspar must not be obviously abundant, but may be present as obscure phases.

This section does not include the alkaline porphyritic rocks, some of which contain hornblende and little quartz.

Hornblende is the characteristic mafic mineral in these rocks but pyroxene may be the primary mafic mineral in a few. In sample 29987 (Leonora) primary green amphibole along with feldspar phenocrysts are set in a micrographyric groundmass with fine elongate grains of secondary colourless amphibole and irregular grains of secondary biotite. Three samples from the Laverton sheet area (samples 37821, 37822 and 37823) have altered phenocrysts of amphibole or pyroxene and plagioclase phenocrysts in an extremely fine crystalline matrix. Some samples, as 38123 and 38684B (Laverton), are sufficiently altered that even the presence of original mafic phenocrysts cannot be established. Here heavily saussuritized glomeroporphyritic plagioclase phenocrysts are set in an apparently quartz-free matrix of microlites and poorly developed micrographyre. Mafic phenocrysts are clearly absent from some rocks, as in the even-grained sample 17262 (Menzies). This sample is an interlocked network of plagioclase microlites, less elongate plagioclase, minor quartz and chlorite, and secondary colourless amphibole, epidote and carbonate. Samples 25080 and 25081 (Edjudina) are hornblende-plagioclase microbreccias with minor quartz in a microlite-rich groundmass. Sample 25076 (Edjudina) has pyroxene overgrown with amphibole and set in plagioclase. The pyroxene may not be primary. Samples 9110, 9112 and 9186 (Kalgoorlie) all contain amphibole. In sample 9110 hornblende is clearly primary and the rock seems to be andesitic.

Although the intermediate rocks have the same general range of textures as the fine-grained acid rocks, there is a tendency towards a higher degree of crystallinity. They tend to have a groundmass which is highly charged with microlites, though these may be set in nearly cryptocrystalline granular or microgranulitic material similar to that in the more acid rocks. Gross textures are variable. Most samples are porphyritic but many are even grained and at least one sample (25087, Edjudina) is seriate, though this may be a breccia or even a little-transported tuffaceous greywacke.

SUMMARY

A wide variety of rocks in the Eastern Goldfields Province is included under the heading "felsite". Of the rocks sampled, most abundant are acid porphyries, including both hypabyssal and flow rocks, and alkaline porphyries, probably mainly hypabyssal. A few are intermediate between acid and basic rocks, characterized by little or no quartz, plagioclase of intermediate composition, a greater abundance of mafic minerals than is common for acid rocks, and a tendency for hornblende rather than biotite to be prominent in the mafic mineral suite.

Chemical evidence suggests that though a few of the common felsites may be genetically related to spatially associated granitoid rocks, most are not.

Many of the groundmass textures in the porphyritic felsites suggest devitrification; that is, crystallization from glass at temperatures below the solidus for the system.

Despite the preservation of devitrification textures, some of which are quite delicate, every sample studied has been affected by secondary crystallization. Such recrystallization in some rocks is limited to sericitization of plagioclase. In others, plagioclase has been albitized, carbonatization is rampant, or secondary colourless mica is abundant. In rocks which have been even more altered the groundmass has been recrystallized to a granular mosaic, and mafic minerals as well as muscovite have developed a hornfelsic texture. Finally, many samples have undergone thorough penetrative deformation with recrystallization of groundmass minerals and breaking, bending, shearing and granulation of phenocrysts.

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WILLIAMS, I.R., GOWER, C.F., and THOM, R., 1976, Edjudina, W.A.: West. Australia Geol. Survey 1:250 000 Geol. Series Explan. Notes.

APPENDIX

LOCATION OF SAMPLES

Samples are located according to 1:250 000 map sheets and the Australian Transverse Mercator Grid, in yards. The first digit of each coordinate indicates hundreds of thousands of yards. Four-digit coordinates have a precision of 100 yards, three-digit coordinates 1 000 yards. Accuracy is less. Letter suffixes on sample numbers have been omitted.

EDJUDINA

15501	4721/3803
15504	4568/3916
15514	4545/3897
15522	4682/3868
15527	451-/375-
15532	4722/3795
24808	5029/3159
25033	4570/3913
25034	4582/3897
25080	4841/3963
25081	4841/3963
41484	441-/180-

KALGOORLIE

7900	435-/204-
9101	Not available
9102	"
9103	"
9110	427-/231-
9112	420-/267-
9130	446-/184-
9153	388-/251-
9186	416-/176-

KURNALPI

6884	510-/173-
11020	Not available
11050	4586/2360
11052	4600/2315

KURNALPI (CONT.)

11053	486-/257-
20919	461-/222-
20926	464-/208-
38647	461-/221-
38659	475-/207-
38660	461-/207-

LAVERTON

20984	5365/4597
29962	4684/4928
29972	4881/4885
30800	558-/432-
37803	5398/4655
37805	5440/4575
37807	5475/4635
37810	5385/4645
37814	5440/4630
37818	5563/4428
37820	5522/4426
37821	4746/4285
37822	4746/4285
37823	4746/4285
38121	534-/525-
38127	540-/522-
38132	543-/526-
38135	545-/522-
38684	474-/428-
39018	4946/4149
39029	4781/4419

LEONORA

32717	4285/4933
32719	4054/5045
32722	3445/5158
32792	4060/4882
32793	Not available
32797	4069/5031
32798	4085/4885
32799	4140/4918
38307	4125/4855
38308	4230/4930
39802	4530/4580

MENZIES

8885	433-/366-
8886	450-/372-
8887	450-/378-
8889	449-/378-
8894	442-/394-
17262	4393/3982
17263	4405/3945
17645	3513/2898
20979	4088/3246

WIDGIEMOOLTHA

6523	4840/1500
13143	4996/0859
40860	499-/092-

P L A T E S

PART I

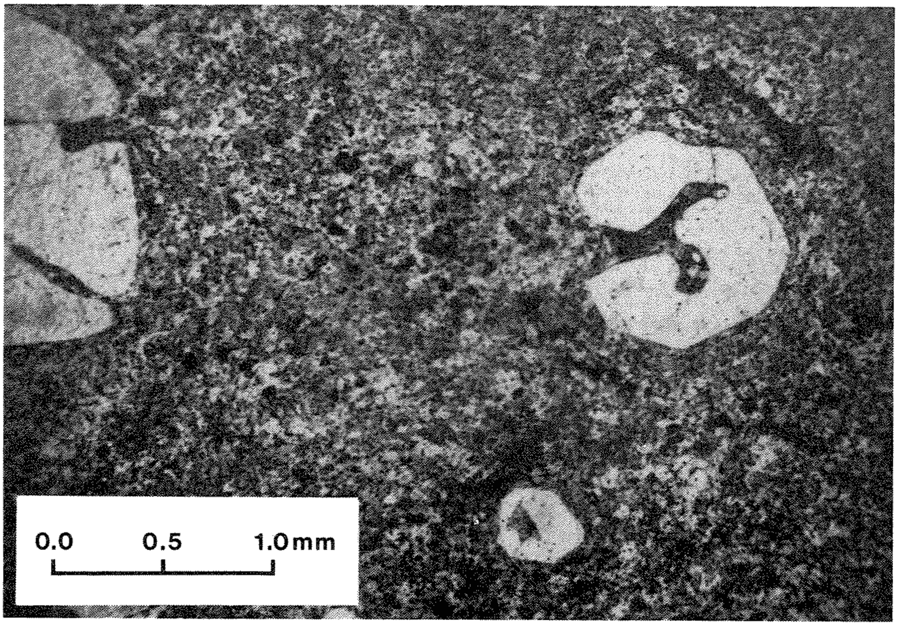

Plate I. Igneous texture: partial resorption of quartz phenocrysts.

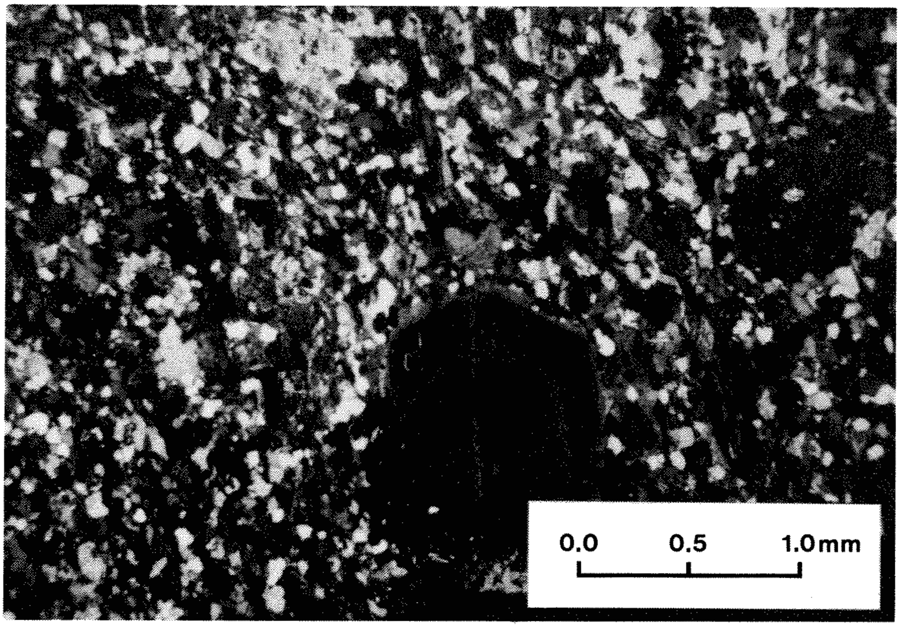

Plate II. Igneous texture: zoned euhedral plagioclase with rounded internal zones.

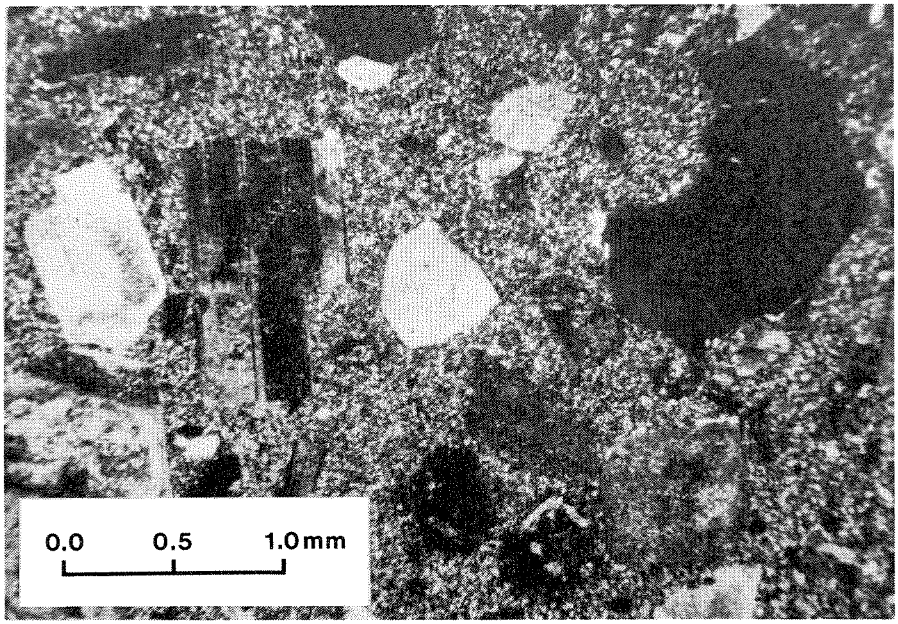

Plate III. Igneous texture: assorted resorbed quartz and euhedral plagioclase phenocrysts.

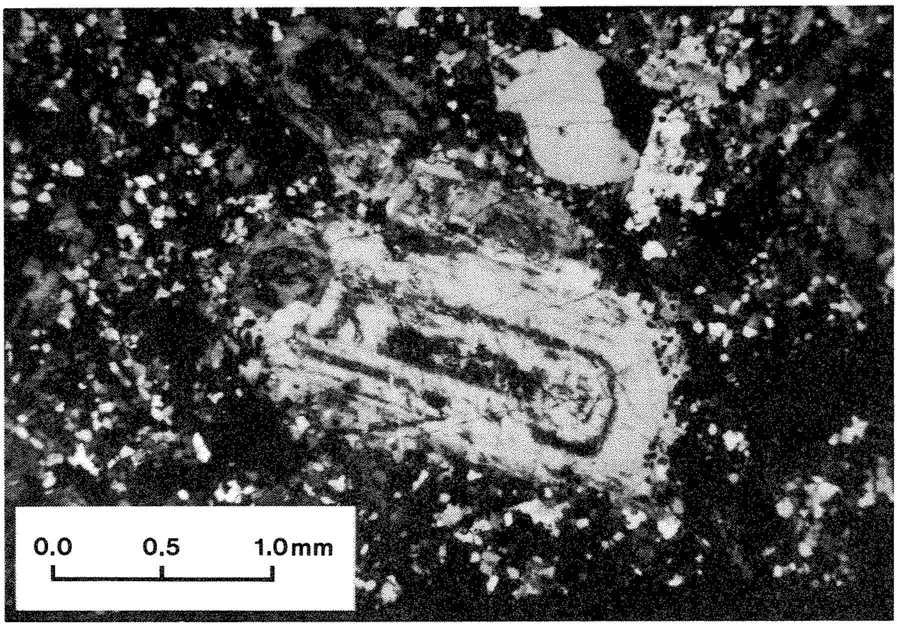

Plate IV. Igneous texture: differential alteration showing relict euhedral oscillatory zoning in plagioclase.

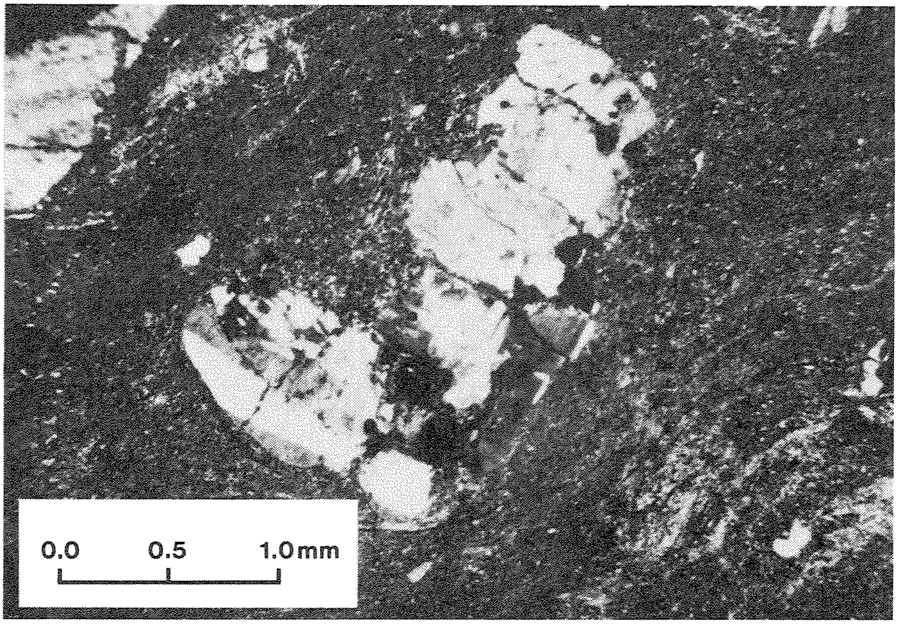

Plate V. Metamorphic fabric: sericitized mylonitic felsite.

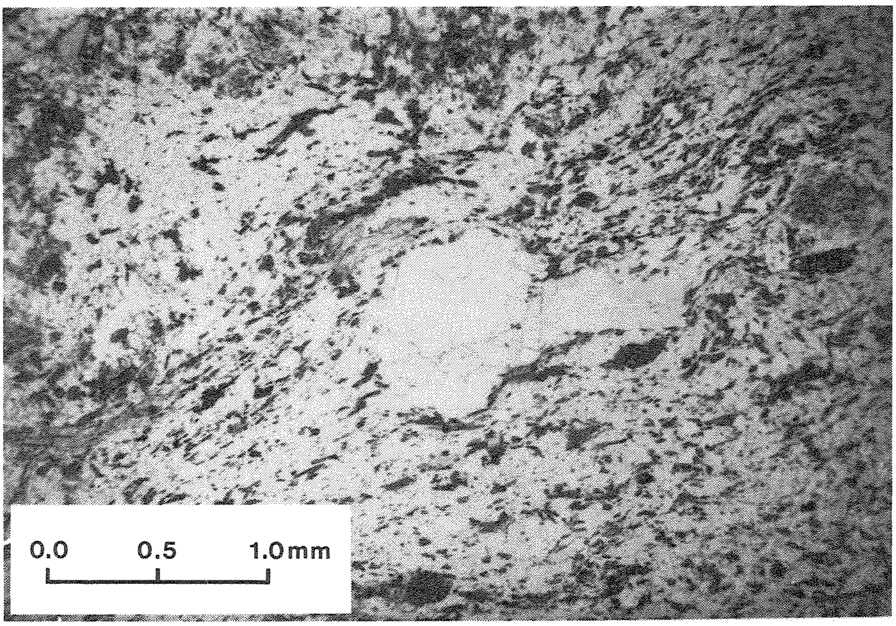

Plate VI. Metamorphic fabric: blastomylonitic felsite.

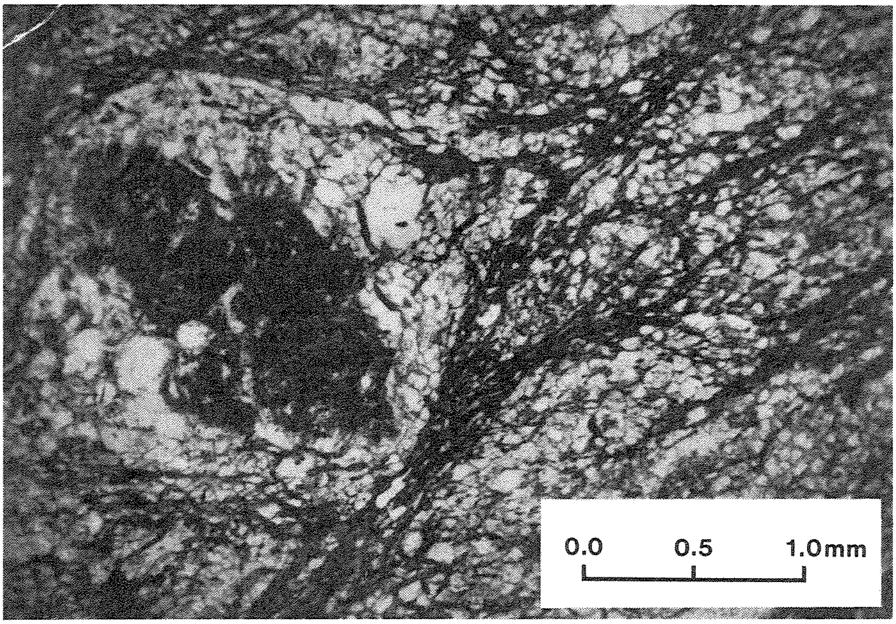

Plate VII. Metamorphic fabric: blastomylonitic felsite.

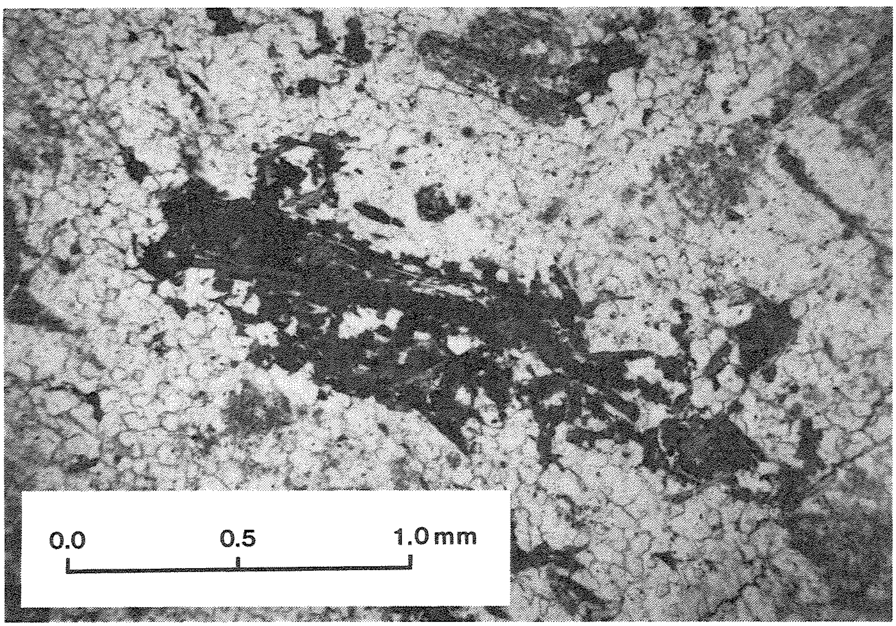

Plate VIII. Metamorphic fabric: hornfelsic biotite in felsite.

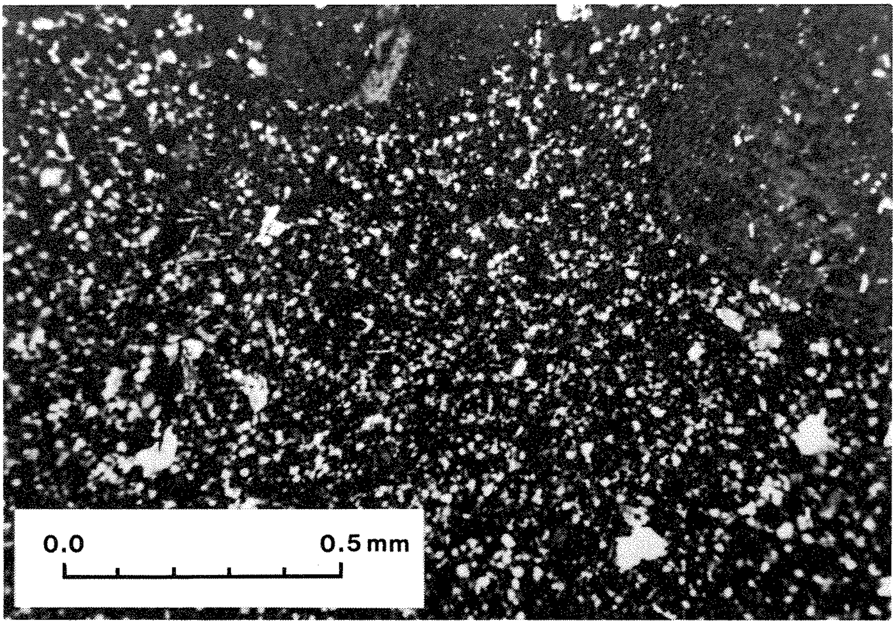

Plate IX. Microcrystalline and micropoikilitic textures: microcrystalline groundmass texture.

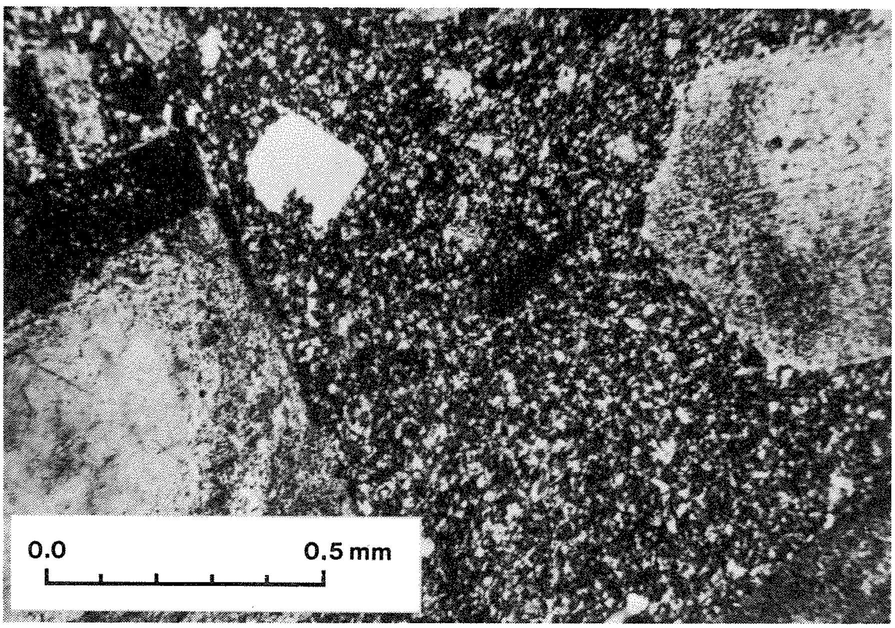

Plate X. Microcrystalline and micropoikilitic textures: microcrystalline groundmass texture.

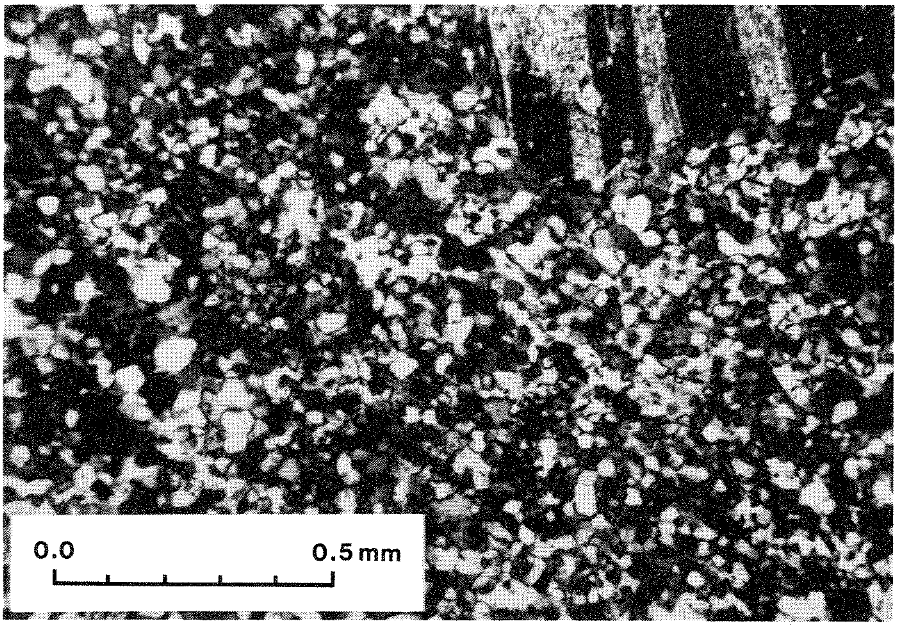

Plate XI. Microcrystalline and micropoikilitic textures: microcrystalline texture transitional to micropoikilitic (coarse) texture.

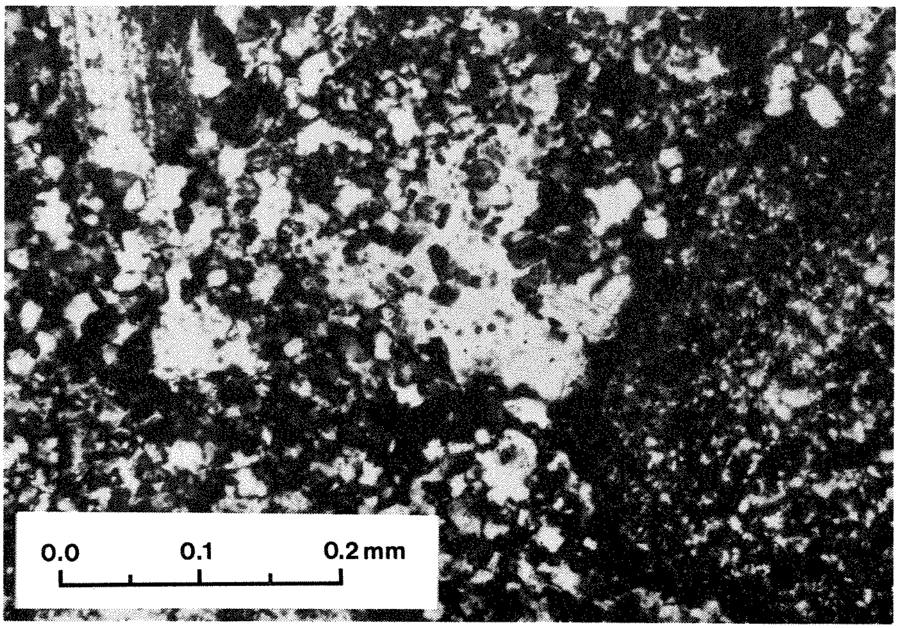

Plate XII. Microcrystalline and micropoikilitic textures: micropoikilitic (coarse) texture.

79306–4

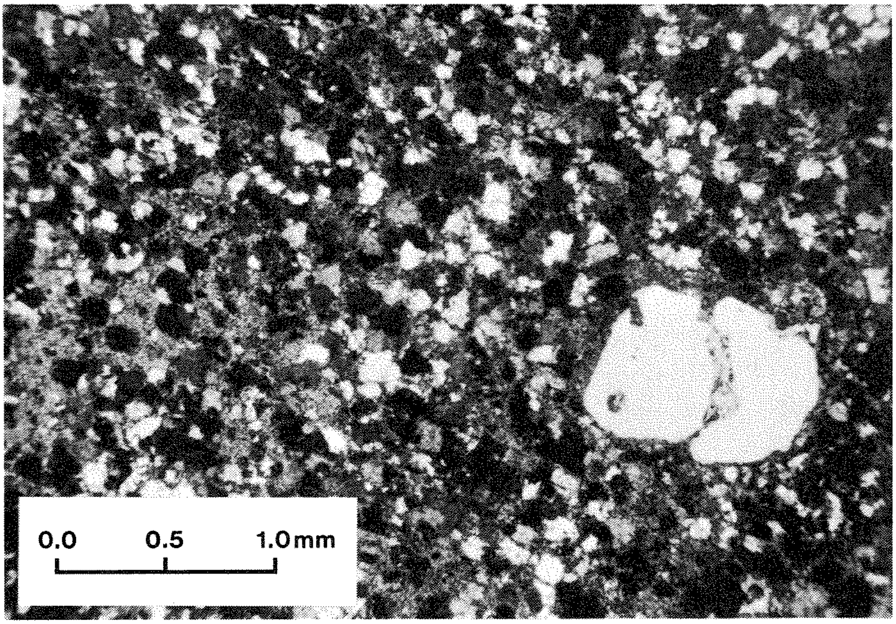

Plate XIII. Microsymplectic textures: micropoikilitic (fine) texture.

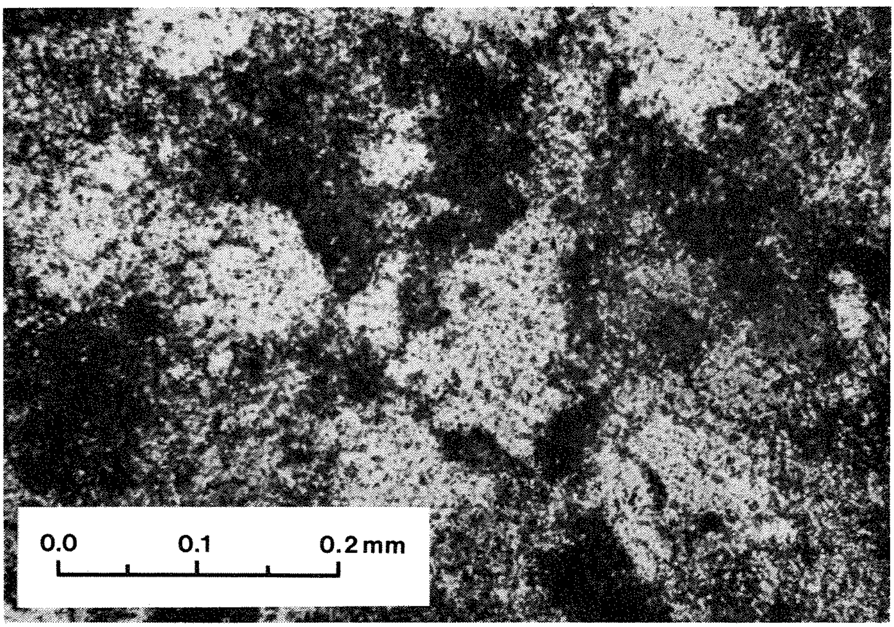

Plate XIV. Microsymplectic textures: micropoikilitic (fine) texture.

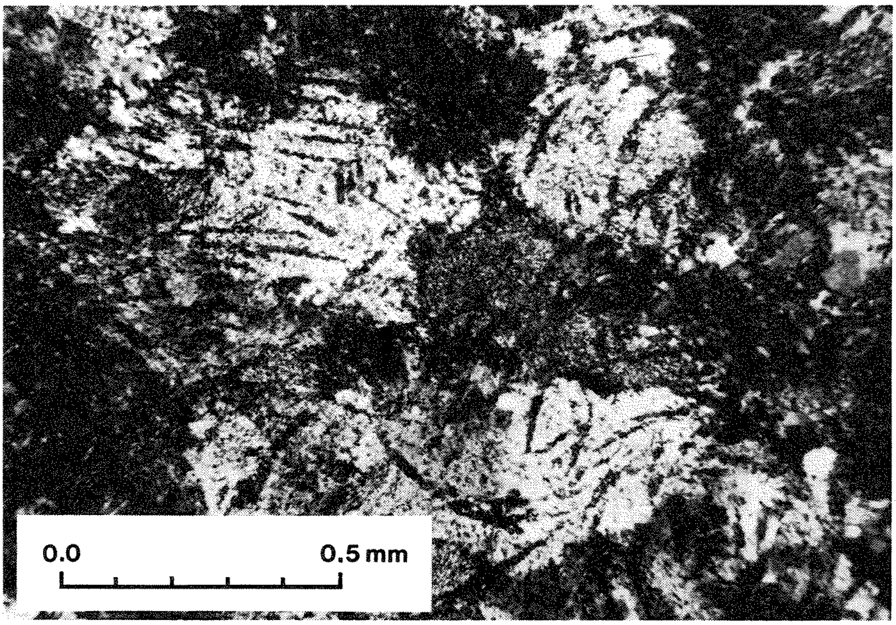

Plate XV. Microsymplectic textures: micropoikilitic texture in rock with relict perlitic cracks.

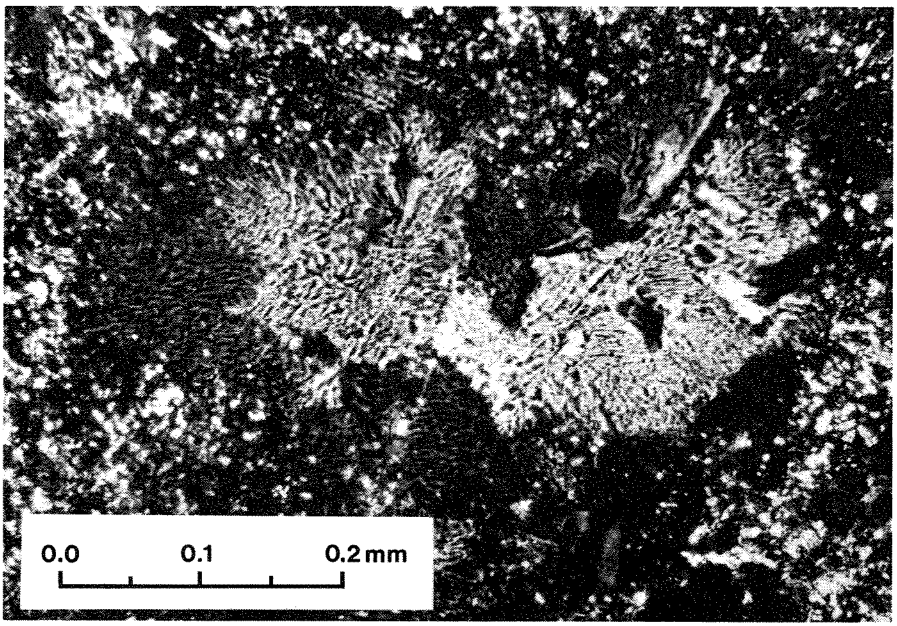

Plate XVI. Microsymplectic textures: vermicular-granophyric texture.

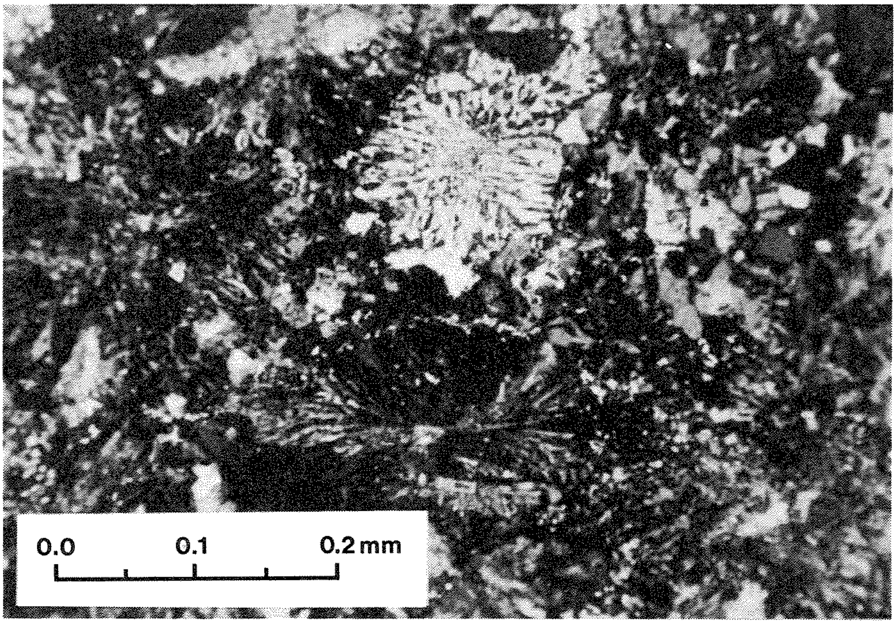

Plate XVII. Microsymplectic textures: sheaf-like and equidimensional forms of vermicular-granophyric texture.

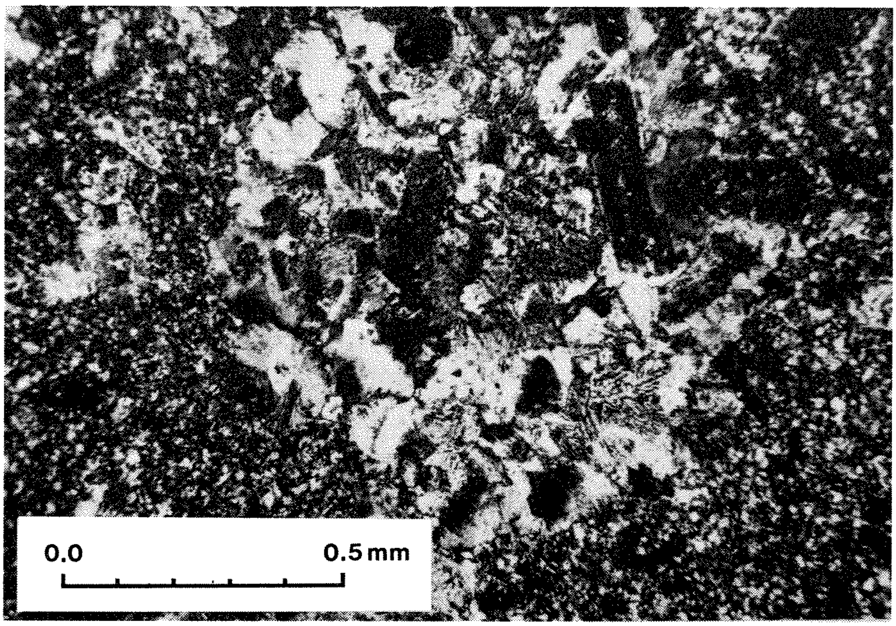

Plate XVIII. Microsymplectic textures: vermicular-granophyric clots in microcrystalline groundmass.

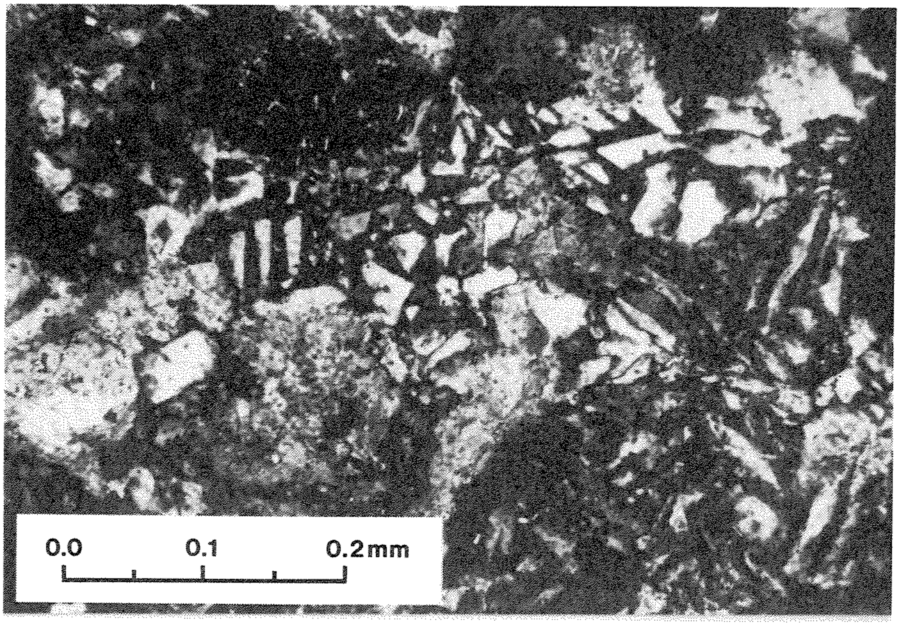

Plate XIX. Microsymplectic textures: micrographic texture.

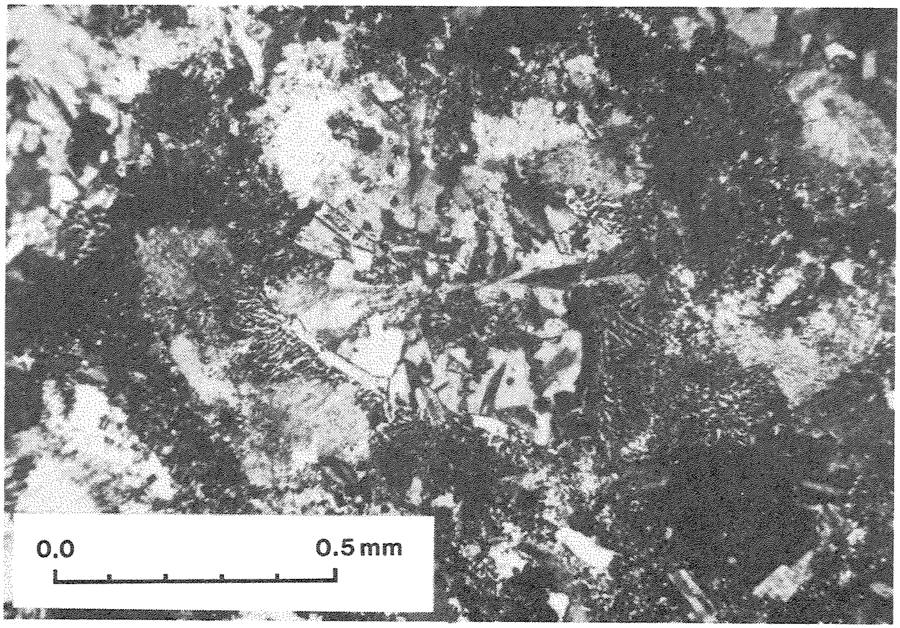

Plate XX. Microsymplectic textures: micrographic cores surrounded by vermicular-granophyric groundmass.

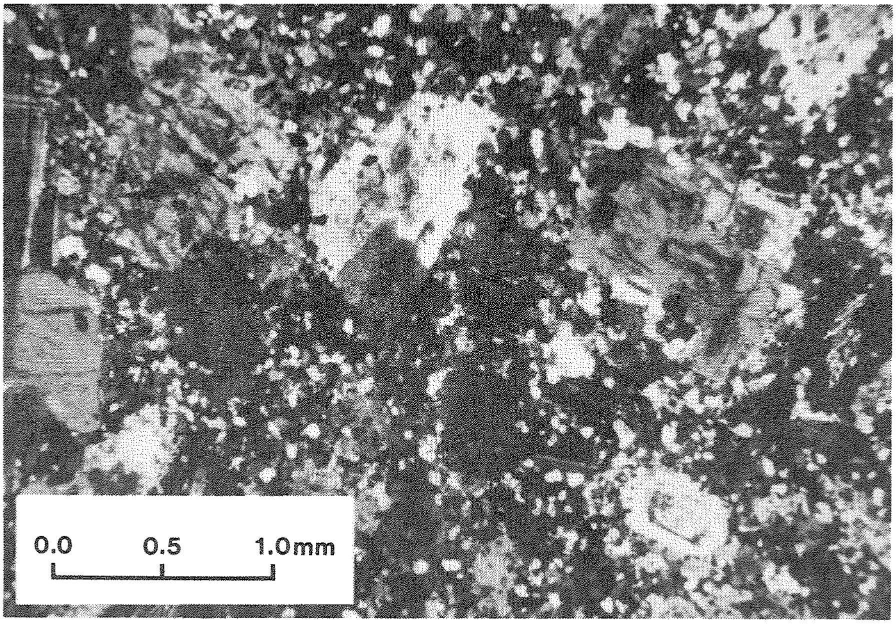

Plate XXI. Microgranular and microlitic texture: microgranular texture.

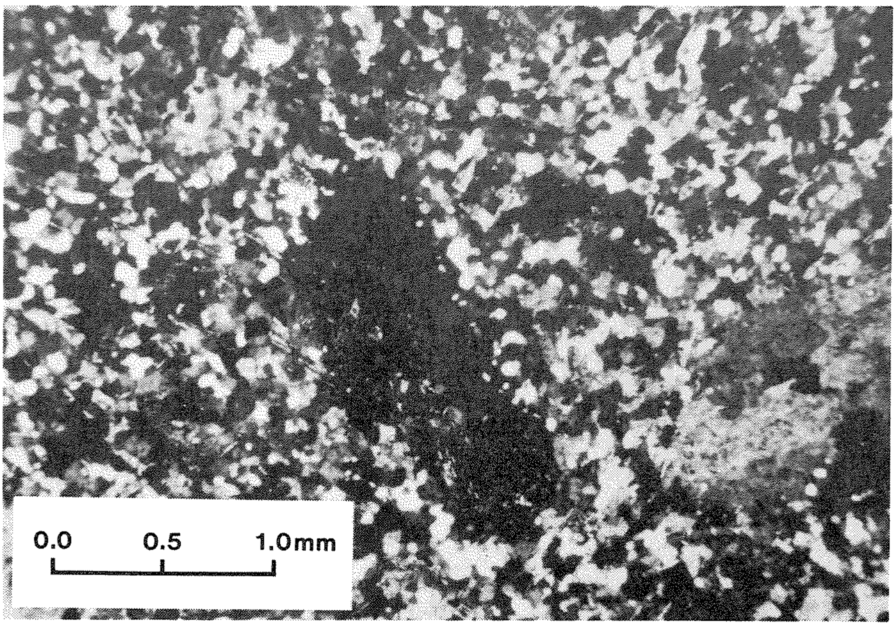

Plate XXII. Microgranular and microlitic texture: microgranular texture.

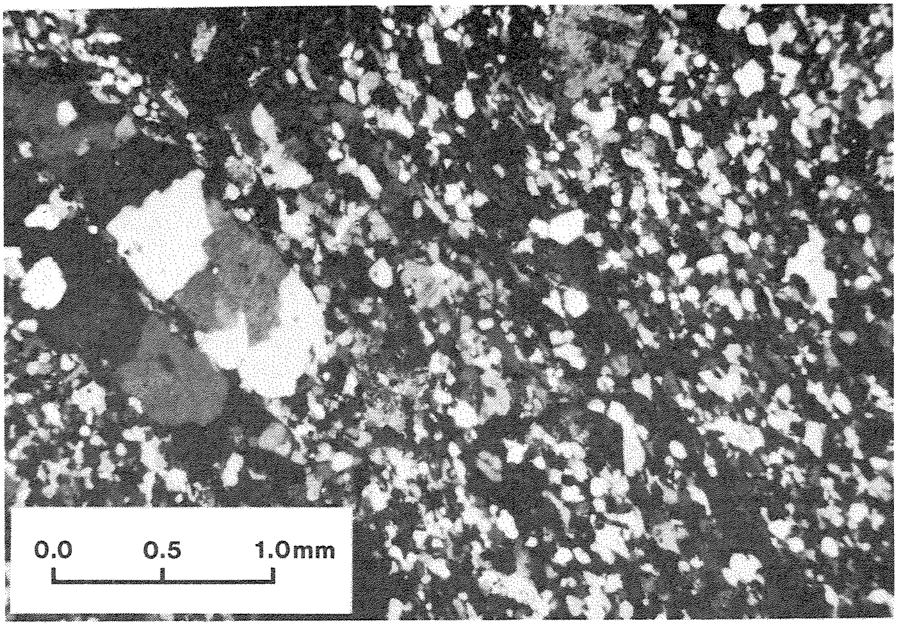

Plate XXIII. Microgranular and microlitic texture: microgranular texture in foliated rock.

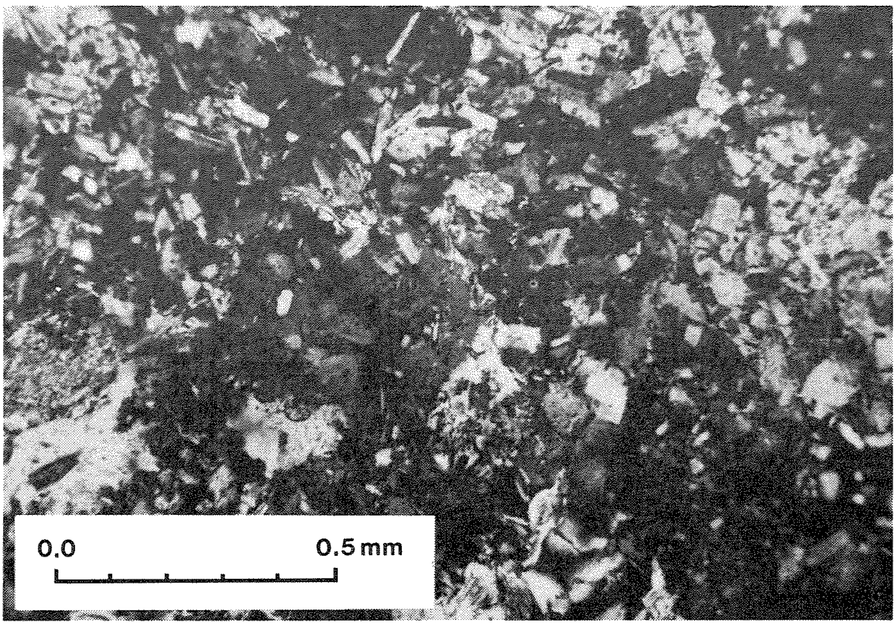

Plate XXIV. Microgranular and microlitic texture: microlitic texture with vermicular-granophyric groundmass.

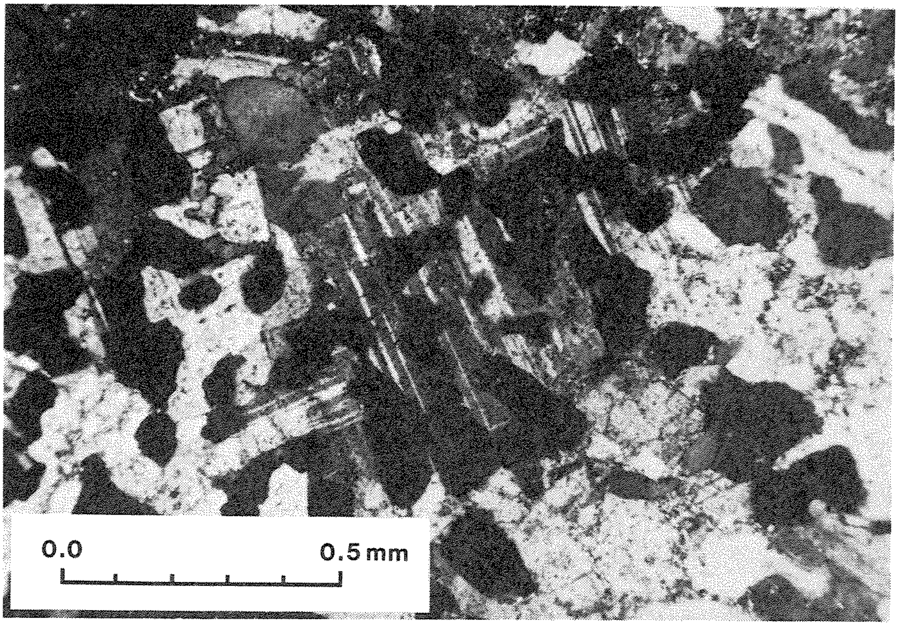

Plate XXV. Various microtextures: granophyric texture.

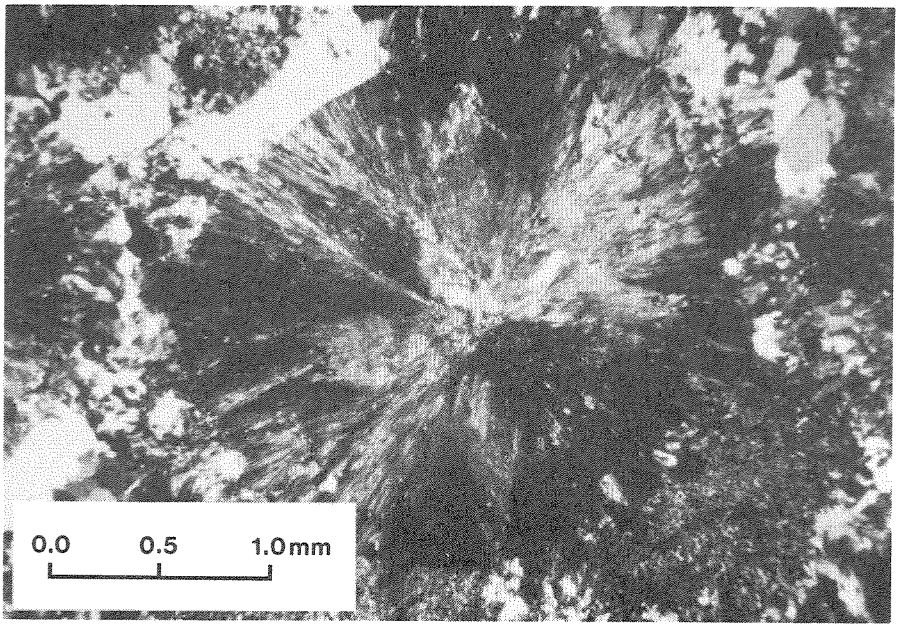

Plate XXVI. Various microtextures: spherulite.

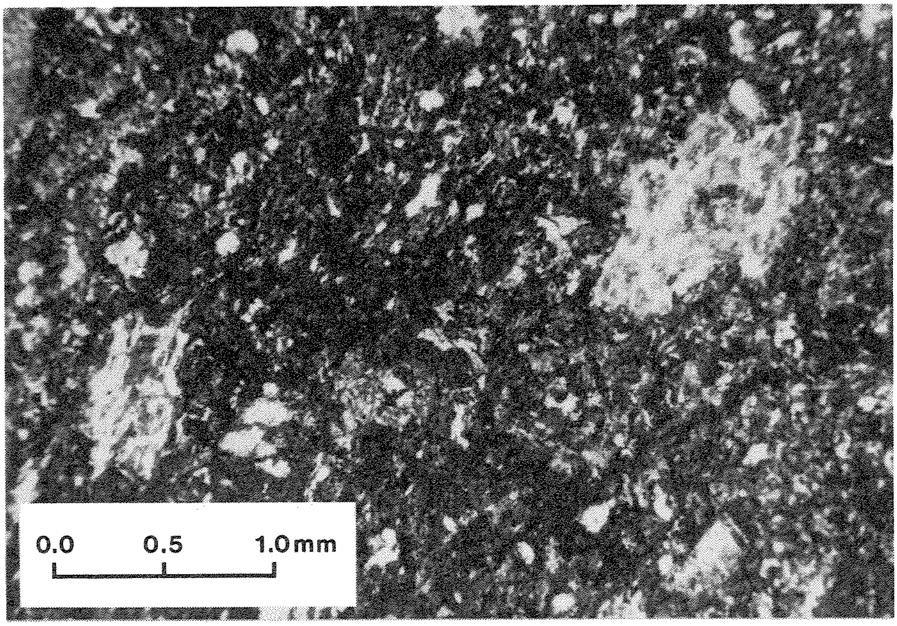

Plate XXVII. Various microtextures: shard(?) structure.

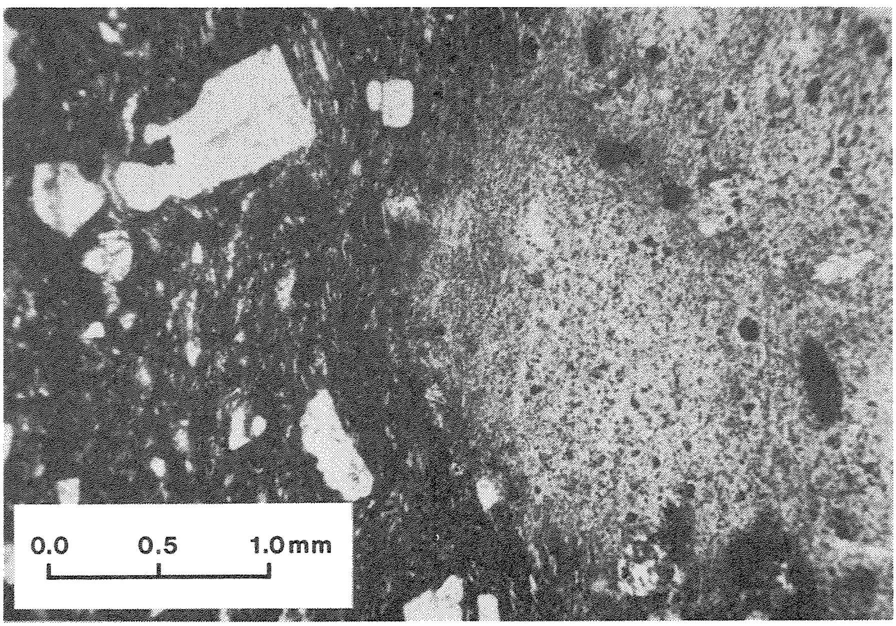

Plate XXVIII. Various microtextures: micropoikilitic patch in a Phanerozoic felsite, Baja California, Mexico.

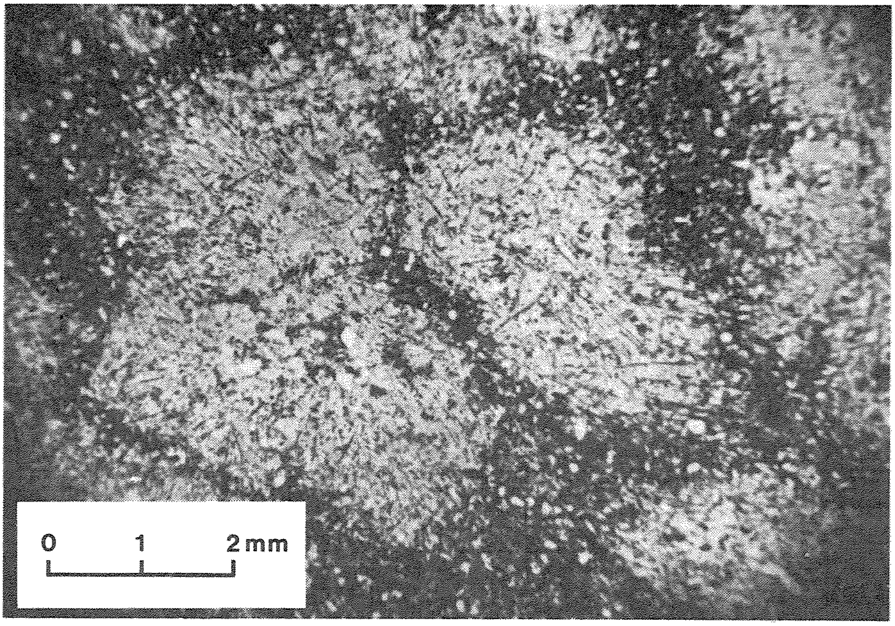

Plate XXIX. Orb and relict perlitic textures: orb texture in recrystallized perlite.

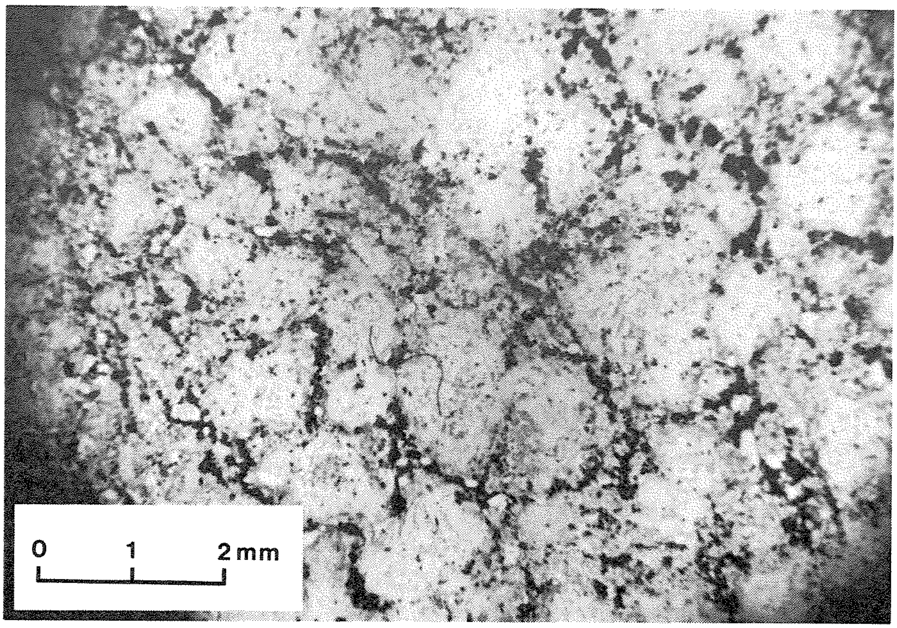

Plate XXX. Orb and relict perlitic textures: orb texture, coarsely recrystallized.

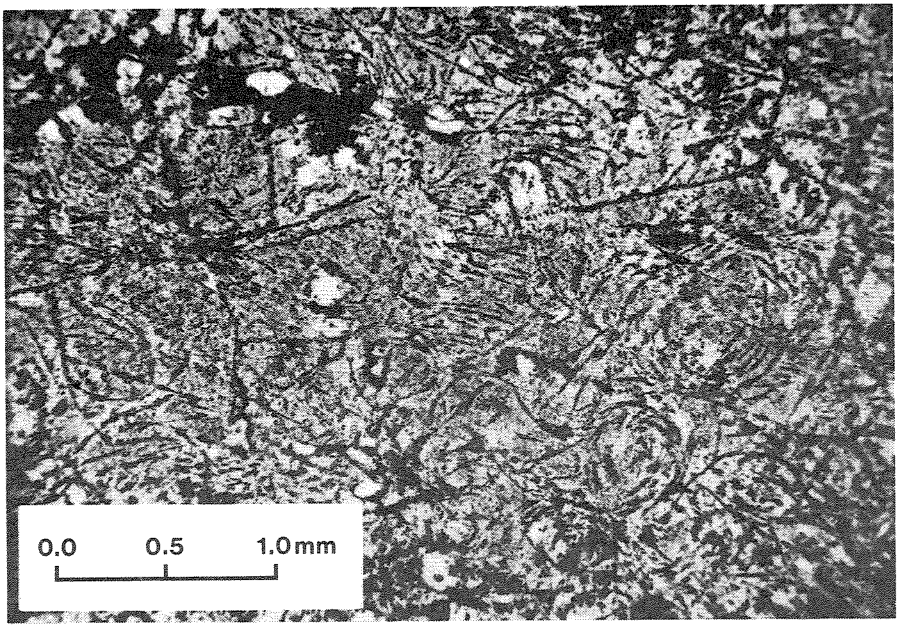

Plate XXXI. Orb and relict perlitic textures: relict perlitic fractures.

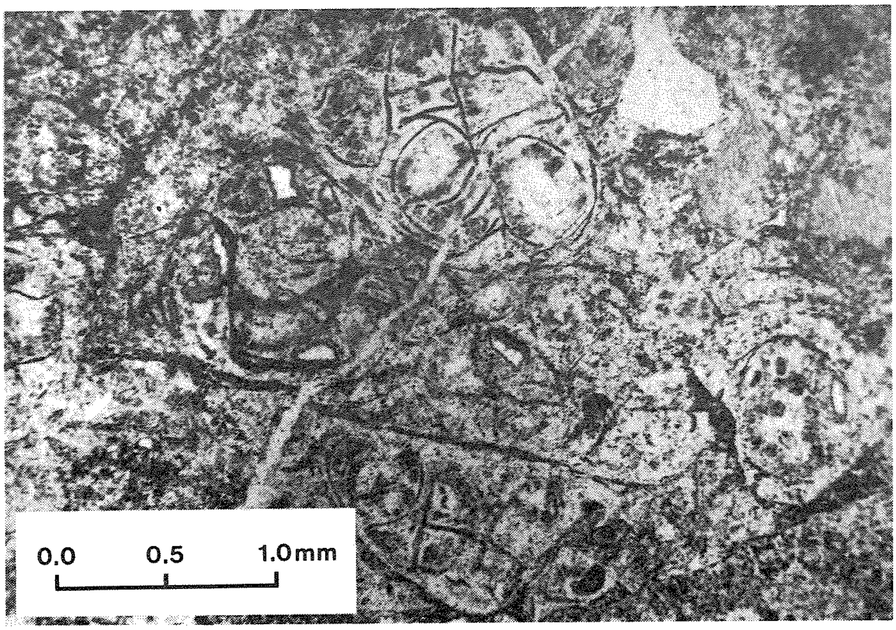

Plate XXXII. Orb and relict perlitic textures: relict perlitic fractures.

P A R T I I

REGIONAL VARIATION IN GRANITIC ROCK

REGIONAL VARIATION IN GRANITIC ROCK

by

W.G. Libby

ABSTRACT

Homogeneous to foliated granitoids dominate the rock suite of the Eastern Goldfields Province. Belts of similar texture and composition tend to be parallel to tectonic belts defined by the trend of metamorphic supracrustal rocks and gneisses.

Cataclastic textures record mild to severe penetrative deformation throughout the area. Recrystallization textures as well as the secondary minerals, epidote, carbonate, prehnite and pumpellyite, record mild but general metamorphic or deuteric recrystallization. This general low-order recrystallization is punctuated locally by more thorough metamorphic recrystallization in gneissic belts.

Fluorite is notably common as an accessory mineral throughout the area. Fluorite, sphene, zircon, and allanite are variously concentrated in several areas.

INTRODUCTION

Granitoid rocks constitute about 70 per cent of the surface area of solid rock in the Eastern Goldfields Province (Fig.1). Despite their importance, these rocks have received little serious attention until recently.

Much of the Eastern Goldfields Province was mapped by the Geological Survey of Western Australia between 1963 and 1974. In the course of this work samples of granitoid rock were collected. Information from thin sections of these samples was used in mapping but no integrated presentation of this material has been available.

The present work is a summary of the petrographic characteristics of granitoid rocks, together with a semi-quantitative study of regional variation in composition over a more limited area. The data has been drawn from thin sections prepared by the Geological Survey in the course of regional mapping, supplemented with material collected specifically for this exercise by I.R. Williams. Almost all the samples were collected since 1960.

The area of study together with a generalized picture of the geological framework of the Yilgarn Block is shown in Figure 1. Places mentioned in the text are located in Figure 11.

PREVIOUS WORK

Archibald and Bettenay (in press) have interpreted the basic architecture of the Eastern Goldfields Province in terms of 'granite tectonics'. Some of this work has been summarized by Binns and Marston (1976). Binns, Gunthorpe and Groves (1976) briefly considered the relation between regional metamorphism of greenstone belts and distribution of granitoids. Lewis and Gower (1978) have described the alkaline rocks of the Fitzgerald Peaks, and Roddick, Compston and Durney (1976) have used granite textures in the interpretation of isotopic data from the Sir Samuel sheet area. Granitic rocks have been dated isotopically in the area of study by Turek (1966), Turek and Compston (1971) and Oversby (1975).

Aspects of granitoid rocks of the Eastern Goldfields Province have been considered by Glikson and Lambert (1973) and Glikson and Sheraton (1972). O'Beirne (1968) discussed the relation of granitoids with porphyritic felsites.

Most regional studies, including explanatory notes for map sheets, have mentioned granitoid rocks; of particular interest are discussions by Gower and Bunting (1976) on the Leonora sheet area.

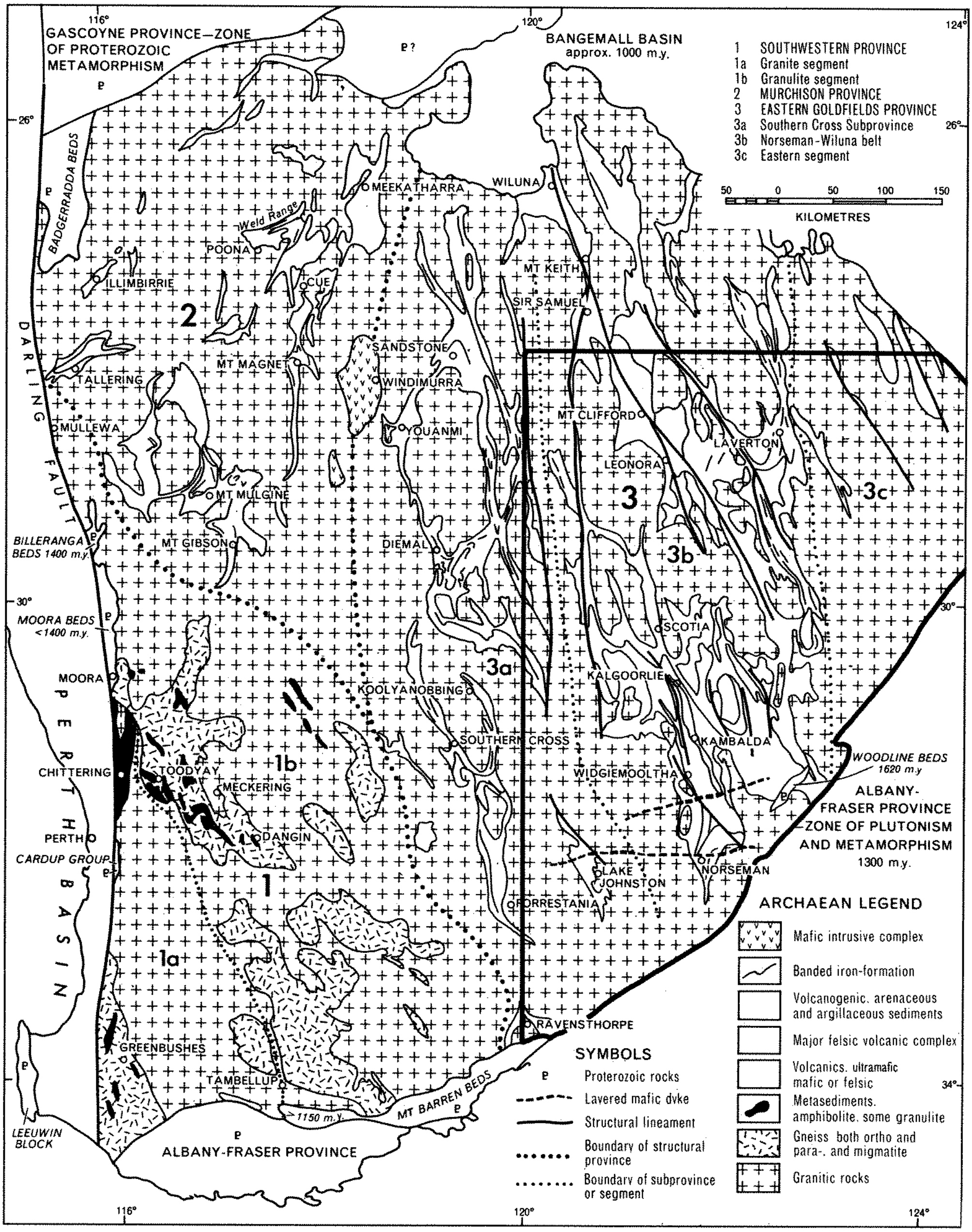

Figure 1. Geologic and tectonic sketch of the Yilgarn Block showing the limits of the area of study (GSWA 17316).

Other regional mapping projects which contributed data are:

Boorabbin (Sofoulis, 1963), Cundeelee (Bunting and van de Graaff, 1977), Edjudina (Williams and others, 1976), Kalgoorlie (Kriewaldt, 1969), Kurnalpi (Williams, 1970), Laverton (Gower, 1974), Menzies (Kriewaldt, 1970), Minigwal (Bunting and Boegli, 1977), Neale (van de Graaff and Bunting, 1975), Norseman (Doepel, 1973), Rason (Gower and Boegli, 1977), Widgiemooltha (Sofoulis, 1966) and Zanthus (Doepel and Lowry, 1970).

The relation of these sheets to the area of the present study is shown in Figure 2.

TERMINOLOGY AND NOMENCLATURE

The term "granitoid" includes all coarse-grained crystalline silicate rocks with a colour index less than 40 and plagioclase less calcic than An_{50}. Metamorphic gneiss and granofels (textural granulite) are included as well as rocks with igneous texture. As adjectives, both "granitoid" and "granitic" are used when the subject is similar to a granite but does not necessarily conform to the restricted definition of the term. Insofar as there is a difference in the terms, "granitic" is used when texture is emphasized, "granitoid" when composition is stressed. Gneiss, unqualified, is a rock of granitoid composition with substantial grain orientation, compositional layering, or both. Because of the difficulty in assigning such foliation to metamorphic deformation or protoclastic flow, use of the word "gneiss" does not mean the rock is metamorphic. However, where gneissic structure is clearly igneous, the term "gneissic granitoid" is applied.

Definitions of the more specific rock names (Fig.3) follow Streckeisen (1973) except that the granite, quartz syenite, and syenite fields of Streckeisen are divided at 35 per cent plagioclase to retain fields for adamellite, quartz monzonite and monzonite.

A small but important subset of rocks of the area are alkaline. Granitoid rocks which do not belong to the alkaline subset are termed subalkaline.

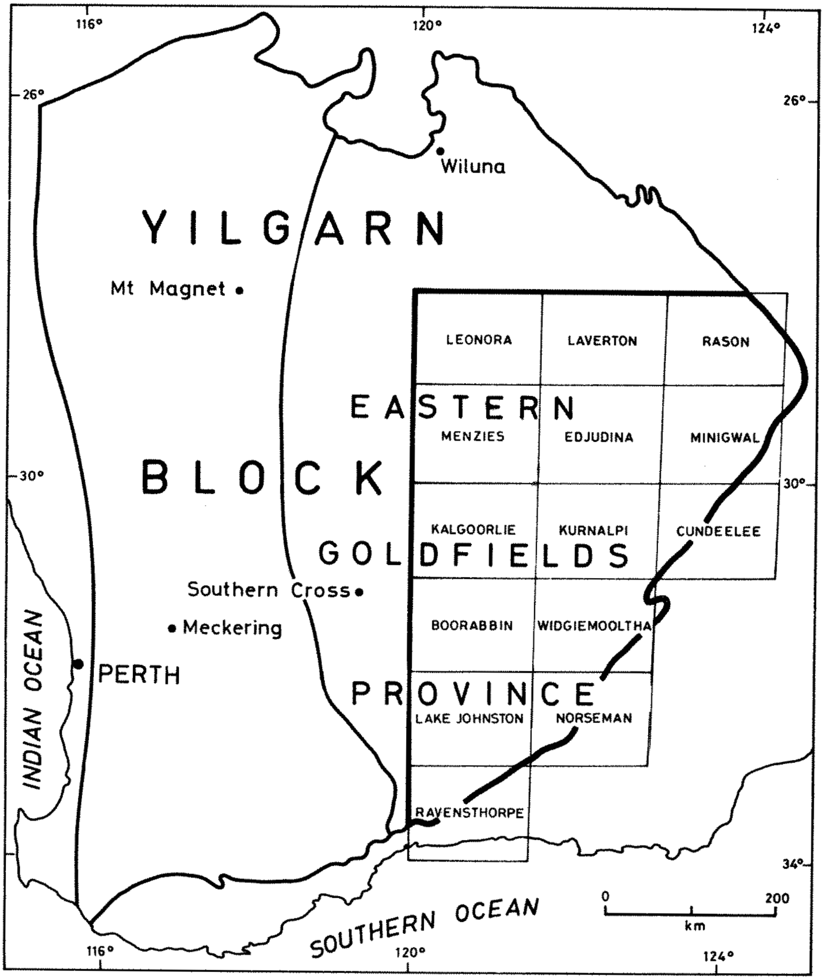

Figure 2. Index to 1:250 000 geological maps in the area of study (GSWA 17317).

Textural terms are largely conventional, self explanatory or defined in the text. A very useful term, applicable to many of these rocks but only in modest current use is "seriate", "A term suggested for variety of granular rocks in which the sizes of crystals vary gradually or in a continuous series" (Johannsen, 1939, p.233).

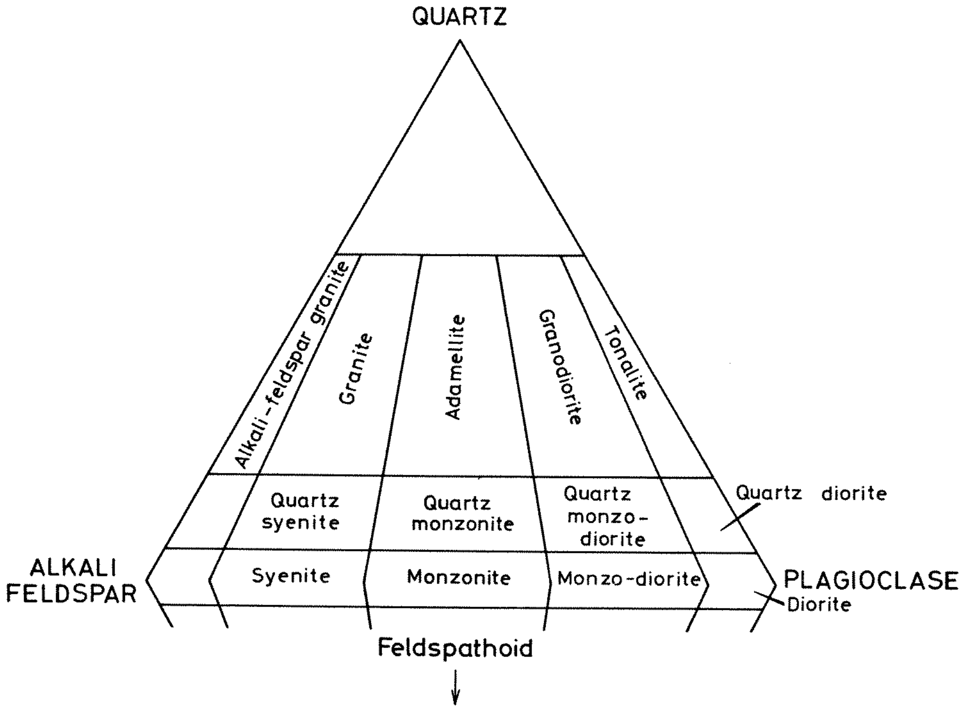

Figure 3. Classification and nomenclature of granitoid rock (GSWA 17318).

REFERENCE TO SAMPLES

Throughout the text reference to specific samples consists of the Geological Survey field sample number followed by the name of the 1:250 000 sheet covering the locality where the sample was collected. The Australian Transverse Mercator yard grid location for each sample mentioned in the text is listed in the Appendix.

PETROGRAPHY

This section includes observations on thin sections and stained slabs of the subalkaline granitoids. Alkaline rocks are discussed in a separate paper (Libby, 1978).

MINERALOGY

GENERAL

The granitoid rocks of the Eastern Goldfields Province range from true granite through tonalite, but are clustered in the adamellite to granodiorite field. Biotite adamellite is the characteristic rock. Thus, major felsic minerals are quartz, plagioclase and potassium feldspar. The manner in which these minerals are combined in individual rocks is shown in Figures 4 , 5 , 6 and 7 which are described later.

Biotite is almost ubiquitous, but other mafic minerals include amphibole and pyroxene, particularly in tonalitic and alkaline phases. Colourless mica is a common secondary mineral. Minor primary minerals include zircon, apatite, tourmaline, sphene, allanite, fluorite and opaques. Secondary minerals include epidote, chlorite, sericite, prehnite, pumpellyite, carbonate, and garnet. Weathering has produced clays and hydrous iron oxide.

MAJOR FELSIC MINERALS

Quartz

Quartz is abundant in most of these rocks, probably averaging about 30 per cent. The average of visual estimates is 26 per cent, but this is probably slightly below the true value, and also includes quartz-poor rocks of the alkaline suite. Quartz ranges from nil to about 50 per cent. Each of the rocks with about 50 per cent quartz is gneissic. Independent evidence suggests these gneisses may be metasedimentary. The granitoids with less than 20 per cent quartz constitute a distinctive group which is considered in a separate paper (Libby, 1978) on alkaline and quartz-poor rocks.

Throughout the Eastern Goldfields Province, quartz in granitoids typically shows some evidence of mild penetrative deformation. Most commonly, it is strained or granulated. Less commonly it seems to have been recrystallized, forming coarse, equant grains, convex against feldspars, or equant blebs within feldspar.

Many samples have large, irregular masses of quartz with uniform extinction; these are typically several times longer than wide, and sinuous in shape (Plate XXII). The dimensions and shape are appropriate for the coalescence of 5 to 10 adjacent quartz grains. A few feldspar grains may be enclosed, but the aspect is not poikilitic. This may be another manifestation of the recrystallization of quartz. Such a grain in sample 17660 (Menzies) is more than 1 cm long and averages 2.5 mm wide in the plane of the thin section.

Feldspars

Plagioclase in the granitoid rocks ranges from albite to andesine. Determinations on 260 samples indicate an average 13 per cent anorthite (standard deviation of 7). Throughout this study, plagioclase has been determined from extinction angles normal to the crystallographic a axis on the flat stage (conversion from angles to composition according to the curves of Tobi (1963) after Kohler).

The significance of the average plagioclase composition is doubtful, as most plagioclase has been altered, either filled with saussuritic epidote or associated with interstitial epidote. In either case the plagioclase probably is less calcic than when originally crystallized.

An unusual alteration effect was noticed in several samples (Plate X). The core of the plagioclase, presumably originally calcic, is crowded with epidote, and has a uniform extinction angle appropriate for a moderate calcium content. Outside the altered core, the extinction angle changes abruptly to a value appropriate for a slightly more calcic composition, before varying gradually to the albitic rim. Assuming that the extinction angles are reflecting only the ratio of Na:Ca, and not structural state, or varying proportions of another ion (?K), the increase in calcium outside the altered core is puzzling. If the outer zone were the product of conventional reverse zoning, it, as well as the inner zone, should be altered. Assuming that the core composition was the equilibrium composition under the conditions of alteration, it may be that a finite amount of Ca above the equilibrium composition was necessary to cause the nucleation of epidote. Once epidote had nucleated, the proportion of Ca in the plagioclase decreased to the equilibrium composition, but where Ca was insufficiently in excess of equilibrium to nucleate epidote the plagioclase remained metastably more calcic than the equilibrium composition.

Plagioclase commonly is subhedral though it ranges from anhedral, particularly in gneisses, to, rarely, euhedral. The overall textures of rocks, to which plagioclase contributed significantly, are considered in a separate section.

Potassium feldspar is almost invariably microcline with well-developed "M" (plaid, or cross-hatch) twinning. Usually it is anhedral; where crystal faces appear they commonly are developed against quartz. Rarely, but most commonly in alkaline rocks, large phenocrysts are quasi-euhedral against all other minerals. Fine film perthite is developed in the great majority of microcline grains, and in the alkaline rocks the alkali feldspar is mesoperthitic. The development of perthite is discussed in greater detail in the section on textures.

QUARTZ AND FELDSPAR RATIOS

In felsic rocks, variations in the proportions of quartz, plagioclase and potassium feldspar, along with differences in the composition of plagioclase, account for most of the variation in chemical composition, and are the basis for most mineralogical classifications. Thus, these relations have been studied in some detail.

Ratios of major minerals in granitic rocks are difficult to assess. Normal thin sections are too small to give a statistically valid sample. To supplement and check estimated data from thin sections, 77 hand specimens were sawn and stained to provide larger samples. Both techniques were used on 19 samples, and provided a means of comparing the techniques. Very significant differences between the two methods emphasize that at least one of the techniques has provided only semi-quantitative data.

The results of counts from stained slabs and estimates of composition from thin sections are shown in Figures 7 and 4 respectively.

Thin-section data

Proportions of quartz, plagioclase and potassium feldspar were visually estimated in 289 thin sections from eight 1:250 000 sheets: Leonora, Laverton, Menzies, Edjudina, Kalgoorlie, Kurnalpi, Boorabbin and Widgiemooltha (Fig.2). The composition of plagioclase was determined in most of these sections.

In principle, the feldspars are classified according to Streckeisen (1973); that is, plagioclase composed of less than 5 per cent anorthite is included with potassium feldspar as alkali feldspar. However, there are several difficulties with this procedure: grains may be zoned through An_5, the albitic composition of a grain may be secondary, and the exact composition is often difficult to determine. Thus, feldspar data was apportioned in two ways. First, all non-potassic feldspar, albite as well as more calcic plagioclase, was combined as plagioclase; potassium feldspar together with perthite constituted alkali feldspar. Second, albite (less than 5 per cent anorthite) was included with potassium feldspar and perthite as alkali feldspar; only the more calcic feldspars were called plagioclase. More precisely, in the second grouping, plagioclase was included with potassium feldspar when the rock failed to produce a significant amount of plagioclase more calcic than An_5. Grains were counted as plagioclase if the composition ranged above An_5 even if the rims of grains fell below that value.

Calculated according to the first method (albite with plagioclase), the average plagioclase content of the granitoids sampled is 41 per cent ($s = 15$) and alkali feldspar (K-feldspar only), 33 per cent ($s = 16$), where s is the standard deviation. Calcualted according to the second method (albite with K-feldspar as alkali feldspar), there is little difference; the average plagioclase ($>An_5$) is 35 per cent ($s = 19$) and alkali feldspar, 39 per cent ($s = 21$). The ratio of mean alkali feldspar to mean plagioclase places the average rock in the adamellite field in either case. The average composition is in the granodiorite side of the adamellite field in the first case, and in the granite side in the second.

Visual estimates of proportions of quartz, plagioclase and alkali feldspar from individual samples have been recalculated to 100 and plotted on the triangular diagrams (Figs 4, 5). In Figure 4 the feldspars have been apportioned according to the first method (albite with plagioclase) and in Figure 5, according to the second method (albite with alkali feldspar). Most estimates were to the nearest 5 per cent, and result in nodes at 5 per cent intervals. Where two or more points have the same value, points are offset slightly for legibility but result in clusters about the nodes.

The plotted points in Figure 4, where albite is included with plagioclase rather than with alkali feldspar, show that adamellite is the dominant rock type. This is consistent with the mean quartz and feldspar ratios considered above. Granodiorite is also abundant, and granite and tonalite are common. Potassium feldspar granites without significant albite are rare. The quartz-poor rocks - syenite, quartz syenite, monzonite, monzodiorite and quartz monzodiorite - are reasonably well represented as a group. These are alkaline rocks with alkali pyroxene and alkali amphibole.

Diorite and quartz diorite are poorly represented. Considering the difficulty in determining the composition of primary plagioclase which has been degraded through saussuritization, some diorites and related rocks may have been identified as gabbro, and not included in the granitoids in this part of the study.

In Figure 5 where albite has been included with potassium feldspar as alkali feldspar, albitic samples which plotted in the body of Figure 4 have migrated to the left margin of the triangle, along the alkali feldspar-quartz join. Because the migrating samples are defined as being free of Ca-bearing plagioclase, all such samples lie strictly on the join despite approximations in plotting to accommodate all of the points. Figure 6 shows the plotted positions of migrating samples before migration. The migrating samples are distributed over the diagram very much in the same way as the plagioclase-bearing samples. The albitic samples do not correlate with samples having a large proportion of potassium feldspar. Failure of granitoids with albitic plagioclase also to have abundant potassium feldspar suggests that the albite-bearing rocks may have been generated randomly from rocks with various plagioclase compositions by secondary albitization consequent on deuteric alteration or metamorphism. Thus

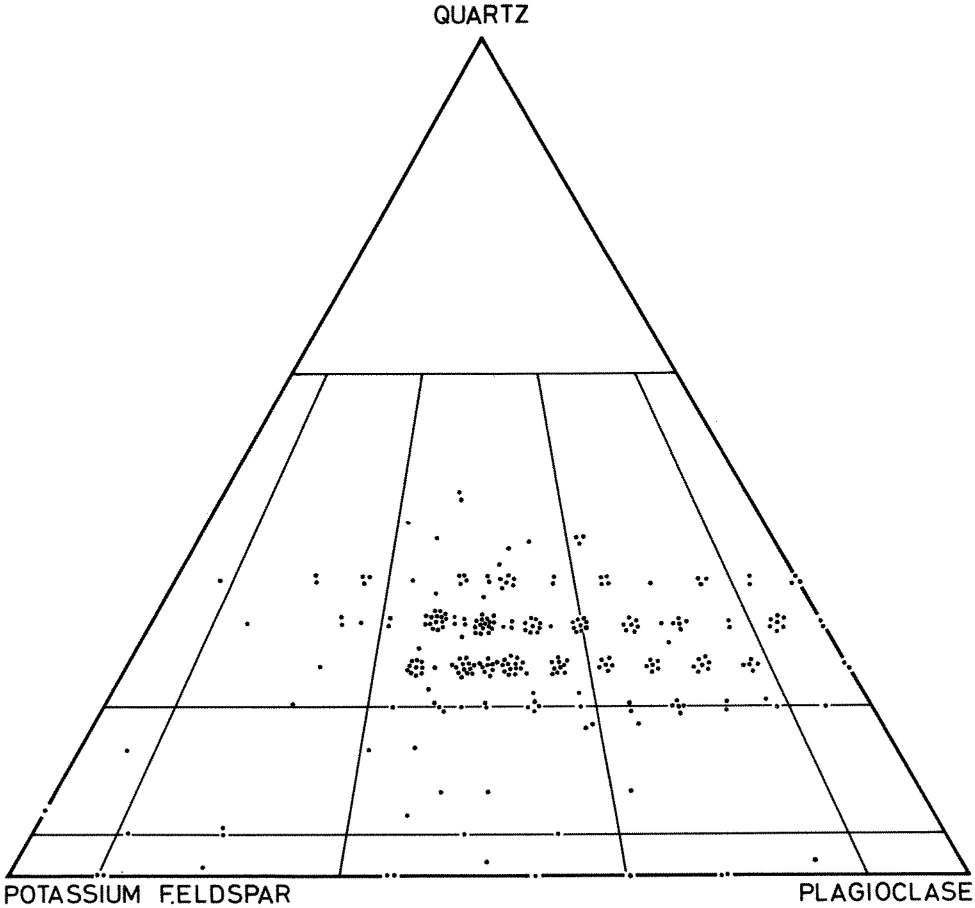

Figure 4. Modal quartz, plagioclase, and potassium feldspar. Albite is plotted as plagioclase. Data are from thin sections. (GSWA 17319)

Figure 4 would seem to be more efficient than Figure 5 as an estimate of mineral proportions in the rock immediately after crystallization.

Data from stained slabs

One hundred and twenty four samples for staining were collected in 1973 by I.R. Williams, mainly from the Kalgoorlie, Boorabbin, and Widgiemooltha sheets, and the western third of the Menzies sheet. Scattered samples are from the Leonora, Cundeelee and Balladonia sheets. The rocks were sawn, etched with hydrofluoric acid, and stained with sodium

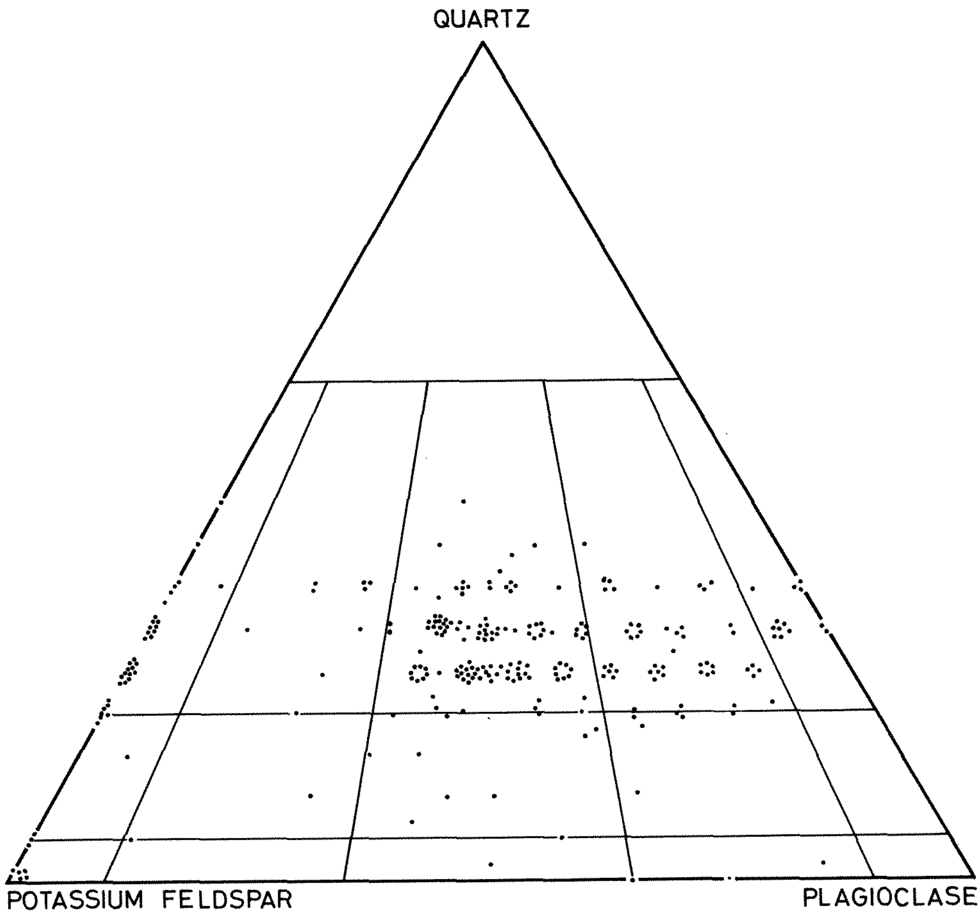

Figure 5. Modal quartz, plagioclase, and potassium feldspar. Albite is plotted as alkali feldspar. Data are from thin sections. (GSWA 17320)

cobaltinitrite, leaving quartz clear, plagioclase chalky-white, and potassium feldspar bright yellow. About 1 000 points were counted on each rock by noting the mineral at the intersection of grid lines ruled at a spacing of 4 mm on a plastic overlay.

Some of the samples were collected outside the study area, and others were either too fine grained for point counting or failed to stain adequately. Seventy-seven samples were chosen for further study. Although potassium feldspar was well stained in most samples, the distinction between plagioclase and quartz was obscured in many cases by a tendency of plagioclase in some samples to remain glassy, lessening its contrast with the glassy quartz. Repetition of point counting on several samples by a

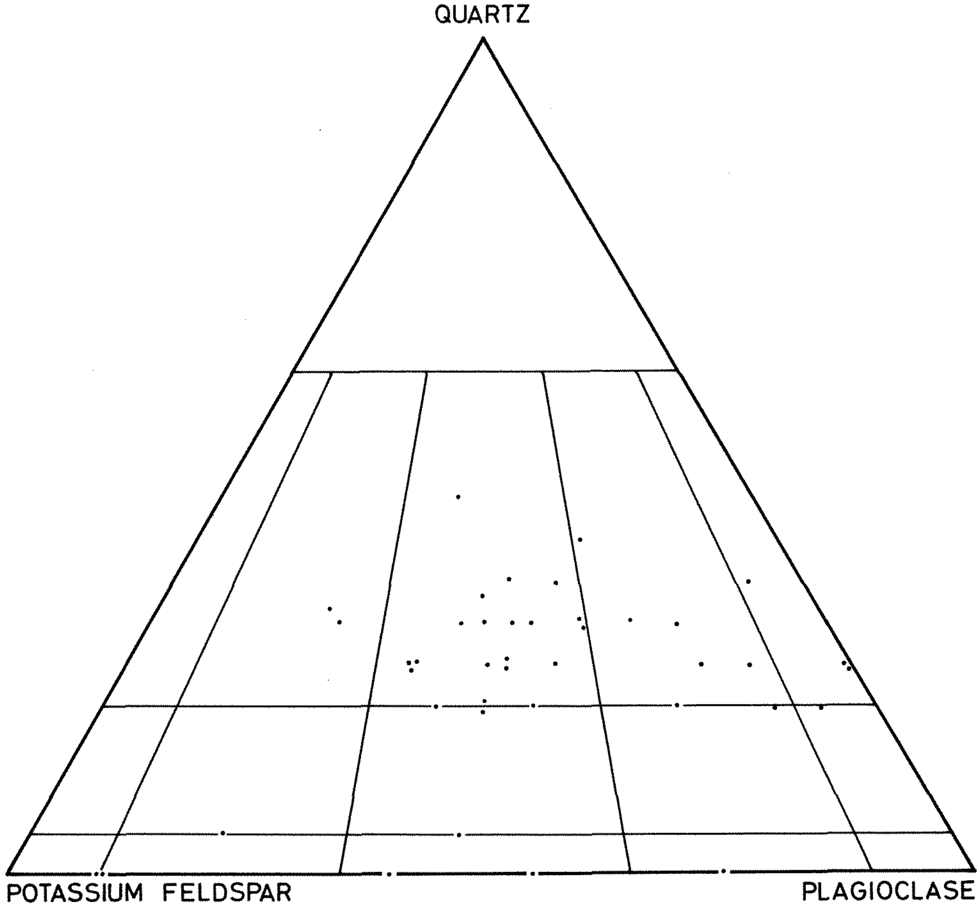

Figure 6. Modal quartz, plagioclase and potassium feldspar. Only samples in which plagioclase is albitic. Albite is plotted as plagioclase. Data are from thin sections. (GSWA 17321)

second operator confirmed that quartz:plagioclase ratios were less reliable than total potassium feldspar values. Average differences between values obtained by the second operator and those by the first operator were: potassium feldspar, -3 per cent; quartz, -3.5 per cent; and plagioclase, +6.5 per cent. The reported values probably are no more accurate than 5 per cent, but the errors were quite systematic, suggesting that relative values are more useful.

Quartz and feldspar data from stained slabs have been plotted on a triangular diagram in Figure 7. The general pattern is similar to that of Figure 4, which is a plot of data from the thin sections, described above.

In both diagrams, the average composition is in the granodiorite side of the adamellite field. The data from slabs differ from thin-section data mainly in the more restricted compositional range and the greater apparent proportion of quartz. Probably quartz was both overestimated in stained slabs and underestimated in thin sections. The more restricted compositional range among stained slabs may be partly due to rejection of syenite and monzonite, as they commonly are porphyritic with a medium-grained matrix which would be unsuitable for counting under low-power magnification. Samples for staining were collected predominantly from the more potassic western zone and the thin section samples were collected mainly from the less potassic eastern zone. This may explain the lower proportion of granodiorite and tonalite among the stained rocks.

Although some of the difference between data from thin sections and data from slabs is real, some is an artifact of the techniques. To study the effect of the techniques on the results, 19 of the samples with thin-section data were also slabbed. The average difference in percentage between the thin section and slab values for each mineral was calculated. Stated as mean ($\bar{x}$) and standard deviation (s), these differences are: potassium feldspar, $\bar{x} = -1.4$, $s = 9.6$; plagioclase, $\bar{x} = -8.6$, $s = 13.2$; quartz, $\bar{x} = +11.1$, $s = 6.0$. Differences are positive when the mineral seems more abundant in stained slabs than in thin sections. The small difference between thin section and slab results for potassium feldspar suggests that the data for this mineral are reliable. The plagioclase and quartz data seem less reliable.

MAJOR MAFIC MINERALS

The mafic suite in the granitoid rocks of the Eastern Goldfields Province is dominated by brown biotite, but a few samples, especially tonalite and alkaline rocks, contain amphibole. Pyroxene is a primary mineral in alkaline rocks and is a metamorphic phase in some gneissic granitoids.

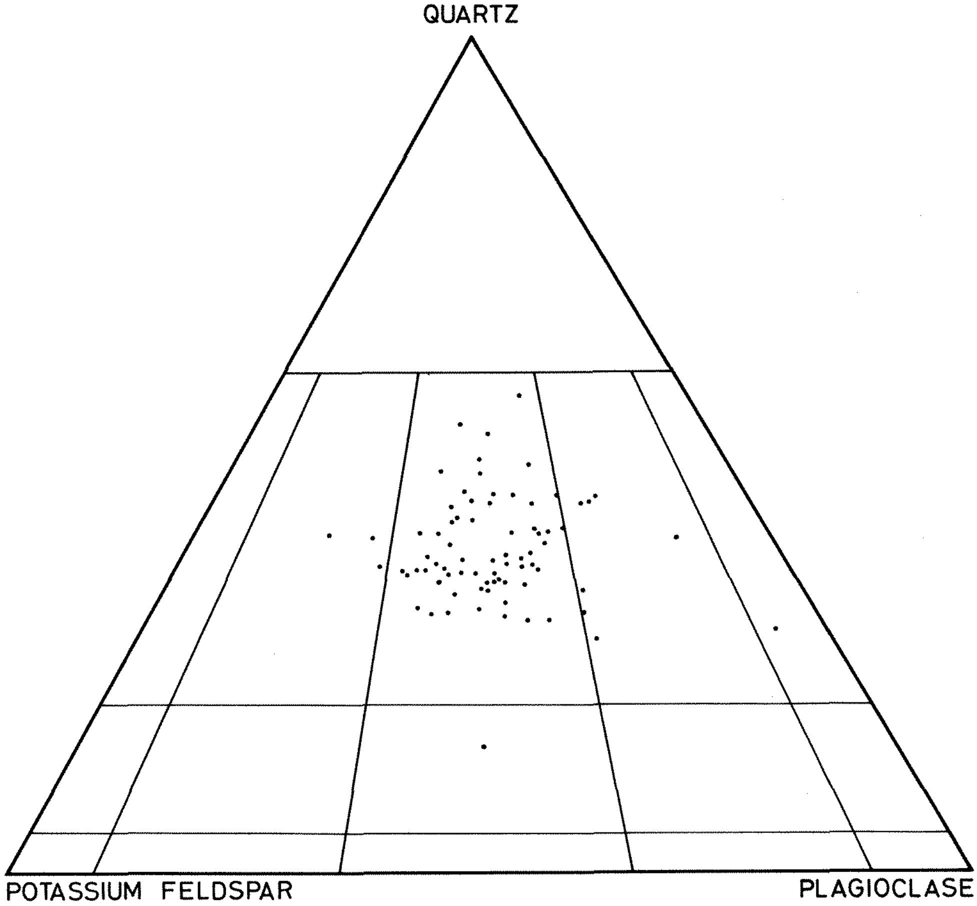

Figure 7. Modal quartz, plagioclase and potassium feldspar. Data are from stained slabs. (GSWA 17322)

Biotite

The biotite in almost all samples is deep brown; rarely, it is green (sample 24801, Edjudina), or olive green (sample 24802, Edjudina). Most of the biotite is subhedral-blocky to irregular, but occasionally is euhedral, hexagonal in outline (sample 24832, Edjudina). In rocks with independent evidence of significant cataclasis, biotite forms aggregates of equant or platy grains, and where planar cataclasis is more intense elongate aggregates of finely comminuted biotitic material are common. The colour of the biotite in these cataclastic habits is not consistently different to biotite which seems to have primary igneous form. The blocky habit of biotite seems to correlate with other indications of primary igneous crystallization, such as zoned or euhedral to subhedral plagioclase.

Much biotite is fresh and unaltered, but more than half has been partly altered to green chlorite, and some has been entirely chloritized. The biotite of some weathered samples has been altered to a complex of iron hydroxides. Biotite, especially when partly chloritized, has acted as host to secondary epidote, sphene, fluorite, prehnite and pumpellyite.

Amphibole and pyroxene

An appreciable number of samples contain amphibole. Much of this, however, is in material which shows independent evidence of metamorphism. Of the remainder, most is in the alkaline or quartz-poor rocks. However, even after eliminating these associations, some samples with hornblende remain. Of these, a few, as sample 39003 (Laverton), are granodiorite or tonalite with moderately calcic plagioclase. Ferrohastingsitic amphibole, dark green with a small optic axial angle and strong dispersion, is common in the suite of granitic rocks which have been recrystallized, are cataclastic, or show other evidence of metamorphism.

Igneous clinopyroxene is clearly present only in samples of the alkaline and quartz-poor suite described by Libby (1978). Green clinopyroxene, apparently diopsidic, is present in several gneisses (sample 41475, Boorabbin), and in granitic rocks which show independent evidence of metamorphic recrystallization. Optical properties suggest that clinopyroxenes in the non-alkaline granitic or metamorphosed granitic rocks are restricted to diopside-hedenbergite, whereas the pyroxenes of the alkaline suite seem to range from diopside-hedenbergite through aegirine-augite to aegirine.

COLOURLESS MICA

Plagioclase has been sericitized in almost all of the granitoid rocks of the Eastern Goldfields Province, and in many grains the mica has grown to appreciable size as individual flakes. Coarse interstitial muscovite is also common but in no case does it seem likely that appreciable colourless mica is a primary igneous mineral. Most of the rocks with coarse, interstitial, colourless mica have independent evidence of recrystallization The abundance of muscovite in a few gneissic rocks may have genetic significance, suggesting a peraluminous composition and sedimentary parentage. Examples of possible peraluminous gneisses are samples 17655 and 17681 (Menzies) and 2364 (Kurnalpi).

MINOR MINERALS

The minor minerals described in this section include the accessories which are present in small amounts in most or many granitoids, minerals which may be major constituents of some rocks, but which are not abundant in the granitoids of the Eastern Goldfields Province, and finally secondary minerals regardless of abundance which are not products of thoroughgoing metamorphic recrystallization of the enclosing rock.

Accessory minerals

Zircon, apatite and opaque minerals are common, though they vary in abundance and habit.

Zircon averages several medium grains per thin section, but ranges from coarse and abundant to fine and rare, and was not found in some rocks. Large, metamict grains with the shape and habit of zircon are common in some areas as seen in sample 40807A (Edjudina) and 31131 (Laverton). Pleochroic haloes surround zircon where it is in contact with biotite.

Apatite is similarly variable. Most granitoids in which apatite was noted to be either coarse or particularly abundant, either had metamorphic elements or belonged to the alkaline suite. One of several exceptions is sample 39003 (Laverton) which is a calcic oligoclase granodiorite with abundant coarse apatite.

Most opaque minerals in the granitoids of the Eastern Goldfields Province are black under oblique reflected light, suggesting magnetite, but hematite and titanium-bearing opaques are present. Sulphides seem scarce, possibly they have been oxidized to hematite.

Minor primary minerals

The remaining minor primary minerals are tourmaline, sphene, allanite and fluorite. They are less common than zircon, apatite or opaque minerals but where present they may be much more abundant than the common accessories.

Tourmaline was identified only in sample 11099 (Kurnalpi), an alkaline rock, and sample 41480 (Leonora), a blastomylonite gneiss. The thinly scattered, generally fine tourmaline in Yilgarn Block rocks poses a problem for the source of the nearly-ubiquitous coarse clastic tourmaline in sandstones of the Bangemall Basin.

Sphene is common, both as spindle-shaped grains (Plate I) which are probably of igneous origin, and as irregular masses associated with chlorite (Plate II), probably a consequence of the alteration of biotite. Primary sphene is most common in rocks which contain andesine, but is also common in rocks with plagioclase which is less calcic, even where there is no epidote to suggest that the sodic composition of the plagioclase may be due to albitization. Much of the sphene of the Eastern Goldfields Province has patchy pleochroism and is a warm, orange colour. The patchy colour does not seem to be parallel to growth zones. Especially strong colour is associated with lowered birefringence. Deer and others (1962, p.74) attribute orange colour to rare-earth elements. The same source suggests that lowered birefringence is due to substitution of any of various elements for titanium. The geographic distribution of sphene is discussed in a later section.

Allanite is commonly metamict in Archaean rocks and is thus difficult to identify in thin section. In some instances grain shape, cracking of surrounding minerals, or association with non-radioactive epidote provides reasonable evidence that the metamict material is allanite. In the Eastern Goldfields Province allanite is restricted to certain plutons, in which it may be abundant. The regional distribution of allanite is discussed in a later section. Metamict allanite from the Laverton sheet is pictured in Plate IX.

Fluorite is a common accessory in the granitoid rocks of the Eastern Goldfields Province; it was found in 79 of the 278 thin sections of granitic rock studied. Fluorite is especially abundant in the western part of the Menzies and Leonora sheets but is also common in the Boreas Adamellite in the northern part of the Laverton sheet. Details of the regional distribution of fluorite are discussed in a later section.

The associations of fluorite were studied in 67 samples. It is enclosed in plagioclase in 58 (Plates V and VI), interstitial in 41 (Plates VII and VIII), enclosed in potassium feldspar in 10, and enclosed in chlorite in 9 samples. Fluorite was also found in muscovite, biotite, sphene, allanite and hornblende. Where fluorite is enclosed in plagioclase it is usually in the calcic, or formerly calcic, core of the grain, suggesting that fluorite grew during alteration of feldspar by the combination of F with Ca released by albitization of the plagioclase.

The purple colour of the fluorite is patchy, even in very small grains. Usually, fluorite enclosed in the core of plagioclase grains is colourless, but fluorite associated with chlorite is more commonly coloured, as is interstitial fluorite, especially where it is in contact with opaque grains or zircon. In a few cases, a grain which is largely colourless is coloured where it is in contact with an opaque grain.

Secondary minerals

Secondary minerals include kyanite, garnet, epidote, pumpellyite, prehnite, chlorite, sericite, carbonate, and hydrous iron-oxide. Some of these are normally considered to be metamorphic minerals, others are normally considered to be products of low grade hydrothermal alteration or weathering. The lower grade materials, iron-oxide and sericite are abundant; garnet, pumpellyite and prehnite are less common in granitoids; and kyanite was found only in an associated schist.

Hydrous iron-oxide is a common, incomplete pseudomorph of mafic and opaque minerals in samples which have been severely weathered, and is a minor stain in most samples. It may be secondary after sulphides.

Sericite has been described in the section on colourless mica. It is almost ubiquitous as an alteration product of plagioclase, grades into coarser, discrete grains of colourless mica in plagioclase, and is interstitial in some samples.

Carbonate is a sparse component of about ten per cent of the rocks studied; it is found in metamorphic, alkaline, and altered igneous granitoid rocks alike. Rarely is it abundant, as in the heavily carbonated and sericitized sample 15507 (Edjudina). It seems to be a product of low-grade alteration in most cases, but could be metamorphic in a few of the gneisses.

Chlorite is an abundant product of complete or partial alteration of biotite. It acts as a host to secondary epidote, sphene, fluorite, prehnite, pumpellyite, opaques and other minerals. Some of these inclusions seem related to the release of elements on the breakdown of biotite to chlorite, others do not. All the coarse chlorite seems related to the breakdown of mafic minerals; there is little or no independently crystallized coarse metamorphic chlorite.

Pumpellyite and prehnite typically are found in rocks which have been mildly recrystallized and severely sericitized, or in which feldspars have been heavily dusted with cryptocrystalline secondary material. Thus, they seem to be products of low-grade alteration or of metamorphism which has failed to bring either the textures or mineral assemblages into equilibrium with the metamorphic conditions. Grains of pumpellyite are small and scarce. They are commonly between 20 μm and 60 μm in diameter, and there are seldom more than two or three grains in any thin section. Birefringence is moderate and dispersion of optic axes strong, resulting in anomalous interference colours, probably in the upper part of the first order. Colour is variable between grains and within grains. Most commonly the pumpellyite is pleochroic in shades of pale to bright yellow, but some grains are green and a few range from yellow to green. Nearly colourless material in sample 41472 (Norseman) was confirmed as pumpellyite by X-ray diffraction (written communication, M. Pryce, West. Australia Government Chemical Laboratories, 26 August 1975). Typical pumpellyite is pictured in Plates III and IV.

Pumpellyite was found in 35 of the 289 thin sections studied in detail. The distribution of pumpellyite does not seem to conform to patterns of metamorphism which have been suggested, or to any accepted tectonic framework. Furthermore, it does not seem to be concentrated in areas defined in this report on other mineralogical criteria. Further study of pumpellyite in these rocks should prove productive.

The identification of prehnite ranges from tentative to confident. It was found only in seven, widely scattered samples. The only evident regional association is that three of the seven prehnite-bearing samples are in the belt west of the Coolgardie-Mount Ida greenstone arm of the Kalgoorlie greenstone belt. Correlation with other calc-silicate minerals is more convincing than correlation with tectonic belts. In four of the seven prehnite-bearing samples pumpellyite is also present as an accessory and in three of those, epidote is also present. Presumably, the three calcium-aluminium-silicate minerals did not develop simultaneously. In one of the other three samples epidote is an accessory, and in the other two the prehnite is associated with a carbonate mineral.

Prehnite and pumpellyite, along with sericitization of feldspars and development of blebby quartz, show that at least some of the granitoid rocks of the Eastern Goldfields Province have been partially recrystallized, even where penetrative deformation is not evident. It is not clear whether the alteration producing this recrystallization is the result of deuteric alteration, local hydrothermal alteration or regional metamorphism.

Epidote is a characteristic alteration product of calcium-bearing plagioclase. It is abundant in the Eastern Goldfields Province, both as finely granular saussuritic alteration of plagioclase and as coarser interstitial grains. Commonly, saussuritic epidote has low birefringence and is probably clinozoisite; whereas interstitial epidote has higher birefringence and is pistacite.

Garnet was found in five samples. Four of these are the gneissic rocks associated with the Coolgardie-Mount Ida greenstone arm of the Kalgoorlie greenstone belt in the northern part of the Kalgoorlie sheet (sample 9155C), the Menzies sheet (samples 17617A and 17625) and the south-central part of the Leonora sheet (sample 40575D). These rocks are gneisses, but, except for sample 40575D, have compositions similar to other granitoids of the area. Sample 40575D is rich in quartz, and may be a paragneiss. These four localities are from the general trend of "metamorphic domains" mapped by Bettenay (Binns and Marston, 1976). The fifth garnet-bearing sample (38143) is from the northeastern part of the Laverton sheet. The rock has been crushed and partly recrystallized under stress. It is isolated; no other samples from this area are similarly metamorphosed.

The five garnet-bearing samples are all gneissic, and the garnet is most easily explained as a product of medium or high-grade metamorphism.

Kyanite was found in a schistose phase of the gneissic rock of Maroon Range in the central part of the Leonora sheet (sample 39805). Although not from a granitoid rock it is included as a mineral from an associated rock unit.

TEXTURE AND MICROSTRUCTURE

GENERAL

Typical granitoid rocks in the Eastern Goldfields Province are hypidiomorphic granular, although well-formed feldspars may be less common than in many granitic terrains, possibly because penetrative cataclasis and mild to severe recrystallization have affected the rocks of much of the area. Nonetheless, euhedral feldspar does exist, especially in the alkaline and more calcic rocks.

CATACLASIS AND RECRYSTALLIZATION

Cataclastic and healed cataclastic textures

Almost all rocks are at least mildly cataclastic, or have a texture which suggests healed cataclasis. Quartz in most rocks is strained, and is often polygonized into mosaic pseudomorphs of primary grains, or completely recrystallized and redistributed about the rock in fine grains. In some samples quartz is drawn out into a mortar sheath around feldspar grains, or forms blastomylonitic trains. Much of the feldspar has been bent or fractured. A more subtle recrystallization texture is the development of quartz blebs (Plate XXI), often within feldspar grains, and often forming rounded bipyramids of quartz in the margins of feldspar grains. The origin of the blebby quartz is uncertain, but associations suggest that, despite the occasional quasi-euhedral habit, blebby quartz may be due to recrystallization following comminution of quartz into mortar. The large, roughly oriented amoeboid seas of quartz (Plate XXII) described earlier may also be a recrystallization product. They may result from the amalgamation after comminution of several adjacent grains which originally were independently oriented.

Most samples are even textured but porphyritic and seriate textures are also abundant. Seriate texture (Plates XXIII and XXIV) is common even in normal adamellites; grains range evenly from coarse or very coarse to medium, or even in some cases, fine. Again, it is possible that the seriate rocks have been deformed penetratively and recrystallized, the ultimate size of a grain depending both on the size to which it was reduced and on the size, proximity and number of neighbouring quartz grains. A possible secondary origin of seriate texture is shown in Plate XXIII; in Plate XXIV the texture probably is dominantly igneous.

Metamorphic textures

Although some gneissoid rocks are deformed and mildly recrystallized igneous granitoids, others, true gneisses, have fully crystalloblastic texture with strongly oriented micas.

The relation between gneiss and the less recrystallized isotropic granitoids is not clear. There is some suggestion in the southwest corner of the Menzies sheet that isotropic granitic rock may grade into gneissic rock, suggesting that the gneiss may be in part metamorphosed granite, but the evidence is not compelling. Kriewaldt (1970) has said that the granitic mass north of Lake Ballard is intrusive on the east and strongly foliated on the west, suggesting gradation from an isotropic, igneous aspect into a gneissic, metamorphic habit. Archibald and Bettenay (in press) have been particularly concerned with these relationships (Binns and Marston, 1976).

TEXTURAL AND MICROSTRUCTURAL CLASSIFICATION

Textures and microstructures in thin sections were graded roughly in progression from those suggesting a metamorphic origin to those suggesting an unrecrystallized igneous origin. These grades are: gneissic, foliated granitic, statically recrystallized, cataclastic granitic, hypidiomorphic granular (granitic), and igneous.

Gneissic rocks (Plate XI) are equigranular with strongly oriented mafic grains. The mafic grains are at least partly enclosed in individual quartz or feldspar grains. Quartz grains define at least a weak foliation, either by elongation and orientation of individual grains, or by variation in abundance in succeeding layers.

Foliated granitic rocks (Plate XII) have obviously been deformed, but recrystallization is less complete than in gneissic rocks. Mafic minerals are less than perfectly oriented, and compositional layering is weak or absent. Still, planar deformation is obvious and is more prominent than recrystallization in rocks of this class. Mylonites are included in this group.

Statically metamorphosed rocks (Plates XIII, and XIV) have the granoblastic, even-grained texture of the gneisses, without grain orientation or compositional layering to define a planar element. Crystallographic faces on quartz and feldspar, typical of hypidiomorphic granular texture, are absent or rare. Grain junctures at 120° are characteristic.

Cataclastic granitic rock (Plate XV) has igneous features such as subhedral feldspars or multiple oscillatory zoning in plagioclase, but grain margins have been crushed by cataclasis, with or without the development of a significant directional fabric.

Hypidiomorphic granular granitoids (Plates XVII, XVIII and XVI) have typical granitic texture. Quartz is interstitial and feldspars are in part subhedral, though crystal faces are seldom as abundant as in illustrated examples of this texture (Joplin, 1964, Fig.55A, B and C). Plagioclase may have weak oscillatory zoning.

Igneous rocks (Plates XIX and XX) have textures which can be considered prima facie evidence of igneous crystallization. Such textures are euhedral plagioclase with multiple, euhedral, oscillatory compositional zoning; quartz or biotite grains which are euhedral but not enclosed in other grains; and plagioclase twins in synneusis relationship (Johannsen, 1939, p.234) to form combination twins (Ross, 1957). Synneusis texture or combination twinning suggests that grains have drifted together in a melt. Ross (1957) and Vance (1957) discuss combination twinning and coalescent growth which indicate synneusis.

The variation in textures across the area reflects varying tectonic and petrogenetic conditions. Resolution of these trends is poor at the sample spacing used in this report but some trends are recognizable and are reported in a later section.

INTERGROWTHS OF FELSIC MINERALS

Perthite and myrmekite are common throughout the area. Granophyre (sample 38327, Leonora) is very rare and the samples which are granophyric may be genetically closer to the felsites than to the coarse-grained granitoids.

Perthite

The feldspars of more than 60 per cent of the granitoids studied are perthitic or antiperthitic. Most of these have film perthite but patch perthite is also common. Antiperthite is rare. Mesoperthite is characteristic of alkali feldspar of the alkaline suite.

Myrmekite

More than 60 per cent of the samples examined have at least a trace of myrmekite.

Myrmekite seems to be abundant in rocks which contain oligoclase, and rare in albitic rocks. In order that the relation between the development of myrmekite and the composition of plagioclase could be studied systematically, the samples were arranged in three lists according to the amount of myrmekite in the rock. The mean composition of plagioclase was then determined for each list. In the first list were rocks with abundant myrmekite, in the second, rocks in which myrmekite is rare, and in the third, rocks in which no myrmekite was found. The mean anorthite content of plagioclase from samples with abundant myrmekite is 15.4 ($s = 4.5$); in samples with minor myrmekite it is 12.3 ($s = 5.6$); and in samples without myrmekite it is 10.4 ($s = 8.1$). The amount of myrmekite decreases as the anorthite content of plagioclase decreases. At the same time the spread in values (standard deviation, s) increases. These relations are shown in the histograms, Figure 8A, B and C. Histogram A shows that the most common plagioclase in the rocks with abundant myrmekite is sodic oligoclase; histogram C is bimodal, showing that both albite and andesine are characteristic of myrmekite-free rocks. In other words, myrmekite is associated with intermediate plagioclase, and rare in rocks with plagioclase which is either more calcic or less calcic.

The meaning of the relationship between plagioclase composition and myrmekite is not clear. Probably the rocks which contain andesine have a different crystallization history than the more sodic rocks. A few possibilities for oligoclase and albite-bearing rocks are that: 1) a threshold value for calcium in plagioclase is necessary for the development of myrmekite, 2) the more albitic rocks were originally the same composition as those with sodic oligoclase but calcium was lost, and myrmekite annealed during metamorphic recrystallization, or 3) the oligoclase-bearing and albite-bearing suites are unrelated, the albitic rocks not having experienced the physical conditions necessary for the development of myrmekite. The third explanation seems unlikely as all properties seem gradational between albite-bearing and oligoclase-bearing suites (histogram B); there is no reason to prefer either of the two remaining alternatives.

The time of development of myrmekite is not clear. It may be late magmatic, deuteric, or metamorphic; but, whatever the origin, the development and preservation of myrmekite has favoured rocks which have a narrower range of plagioclase compositions than is characteristic of the granitoid rocks of the Eastern Goldfields Province as a whole.

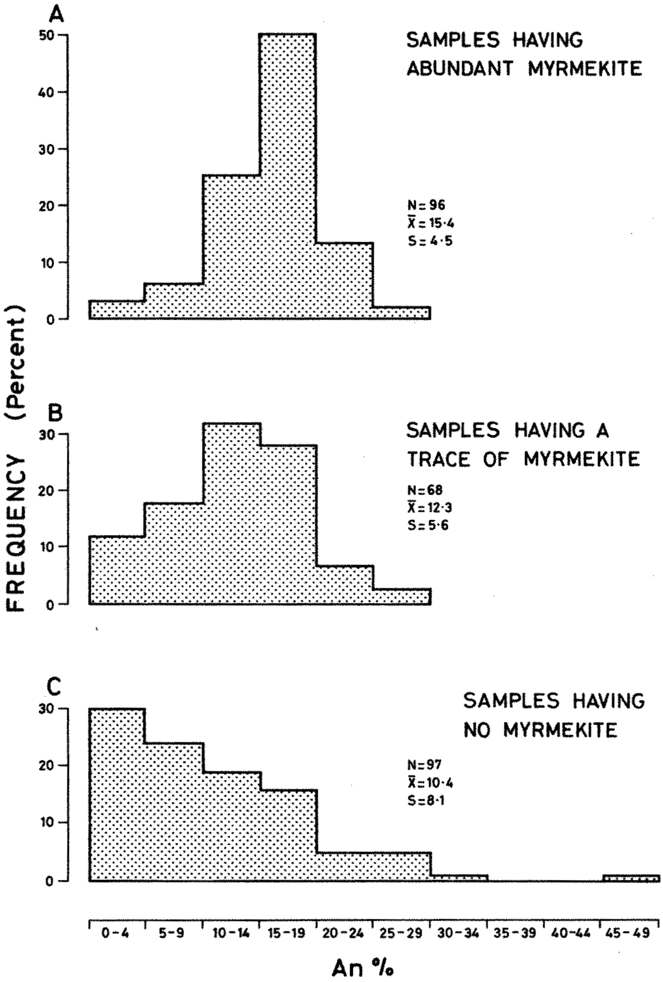

Figure 8. Relation between Ca-content of plagioclase and development of myrmekite. (GSWA 17323)

REGIONAL PETROGRAPHY

In the preceding sections, average properties of granitoid rocks from the study area have been considered. However, the character of an area is defined as much by the distribution of materials within it as by its average properties. In this section the distribution of selected properties over the area is discussed.

DISTRIBUTION OF POTASSIUM FELDSPAR

The technique of staining, and determining mineral ratios from stained slabs was described in the section on major felsic minerals. Although the study covered a limited part of the Eastern Goldfields Province (Fig.9), it suggests the type of variation that can be expected over the entire area. Various comparisons of results suggested that, of the various properties measured, the data on potassium feldspar are the most reliable, so these were used for regional mapping.

The study area can be divided into four zones on the basis of distribution of potassium feldspar (Fig.9). The western zone occupies the western half of the Boorabbin and Kalgoorlie sheets; the central zone lies along the eastern side of the Boorabbin and Kalgoorlie sheets; and the eastern zone trends north-northwestward across the eastern part of the Widgiemooltha sheet and central part of the Kurnalpi sheet. A fourth, northeastern, zone is suggested in the northeast corner of the Kurnalpi sheet.

The eastern and western zones are characterized by an abundance of potassium feldspar; the central zone has less potassium feldspar. The fourth zone, in the northeastern corner of the Kurnalpi sheet, also seems to have less potassium feldspar, but control is poor. The differences between zones are subtle in raw data, but striking on the trend-surface map (Fig.9).

Trend-surface analysis is a mathematical technique for extracting general patterns from data cluttered with random or interfering values. Trend-surface maps are plots of patterns generated by the trend-surface analysis of geographically distributed data. Care is needed in the interpretation of trend-surface maps, as even mathematically random data result in a map which may seem to have an interpretable pattern. The order of a trend-surface map is a statement of the complexity of the mathematical function used to generate the map, and determines the complexity of the pattern generated. The contours of a first-order, or linear, map are all straight, parallel lines, the contours of a plane showing the average direction and rate of increase of values. A second-order, or quadratic, map has a simple paraboloidal pattern. Very high order maps tend to duplicate the raw data in their complexity and are less useful than lower orders for drawing regional trends from geological data. Fourth-order maps

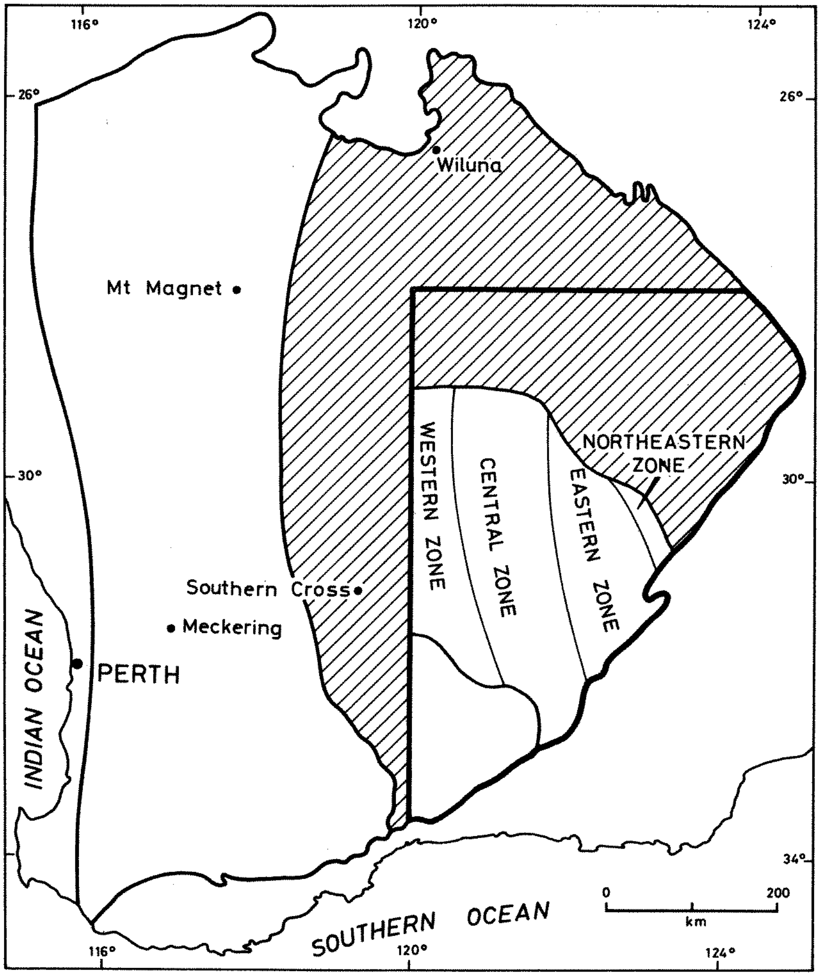

Figure 9. Area of study of potassium feldspar in stained slabs showing zones defined on abundance of potassium feldspar. (GSWA 17324)

normally have enough detail to pick out major trends but are simple enough so that the trends are not masked by detail.

A fourth-order trend-surface map (Fig.10) of potassium feldspar values in the area from which stained slabs were drawn shows well-defined north-northwesterly trends. The three zones suggested above are clearly shown, with abundant feldspar in the eastern zone, less in the central zone and more, again, in the western zone. A fourth zone, with less potassium feldspar, is suggested in the northeast corner of the map.

The line marking the maximum rate of change in abundance of potassium feldspar from high values in the western zone to lower values in the central

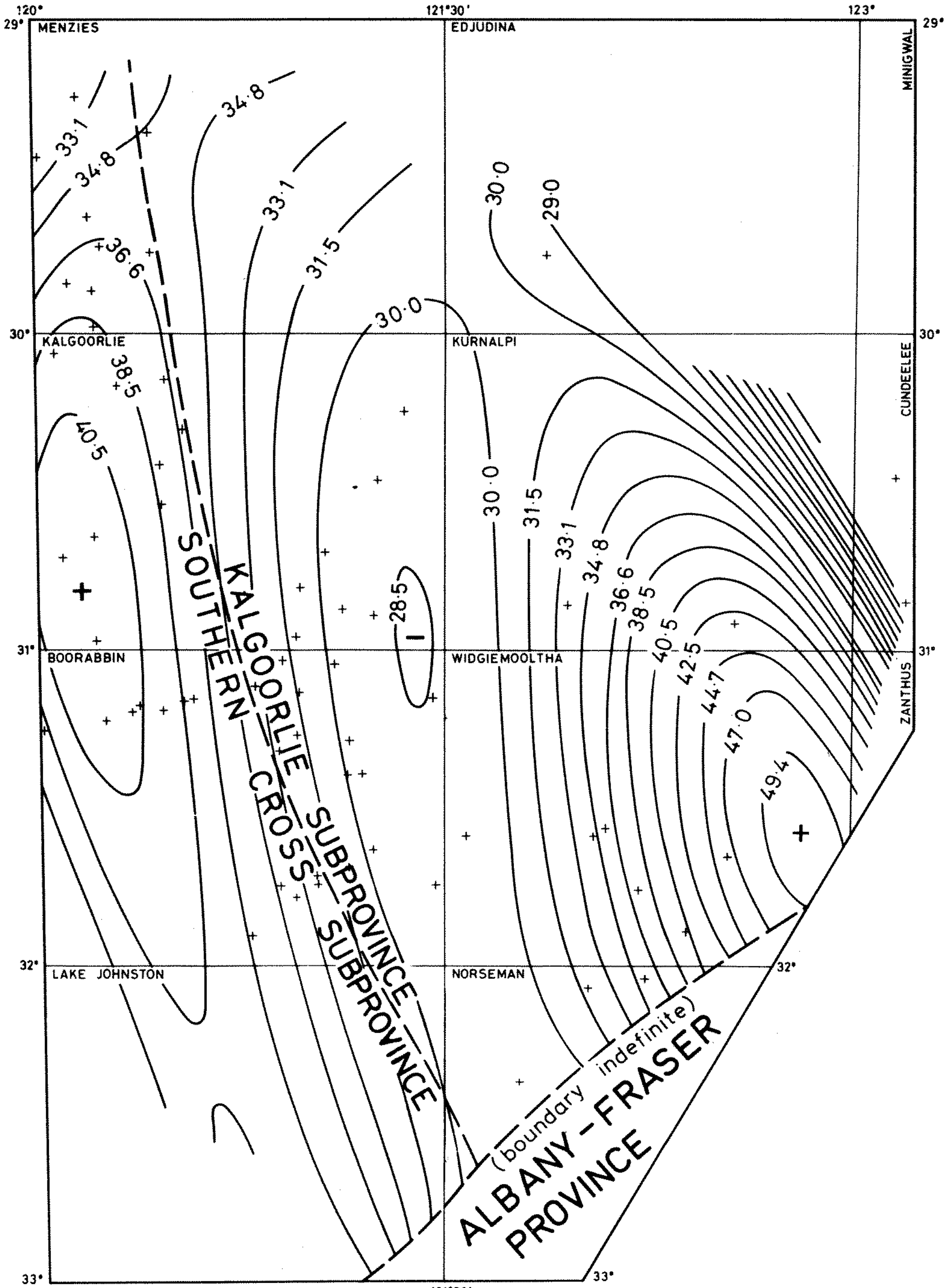

Figure 10. Trend-surface map on potassium feldspar. (GSWA 17325)

zone lies very close to the line drawn by Williams (1974) separating the Southern Cross and Kalgoorlie Subprovinces of the Eastern Goldfields Province.

Because the patterns of percentage potassium feldspar were obscure in the raw data, statistical tests were applied to the data to examine the significance of the differences from zone to zone. According to a test of the significance of the difference in means (t-test), the mean potassium feldspar content of rocks from the western zone differed from that of the central zone at the 99.75 per cent level of significance. This is a strong indication that the difference is real and justifies the distinction between the zones.

Early in the study it seemed that the western and central areas differed in scatter of values as well as in amount of potassium feldspar; the central zone seemed more heterogeneous. The statistical 'F' test measures the significance of differences in scatter (variance) between two sets of data. The 'F' test did not support the hypothesis that the variances of the western and central zones differed significantly, although the difference in variances of the western zone and the pooled central and eastern zones is significant at the 95 per cent level. This is to be expected if the central and eastern zones do indeed form separate populations. Means and standard deviations for each area are listed in Table 1.

TABLE 1. A comparison of potassium feldspar concentration in four areas in the Eastern Goldfields Province.

	Western area	Central area	Pooled central, eastern and southern areas
Number of samples, N	27	38	50
Mean K-feldspar, $\bar{x}$	30.56	25.34	26.45
Standard deviation, s	5.44	6.42	7.70
Variance, s^2	29.63	41.28	59.23

The western zone, rich in potassium feldspar, corresponds to the eastern part of the Southern Cross Subprovince of the Eastern Goldfields Province. The eastern zone corresponds to an axis of alkaline and quartz-poor rocks, the Leonora-Cowarna trend, described in an accompanying report (Libby, 1978) on alkaline granitoid rocks. Possibly the central zone, together with the small area of low values for potassium feldspar in the northeastern corner of the trend-surface map, is typical of the Kalgoorlie Subprovince. In this model the eastern zone, rich in potassium feldspar, is anomalous. This suggestion is supported by the anomalous alkaline petrographic character of the rocks of the eastern zone.

The western zone seems to correlate with the region of postkinematic intrusions of Bettenay (Binns and Marston, 1976); the gradient between the two zones corresponds roughly to the region of dynamic metamorphic domains, synkinematic granitoid diapirs and undifferentiated gneisses. The central zone corresponds roughly to Bettenay's static metamorphic domains.

REGIONAL GEOCHEMISTRY OF K_2O AND MgO

Chemical data on granitoid rocks from the Eastern Goldfields Province have been listed by Joplin, 1963; O'Beirne, 1968; Gower and Bunting, 1976; Thom and others, 1977; and Joplin, 1975. These analyses are scattered and most are accompanied by little discussion. However, Davy (1976, 1977) has considered at length the implications of 252 analyses generated from granitoid rock of the Leonora and Laverton sheets and the Archaean portion of the Rason sheet. The granitoids were analysed for trace elements, and Fe_2O_3, MgO, CaO, K_2O, Na_2O, TiO_2, and, except on the Rason sheet, SiO_2.

The area of the two and one-half sheets was divided by Davy into 6 zones separated by major tectonic lineaments. Average K_2O and MgO values progress sequentially from zone to zone. Lack of convincing evidence of similar trends within zones suggests that each inter-lineament zone is characterized by a particular 'granite' composition.

The detailed modal study of the present work is consistent with Davy's data. Both studies suggest that north-northwestward trending compositional zones are parallel to the north-northwest trending major tectonic discontinuities and belts of grossly similar lithology. Both studies are consistent with the proposal that abrupt changes in composition coincide with major tectonic lineaments.

Some care should be exercised in the comparison of the two studies as the general lithological character of the central and eastern belts changes from greenstone terrain in the area of the present study to granitic in the area studied by Davy.

DISTRIBUTION OF MINOR MINERALS

Whereas the distribution of major minerals establishes the general tectonic framework of the area, subtleties of petrogenesis or areas favourable for exploration for economic minerals may be shown by the distribution of minor minerals either within individual plutons or as characteristics of plutons of certain areas.

FLUORITE

Fluorite is widely distributed through the granitoid rocks and felsites of the Eastern Goldfields Province, but is particularly, generally, and abundantly developed in a few areas.

The largest area of high fluorite concentration is on the southwestern corner of the Menzies sheet, mainly west of the track from Mulwarrie to Mulline and south of a line from Mulline to Galah Rocks. All of the samples rich in fluorite are biotite adamellite. Quartz is abundant, and feldspar ratios are variable; either plagioclase or microcline may be dominant.

The plagioclase of the fluorite-bearing adamellite is dominantly sodic oligoclase ranging from An_8 to An_{17}, though epidote is common and the calcium content may originally have been slightly higher. Most samples are myrmekitic, and potassium feldspar is microcline with film perthite. Colourless mica is universally developed as sericitic alteration of plagioclase but is also common as discrete plates inside plagioclase and is less common as interstitial grains. Epidote is a common minor mineral. Persistent accessories include zircon, apatite and opaque minerals. Metamict allanite is present in 4 of the 17 samples studied. Pumpellyite and carbonate minerals are present in several samples as minor secondary minerals.

The texture of the fluorite-bearing rock dominantly is igneous or granitic; however, near the Ida Lineament metamorphic recrystallization has been imposed on the primary textures. Here the fluorite bearing granitoids are close to the 'dynamic metamorphic domains' and gneisses of Bettenay (Binns and Marston, 1976, Fig.7). The fluorite seems to have either survived significant recrystallization or postdated it.

The Boreas Adamellite at the north edge of the Laverton sheet is host to the other major concentration of fluorite. The Boreas Adamellite has been traced north from Mount Boreas in a belt up to 20 km wide for at least 50 km onto the Duketon sheet, and has been reported by Bunting (pers. comm.) from the middle of the Kingston sheet almost 200 km north of Mount Boreas. The five fluorite-bearing samples of the Mount Boreas unit on the Laverton sheet have a remarkably uniform composition, even though their texture varies from medium to very coarse grained. All are quartz-rich biotite adamellites, and microcline is dominant in all but one. The plagioclase composition ranges from An_{12} to An_{15}. All samples are perthitic and myrmekitic. Intergranular colourless mica and discrete, coarse mica grains within plagioclase as well as sericitic alteration of plagioclase are common. All samples have questionable metamict allanite, and all contain zircon, apatite and opaque minerals. Most samples are porphyritic. Microcline phenocrysts in some samples have inclusions of various minerals which are elongated parallel to the adjacent grain boundaries, suggesting incorporation of microlites during growth in an igneous environment. Further work on the geochronology, petrology and structure of the Boreas Adamellite is in progress.

SPHENE

Sphene is widely distributed in granitoids throughout the Eastern Goldfields Province, particularly as primary grains in rocks with plagioclase of intermediate composition, and as secondary grains associated with chlorite where chlorite has resulted from the alteration of biotite.

Primary sphene (Plate I) is particularly abundant in the northeastern part of the Laverton sheet, the southwestern part of the Edjudina sheet, and the northeastern part of the Widgiemooltha sheet. The latter two areas are in the Leonora-Cowarna trend of abundant syenite and support the suggestion that this is a distinctive petrogenetic province.

Coloured sphene is particularly characteristic of the northwestern corner of the Laverton sheet and is scattered through the alkaline rocks of the Leonora-Cowarna trend.

ALLANITE

Small, irregular grains of metamict allanite (Plate IX) are difficult to distinguish from other metamict radioactive silicates. However, it seems clear that allanite is less widely distributed than sphene, but in rocks where it is identified it tends to be prominent.

Probable allanite is abundant in four areas. In the northeastern corner of the Laverton sheet allanite accompanies coarse-grained, orange-coloured sphene in a plutonic association consisting mainly of granite, but with less adamellite. The association is presumably rich in radioactive and rare-earth elements. Again on the Laverton sheet, most thin sections of the Boreas Adamellite at the north edge of the sheet contain questionable allanite, which is associated in this unit with abundant fluorite.

A third area with a small amount of allanite is the Leonora-Cowarna trend of alkaline felsites and granitoid rocks. This axis corresponds not only to the belt of syenitic rock but also to a similarly weak concentration of orange sphene and microcline-rich granitoids.

The fourth area is larger but more diffuse; it includes a large belt along the western edge of the study area; that is, the western third of the Leonora and Menzies sheets, the western half of the Kalgoorlie sheet and much of the Boorabbin sheet. This area includes the granitoids lying west of the Coolgardie-Mount Ida arm of the Kalgoorlie greenstone belt and is largely restricted to the granitoids of the Southern Cross Subprovince of the Yilgarn Block as defined by Williams (1974). The northern part of this area, at least, is characterized by fluorite as well as allanite.

Allanite seems to favour granite (strictly defined) and seems to be associated with fluorite, and with sphene which has unusual colour.

DISTRIBUTION OF TEXTURES

Textural categories were described in the section on textures. When samples with these textures are plotted on a map only vague, ill-defined trends appear, presumably because of both the great spacing of samples and the subjective nature of the data.

Several of these weak patterns may have petrogenetic significance. In Figure 11 the region has been subdivided into several areas. Each area is characterized by a dominant texture. Some of these areas correspond to mapped geological units, others do not.

The most obvious textural trend is the belt of gneissic rock from near Norseman northward along the west side of the Kalgoorlie greenstone belt and along the Ida Lineament to the Lawlers Anticline near Agnew at the north edge of the Leonora sheet (Fig.11, area I). Both deformational textures and varied lithology, including gneiss and greenstone, follow this trend. This belt corresponds to the zones of dynamic metamorphic domains and undifferentiated gneiss, migmatite and synkinematic diapirs of Bettenay (Binns and Marston, 1976, Fig.7).

In the south part of the belt, the gneiss seems to be exposed in a discontinuous series of gneiss domes at the southwestern edge of the broad greenstone belt centred approximately on Kalgoorlie. These correspond to the 'synkinematic granitoid diapirs' of Bettenay (Binns and Marston, 1976).

Northward, the gneiss seems more continuous east of an arm of the greenstone belt from Coolgardie to Mount Ida and east of the Ida Lineament (Kriewaldt, 1970, p.5; Thom and Barnes, 1977, Fig.2; and Binns and Marston, 1976, Fig.7). However, even in this area there may be domal elements; an example of this is the pattern on the Menzies sheet (Kriewaldt, 1970) about 20 km east of the physiographic Mount Ida. Gneissic samples 17623 and 17626 (Menzies) are from this ovoid area of "granite" and "gneissic granite".

Looking again at the gneiss domes in the south, sample 41478 (Widgiemooltha) is from Fifty Mile Rock on Pioneer Dome and sample 41475 (Boorabbin) is from Depot Rocks on Spargoville Dome. Northward along the Coolgardie-Mount Ida arm of the greenstone belt, samples 17650, 17651 and 17652 (Menzies) are west of the Coolgardie-Mount Ida arm, sample 17625 (Menzies) seems to be from within the greenstone and samples 17623 and 17626 (Menzies) were mentioned above from a possible dome on the east side of the greenstone.

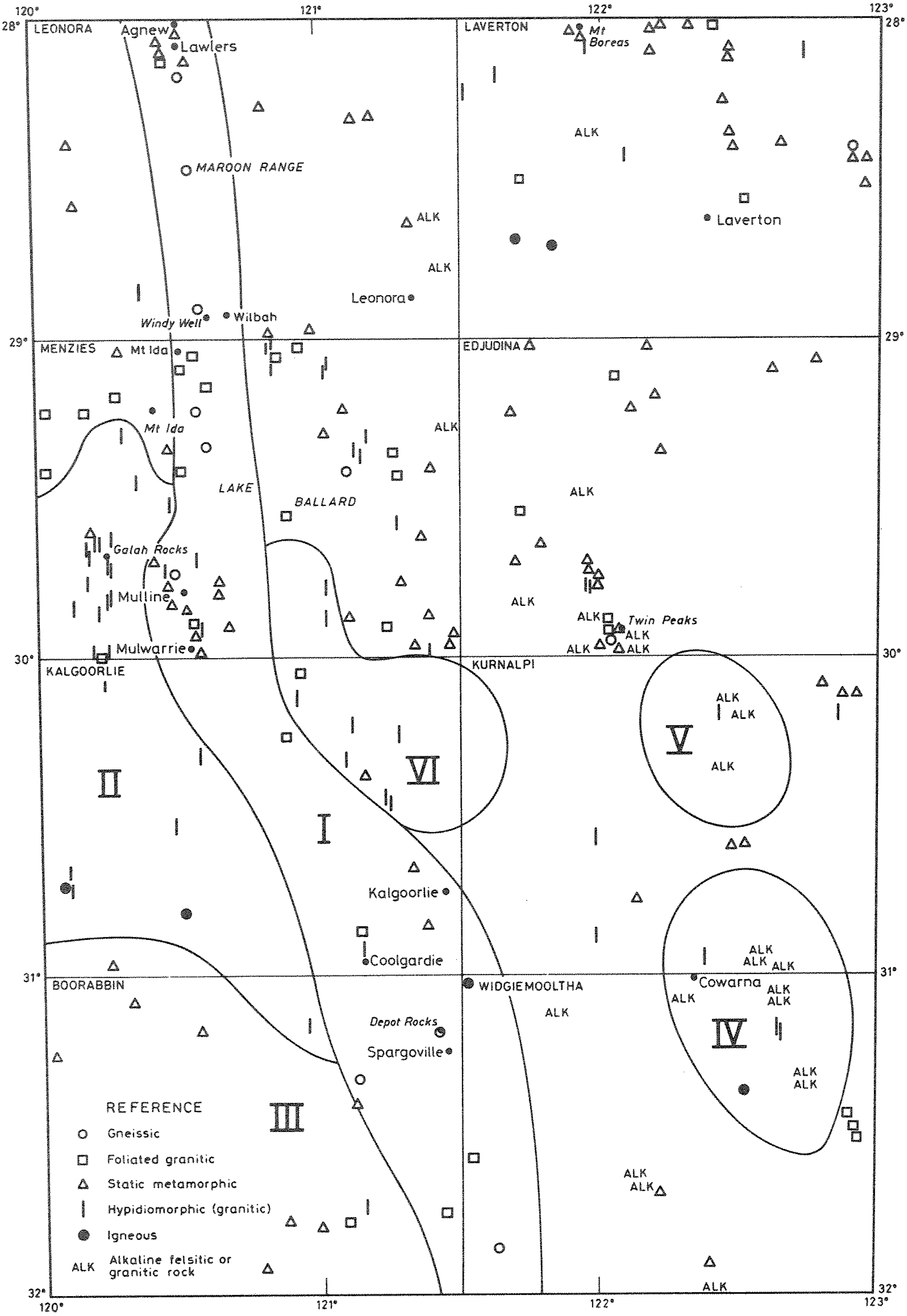

Figure 11. Textural trends.
I. Gneissic trend
II. Igneous and hypidiomorphic textures west of the gneissic trend
III. Statically metamorphosed granitic rocks of the Boorabbin map sheet.
IV, V, & VI. Ill-defined areas of hypidiomorphic granular and igneous textures. (GSWA 17326)

Northward on the Leonora sheet, garnet-bearing sample 40575 is from the broad gneissic area in the vicinity of Windy Well. Samples 39805 and 39806 (Leonora) from the Maroon Range are a kyanite-bearing schistose phase of the gneissic sequence east of the Ida Lineament. The northernmost gneiss found in this area is sample 32708 (Leonora) in the core of the Lawlers Anticline (see Davy, 1978 for chemical analysis).

The quartz-rich, garnet-bearing gneiss of Windy Well and the kyanite-bearing rocks at the Maroon Range suggest that some of the gneiss may be metasedimentary.

Gneisses outside the Norseman-Agnew gneiss belt seem isolated because of the great spacing of samples.

West of the Coolgardie-Mount Ida greenstone arm in the south part of the Menzies and north part of the Kalgoorlie sheets, granitic textures predominate, suggesting igneous granitoids with little metamorphic recrystallization (Fig.11, area II). This is the region rich in fluorite and may be a single batholithic mass or a suite of small related granitic plutons.

South of area II, still west of the gneiss and greenstone belt, static metamorphic textures predominate (Fig.11, area III) through much of the western two-thirds of the Boorabbin sheet. Isotropic crystalloblastic textures interspersed with granitic and weakly gneissic textures continue southward into the Lake Johnston sheet which was not studied in detail.

Areas IV, V and VI in Figure 11 are characterized by granitic to igneous textures but are ill defined. Areas IV and V lie on the southern part of the Leonora-Cowarna trend and may reflect the little-recrystallized igneous origin of that zone. But this igneous trend is interrupted by granofelsic to gneissic metamorphic rocks in the complex near Twin Peaks on the Edjudina sheet.

Thus, textural mapping has outlined one metamorphic trend of regional significance, and has suggested regional tendencies in a few other areas, but sample spacing seems too great at this scale to show trends in the rest of the area.

CONCLUSIONS

The granitic rocks of the Eastern Goldfields Province are clearly not a single homogeneous mass, but are variable both in composition and texture. Compositional trends tend to follow tectonic trends represented by the greenstone belts and tectonic lineaments. Tectonic subprovinces seem to be characterized by recognizably different bulk mineralogical composition.

The degree of deformation and recrystallization is as variable as the composition. Mild to severe penetrative deformation and recrystallization has affected most rocks of the area. Wide distribution of prehnite, pumpellyite, carbonate, and epidote suggests widespread metamorphism of granitoid rocks at low grades; local garnet gneisses indicate more restricted belts of intense metamorphism. The possibility of regional metamorphic mapping on the basis of secondary mineral assemblages deserves further study.

Considering the amount of compositional and structural information contained in the granitic rocks, an understanding of the history of the granitic units would seem to be critical to an understanding of the tectonics of the Eastern Goldfields Province.

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APPENDIX

LOCATION OF SAMPLES

Samples are located according to 1:250 000 sheets and the Australian Transverse Mercator Grid, in yards. The first digit of each coordinate indicates hundreds of thousands of yards. Four-digit coordinates have a precision of 100 yards, three-digit coordinates, 1000 yards. Accuracy is somewhat less. Letter suffixes have been omitted.

BOORABBIN		LEONORA		MENZIES (cont.)	
41409	298-/132-	32708	3474/5054	17660	Not available
41475	445-/144-	38327	4172/4808	17662	3200/3206
		39805	3500/4700	17681	4170/3681
EDJUDINA		39806	3500/4700	17686	4005/3095
15507	4727/3773	39812	4480/4150	17693	4248/2963
24808	5029/3159	40575	357-/415-	20979	4088/3246
24831	4764/3049	41480	341-/515-		
24832	5021/3190			WIDGIEMOOLTHA	
40807	423-/079-	MENZIES		41478	466-/058-
		17606	2970/3559		
KALGOORLIE		17609	3325/3505		
9121	413-/261-	17614	3214/3075		
9155	392-/257-	17616	3065/3048		
		17617	3468/3938		
KURNALPI		17620	3825/4030		
2364	519-/191-	17623	3530/3780		
6852	556-/213-	17625	3570/3644		
11099	571-/167-	17626	3573/3873		
		17641	Not available		
LAVERTON					
29964	4552/4993	17650	3452/3175		
31131	587-/475-	17651	3452/3175		
31142	610-/464-	17652	3454/3170		
38143	522-/524-	17655	3365/3217		
39003	4766/4434	17656	3318/3262		

P L A T E S

PART II

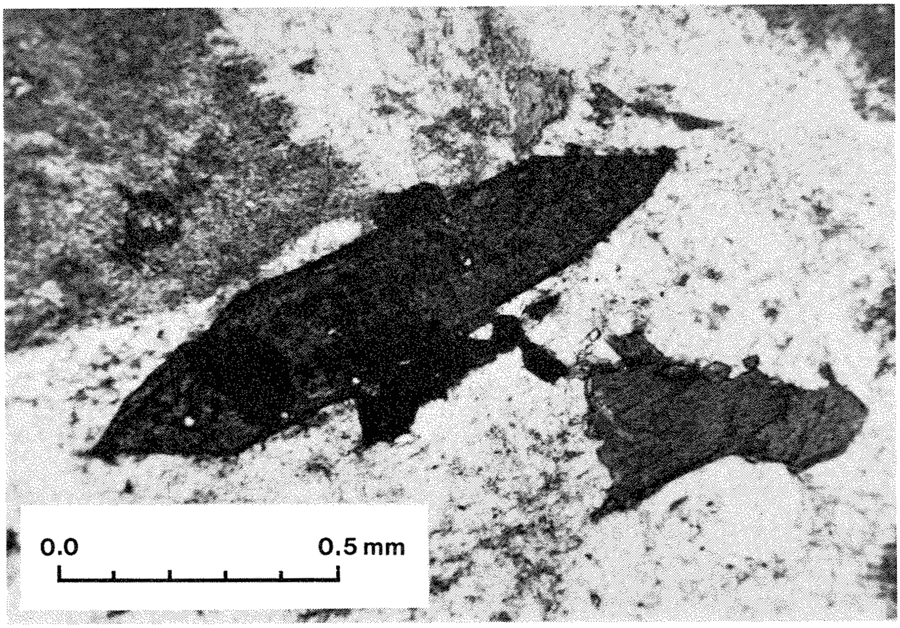

Plate I. Sphene, euhedral.

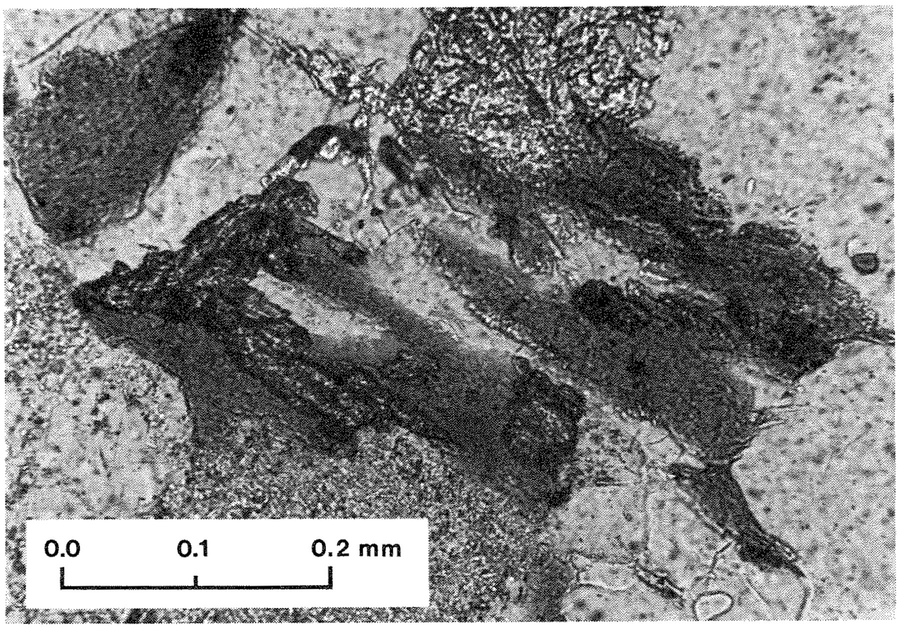

Plate II. Secondary sphene in chlorite.

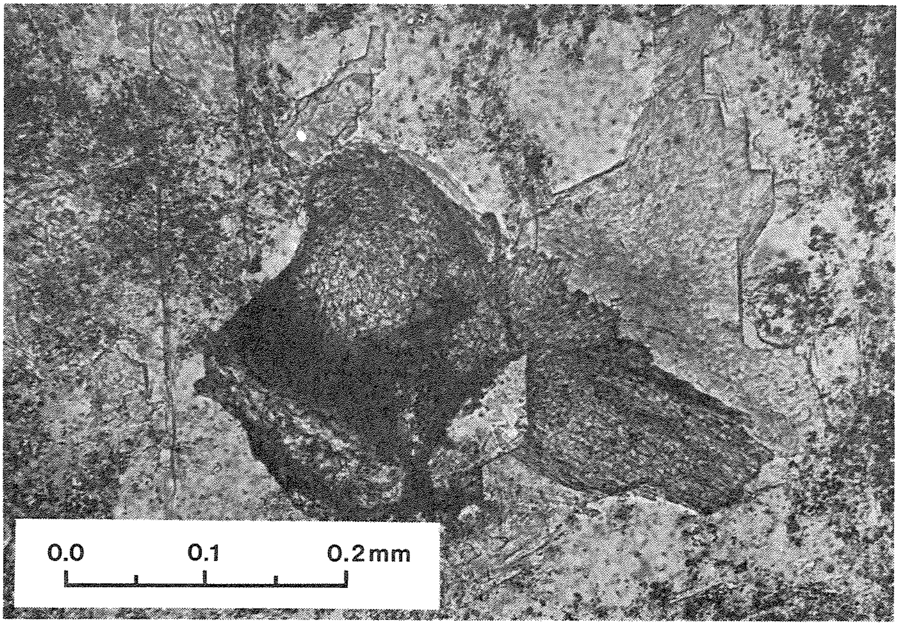

Plate III. Pumpellyite.

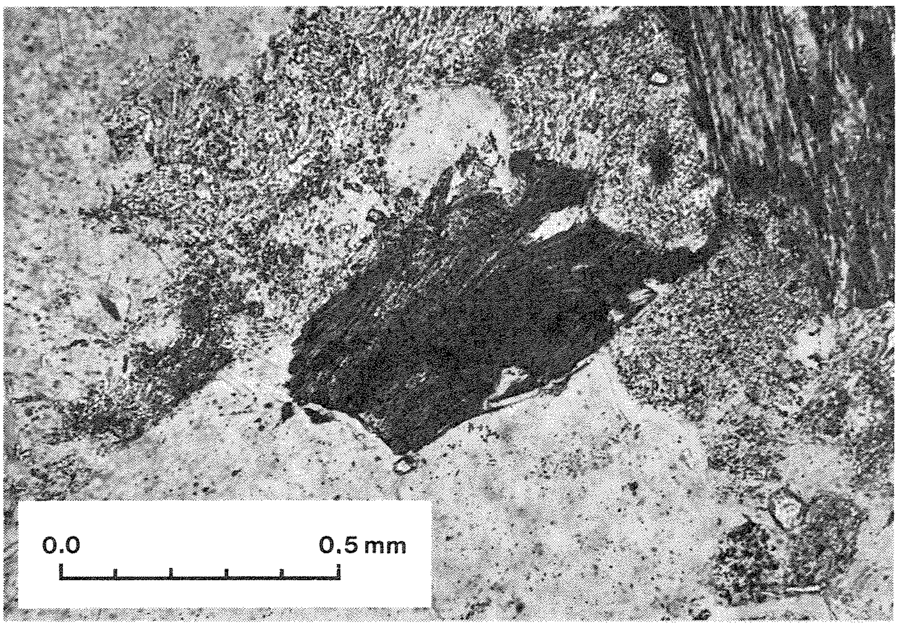

Plate IV. Pumpellyite.

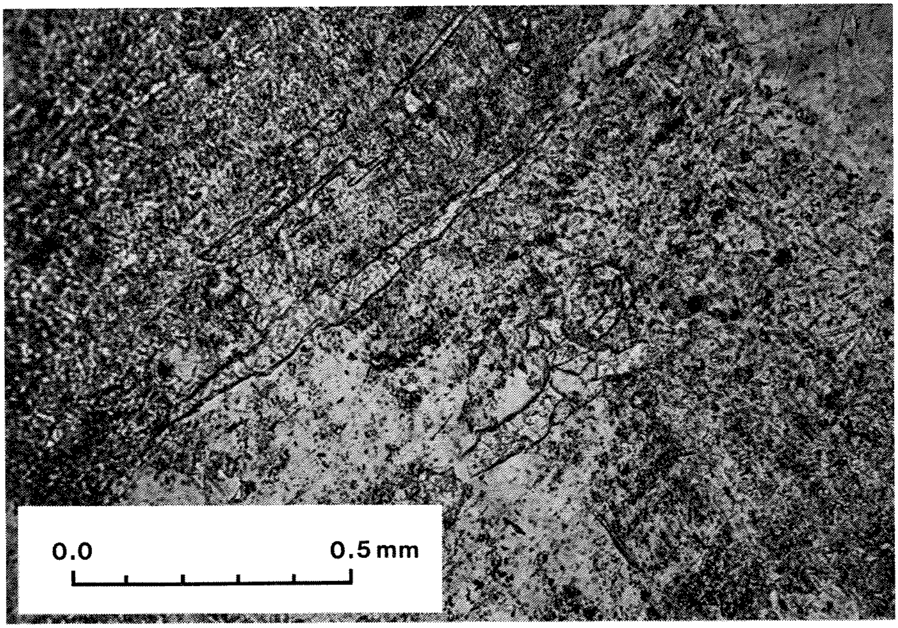

Plate V. Fluorite, veins along plagioclase cleavage.

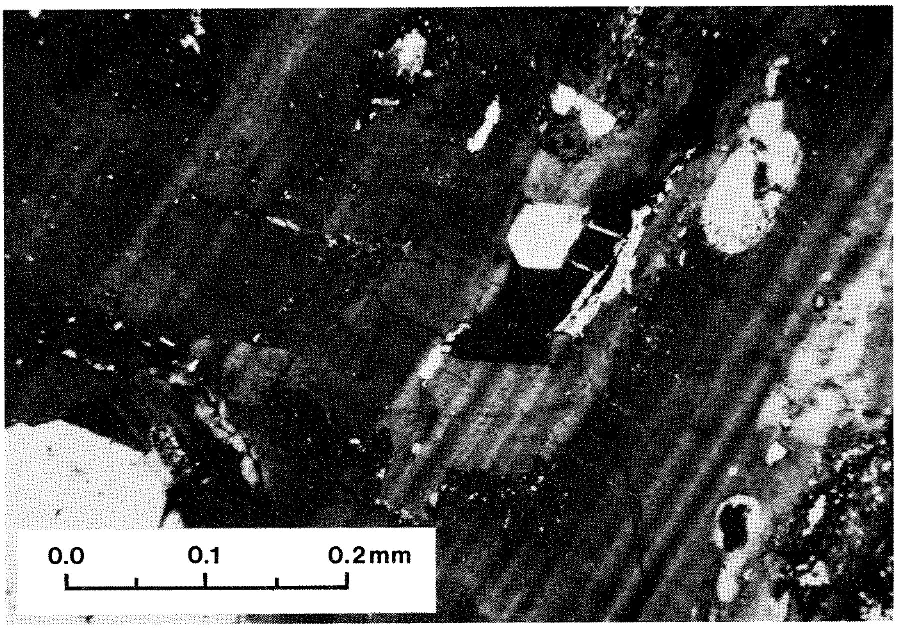

Plate VI. Fluorite in plagioclase.

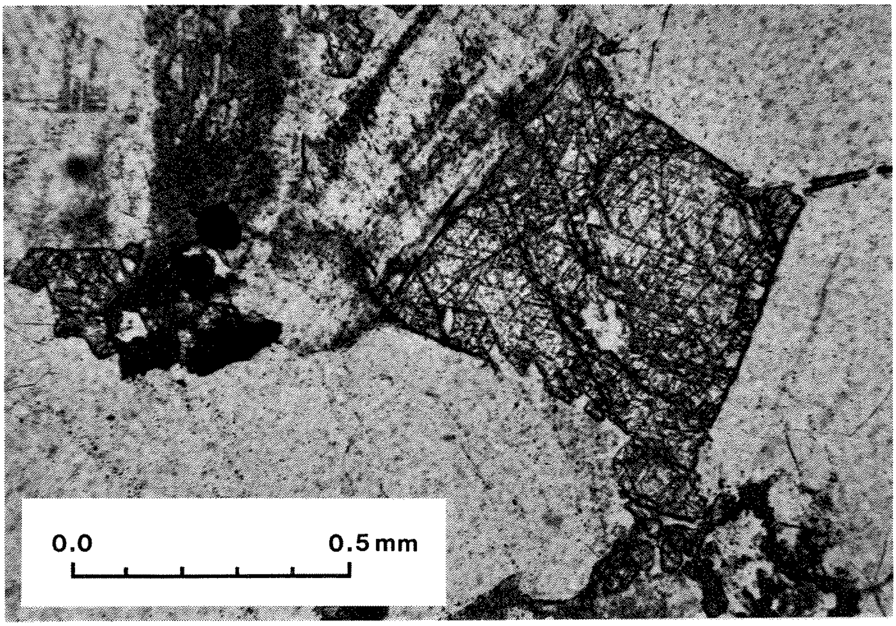

Plate VII. Fluorite, interstitial.

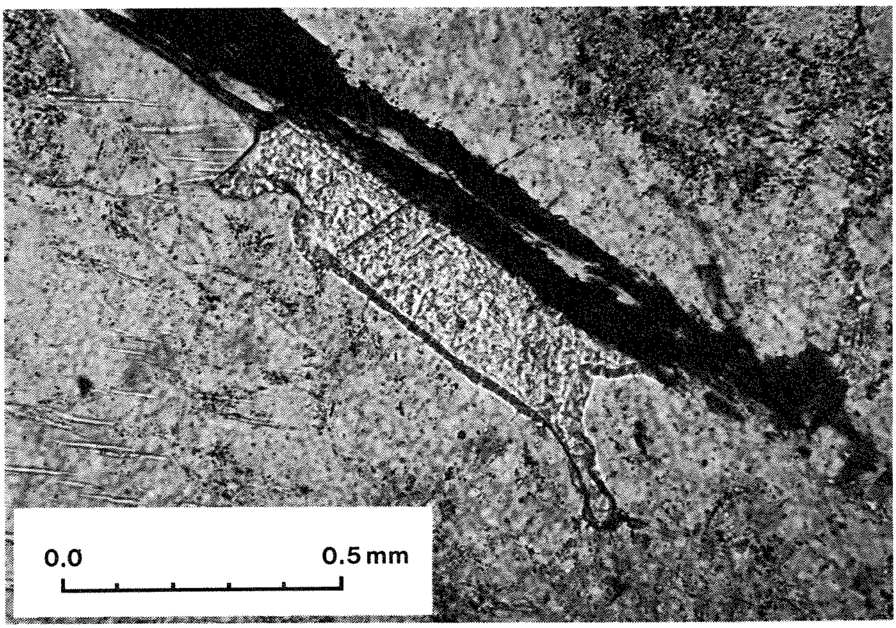

Plate VIII. Fluorite with biotite.

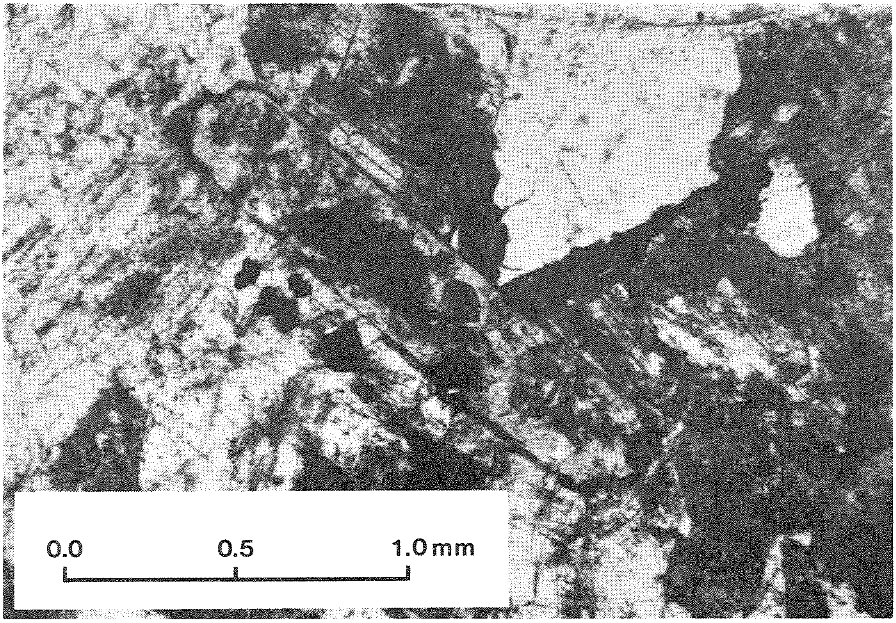

Plate IX. Allanite, metamict.

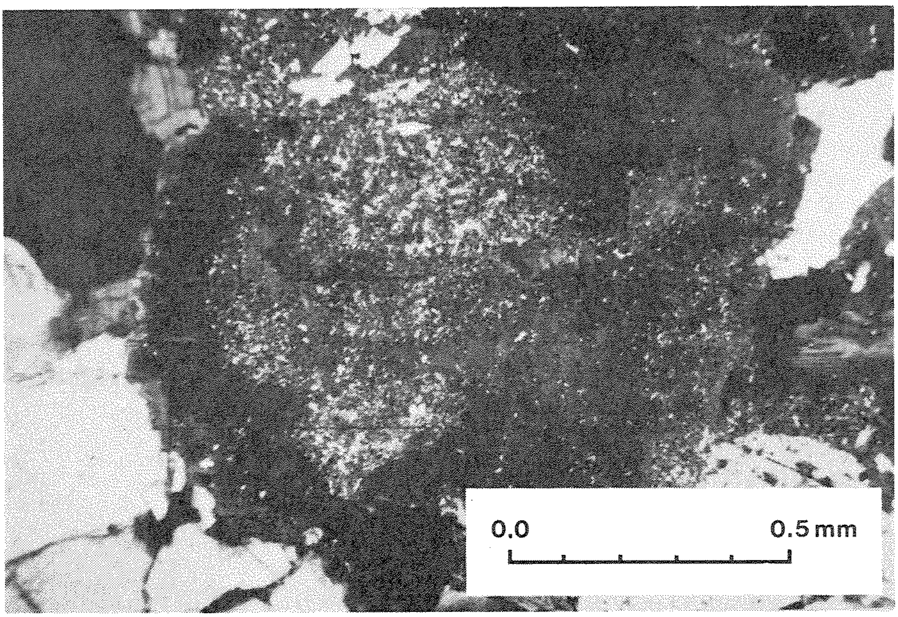

Plate X. Alteration of plagioclase core with reversal of relative core-rim composition.

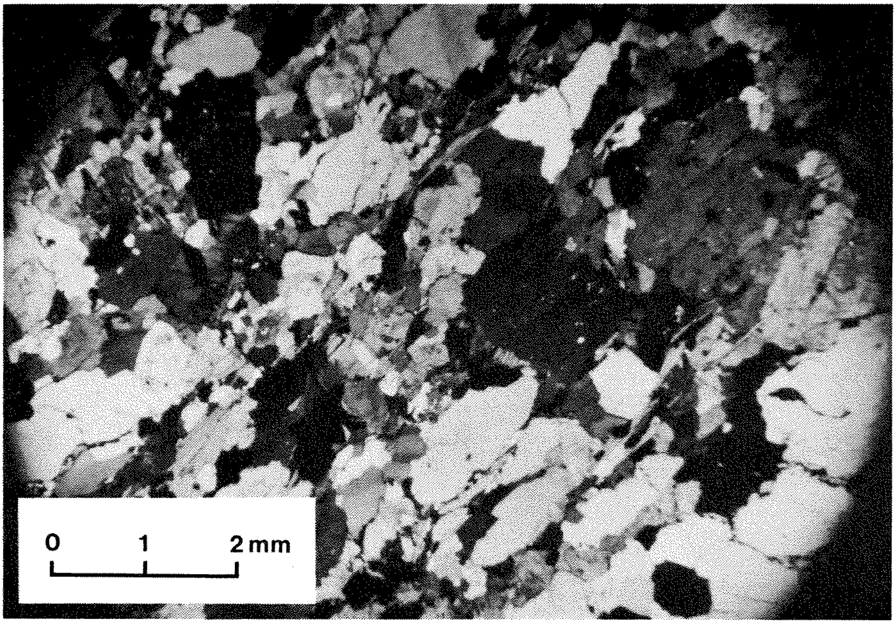

Plate XI. Gneissic texture.

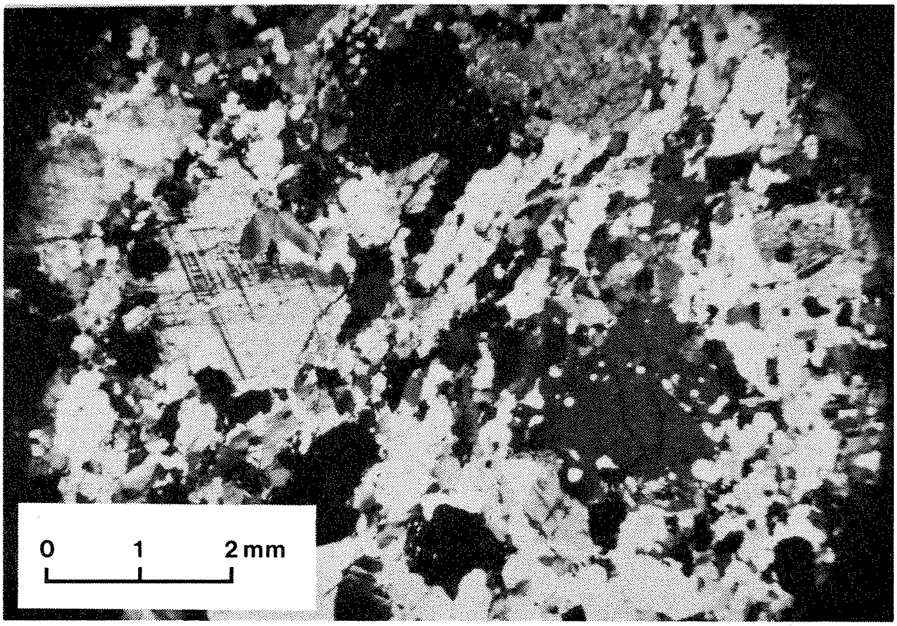

Plate XII. Foliated granitic texture.

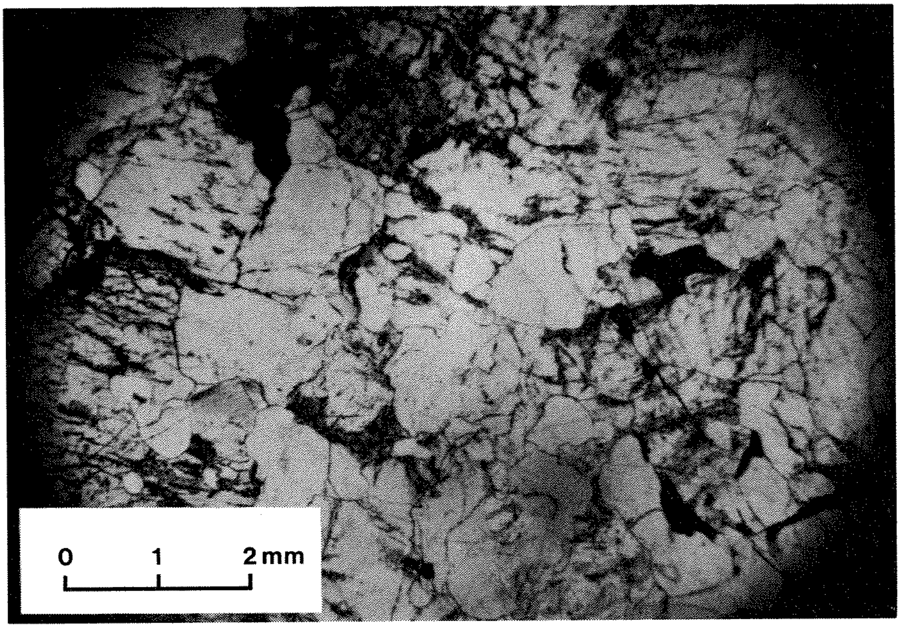

Plate XIII. Static metamorphic texture, plain light.

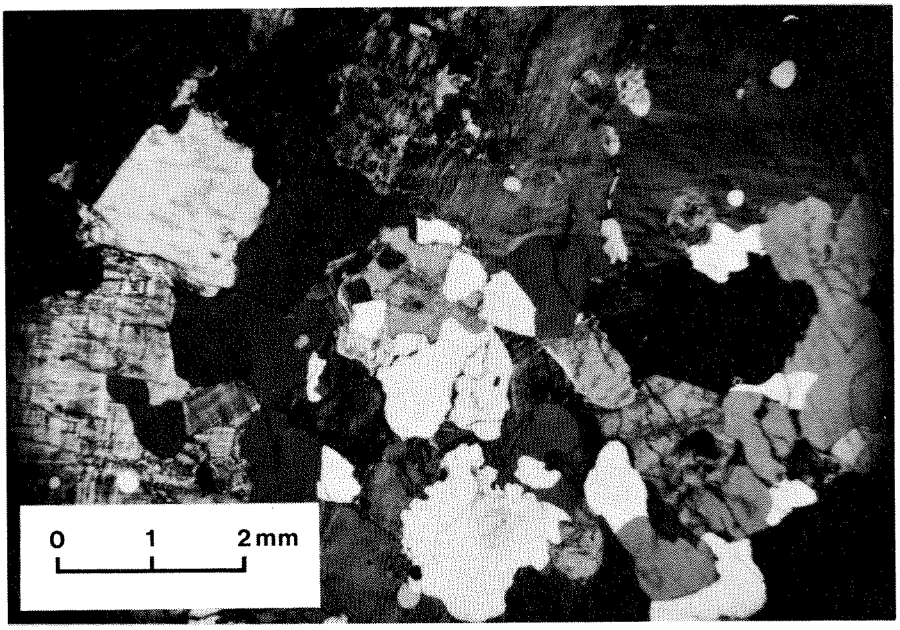

Plate XIV. Static metamorphic texture, crossed polarizers.

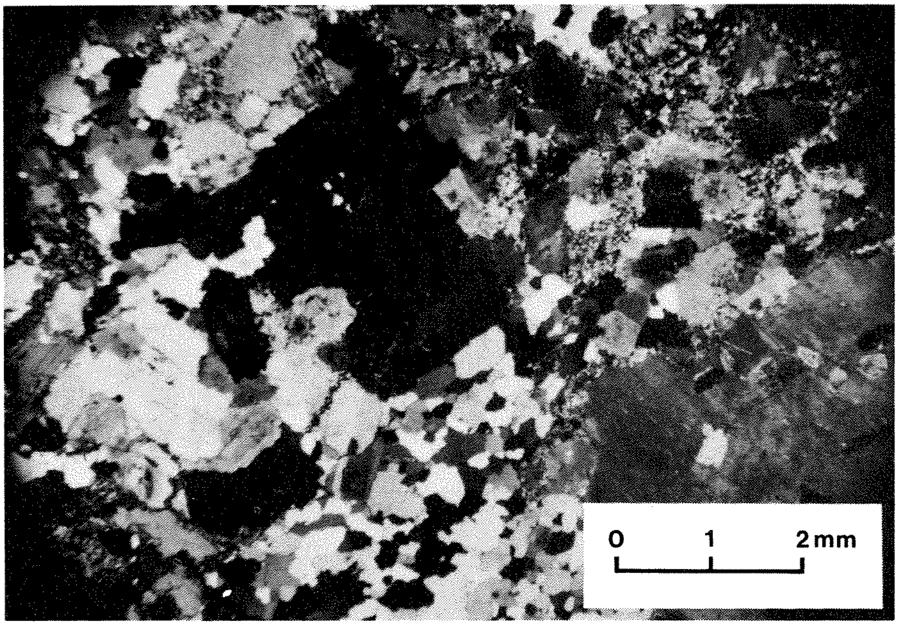

Plate XV. Cataclastic granitic texture.

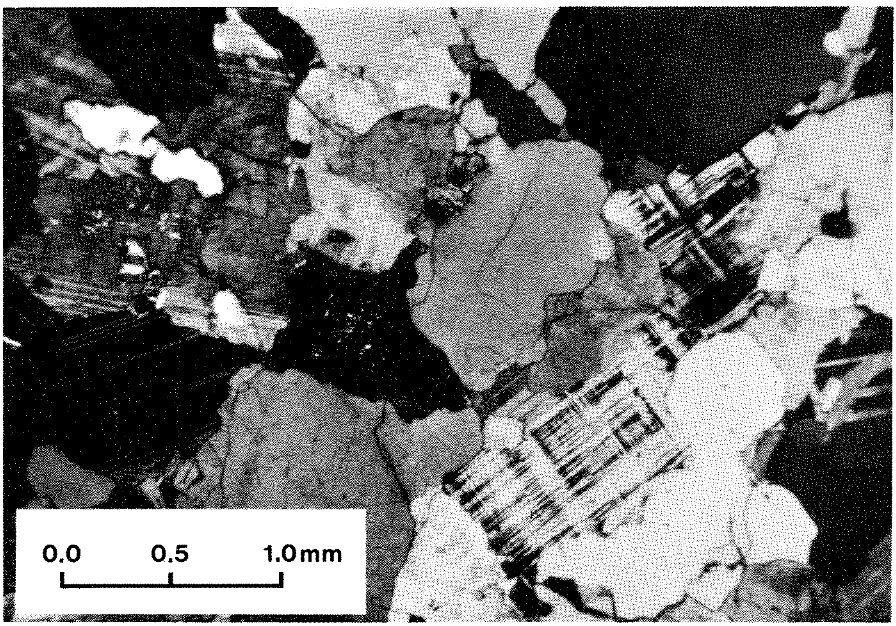

Plate XVI. Transition texture between static metamorphic and hypidiomorphic-granular texture.

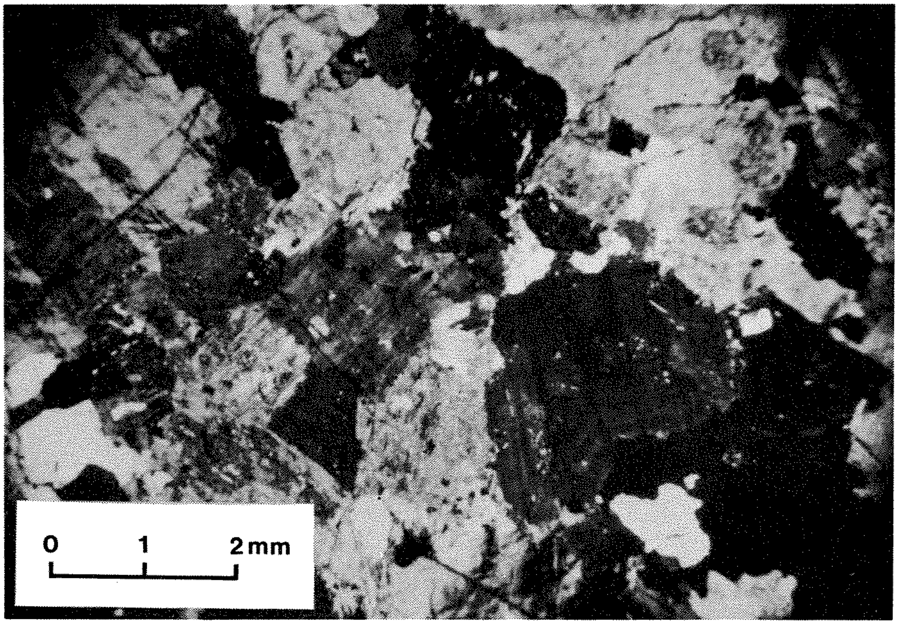

Plate XVII. Hypidiomorphic-granular texture.

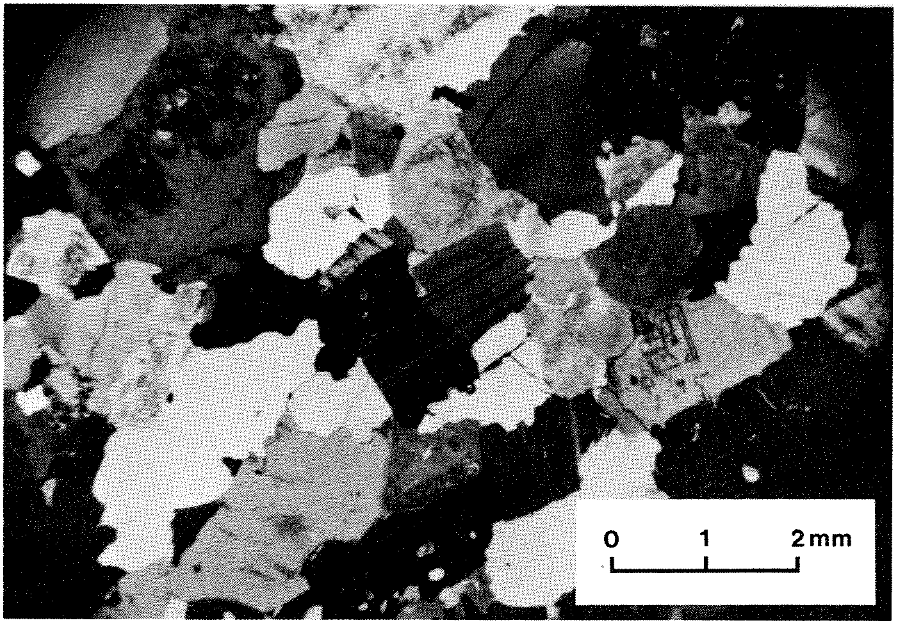

Plate XVIII. Hypidiomorphic-granular texture, exceptional development.

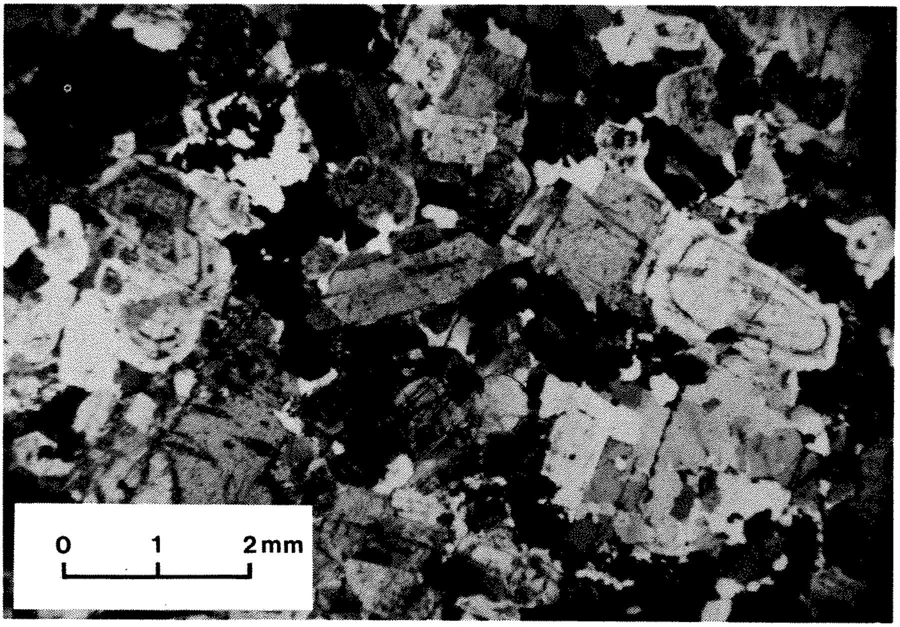

Plate XIX. Igneous texture.

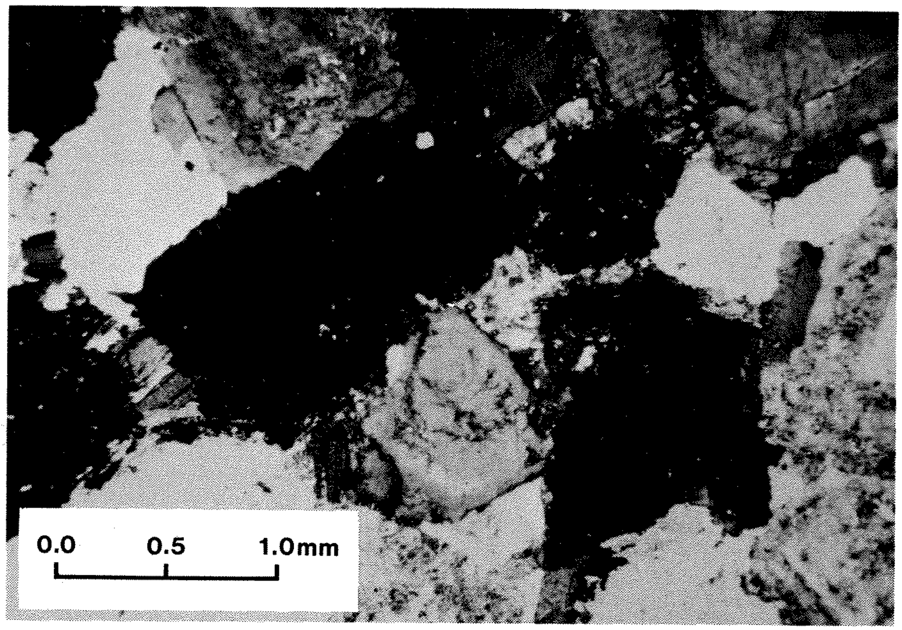

Plate XX, Igneous texture.

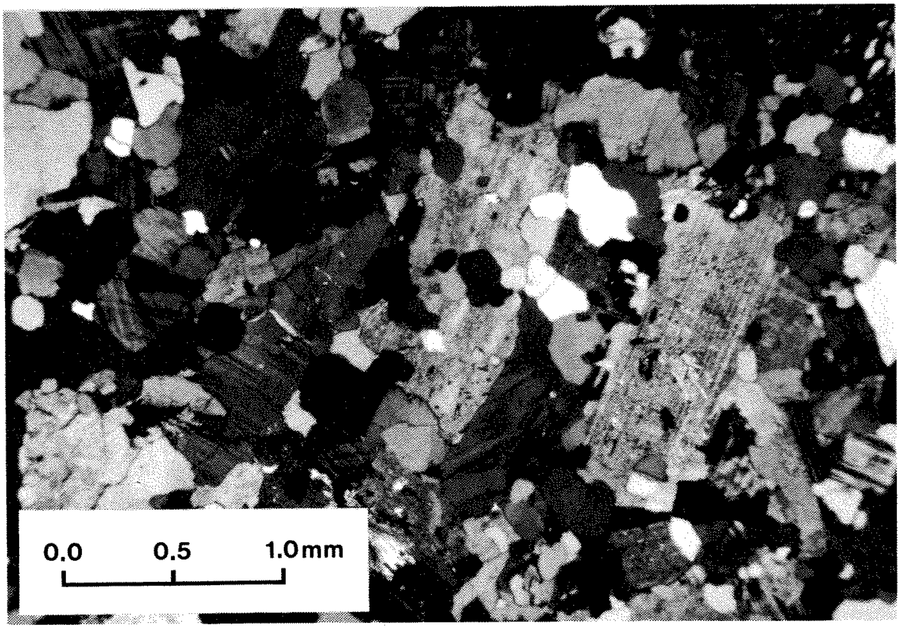

Plate XXI. Blebby quartz, suggesting recrystallization.

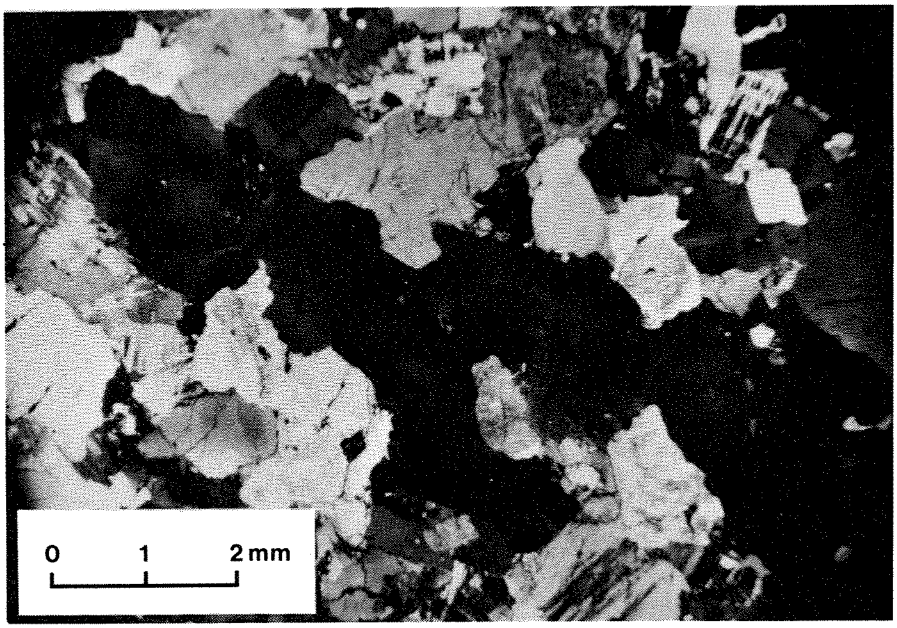

Plate XXII. "Sea" of coarse, sinuous quartz.

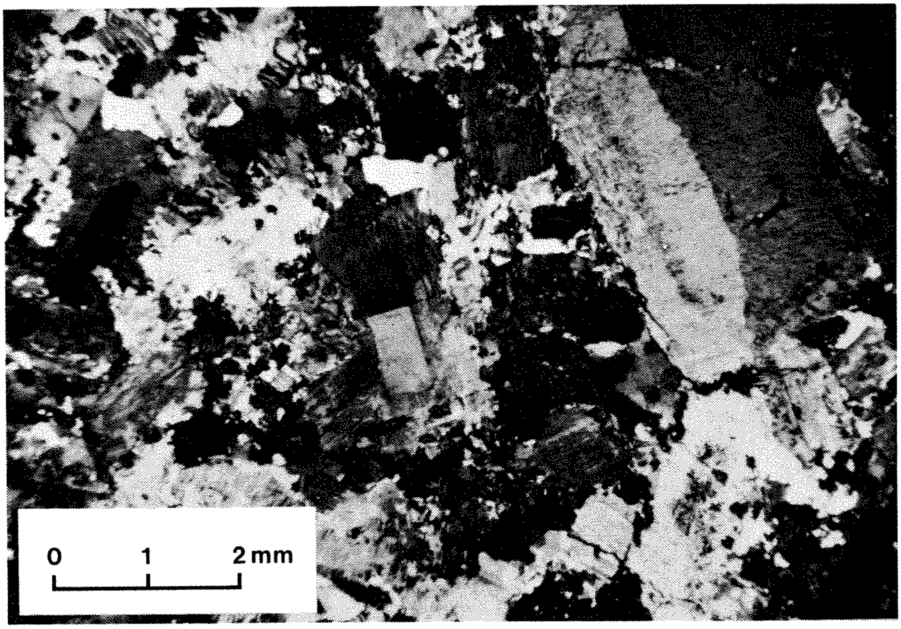

Plate XXIII. Seriate texture, possibly secondary.

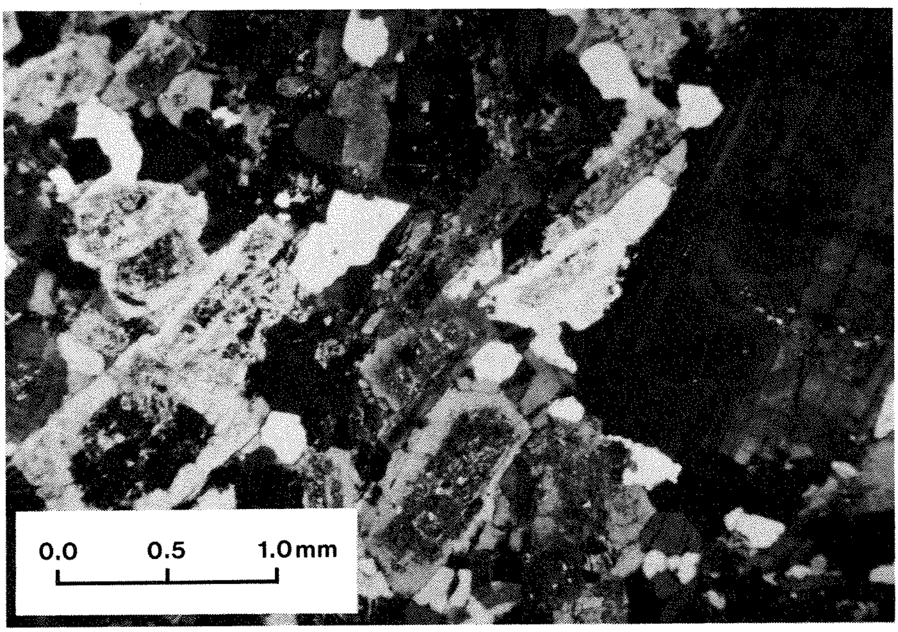

Plate XXIV. Seriate texture, probably primary.

P A R T   I I I

THE FELSIC ALKALINE ROCKS

THE FELSIC ALKALINE ROCKS

by

W.G. Libby

ABSTRACT

Mildly alkaline rocks are sparsely scattered in a broad, arcuate zone from Peak Charles (about 100 km southeast of Norseman) in the south, through the Widgiemooltha, Kurnalpi, Edjudina, Laverton, and Sir Samuel 1:250 000 sheets to Lake Teague in the north, about 100 km northeast of Wiluna.

The alkaline rocks are characterized by alkali pyriboles (aegirine, aegirine-augite and alkali amphibole), mesoperthitic alkali feldspar and low quartz content ranging from zero to twenty per cent.

Genetic relations are not clear, but divergent chemical trends suggest that the alkaline rocks are not related to the regionally dominant subalkaline granitoids in a simple manner.

INTRODUCTION

Felsites and granitoid rocks of alkaline affinity are sparsely distributed over much of the central and eastern part of the Eastern Goldfields Province of Western Australia. Although these rocks are variable in texture and mineral assemblage, certain characteristics persist from area to area, suggesting that these widely dispersed assemblages may have a similar origin. Thus they are grouped under the collective term, "the alkaline suite".

Rocks of the alkaline suite in the Eastern Goldfields Province have one of three characteristics: alkaline pyroxene or amphibole, a low proportion of quartz for a felsic rock, or mesoperthitic alkaline feldspar.

Rocks of the alkaline suite constitute a small but widely distributed fraction of samples collected by geologists of the Geological Survey of Western Australia during 1:250 000 scale geological mapping of the Eastern Goldfields Province between 1960 and 1974. Thin sections were prepared from many samples. Results of the study of the thin sections have been used in mapping but have not been reported systematically prior to this paper.

The rocks of the alkaline suite are reported separately from felsic rocks of more normal composition (Libby, 1978a and 1978b) because they seem to form a chemically and petrographically coherent suite distinct from the subalkaline rocks of the area; because they range from fine to coarse texture, hence cannot be easily discussed in either category; and because they may have substantial economic and petrological significance apart from the more abundant subalkaline rocks.

The alkaline rocks of the Eastern Goldfields Province have received little previous attention. Jutson (1915) and Honman and others (1917) briefly described a syenitic body about 9.5 km east of Yerilla homestead, and Berliat (1956) mentioned quartz-poor syenitic rocks near Lake Carey, east of Linden. Trendall (1964) recognized Na-rich pyroxenes and amphiboles in granitic rocks of the Widgiemooltha 1:250 000 sheet. Various small quartz syenite and syenite bodies on the Edjudina sheet were mentioned by Williams and others (1971, p.17). The only report directed specifically at rocks of the alkaline suite is the comprehensive study of the syenitic rocks of the Fitzgerald Peaks in an accompanying paper (Lewis and Gower, 1978).

The alkaline suite in the Eastern Goldfields Province lies between longitudes 121°E and 123°E and extends from the south margin of the Yilgarn Block at about latitude 33°S to the northern margin at about latitude 26°S. Bunting and Williams (1976) and Bunting (personal communication) have reported alkaline rocks north of latitude 28°S.

Most alkaline samples are from a north-trending zone about 70 km wide, constituting the main belt of Figure 1. Localities in the eastern part of

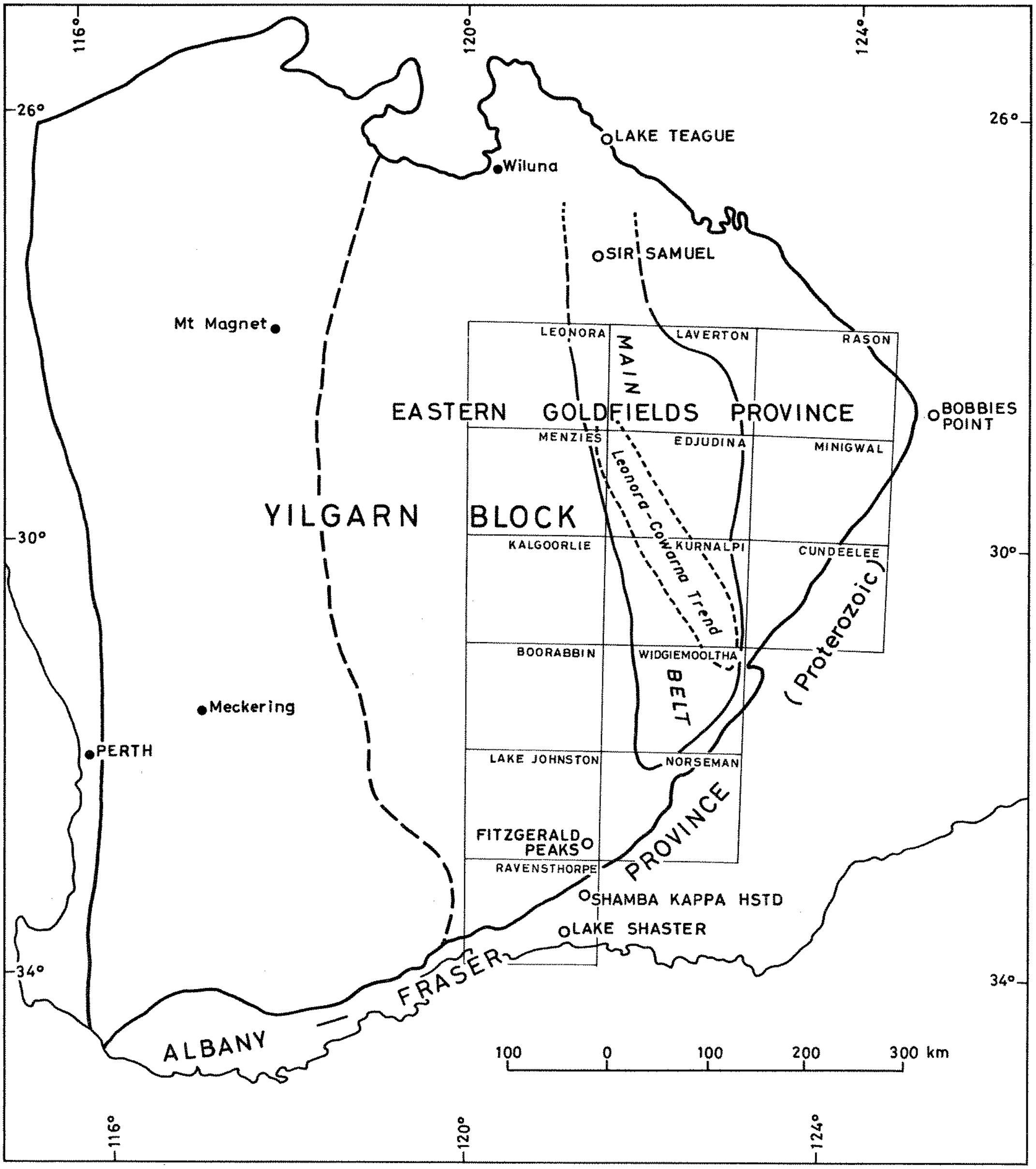

Figure 1. Major localities and trends of alkaline and related rocks in the Eastern Goldfields Province (GSWA 17327)

the Laverton and Edjudina sheets may represent a bifurcation of the main belt or a widening to about 100 km.

The large area of alkaline granite (about 120 km^2) at Fitzgerald Peaks in the southeastern part of the Lake Johnston sheet, lies outside the main belt but within the Yilgarn Block. Outside the Yilgarn Block, in the Proterozoic Albany-Fraser Province, rocks at Lake Shaster, Shamba Kappa homestead and Bobbies Point (Fig.1) have alkaline affinity. If the Fitzgerald Peaks, Shamba Kappa homestead and Lake Shaster localities were included with the main trend it would be arcuate concave to the west.

Most of the samples of alkaline rock available for study came from an area within the main belt about a line between Leonora in the north and Cowarna in the south, the Cowarna-Leonora trend of Figure 1.

DESCRIPTION

GENERAL CHARACTERISTICS

Rocks assigned to the alkaline suite in the Eastern Goldfields Province have one or more of the following properties: quartz ranges from zero to 20 per cent; mafic minerals are alkaline pryoxene and/or alkaline amphibole; and feldspar is alkaline and mesoperthitic. The association of these three characteristics is sufficiently general to encourage the belief that where only one characteristic is developed in the felsic granitoids and porphyries the rock is genetically related to others in the alkaline suite. Other, less persistent mineralogical characteristics are an abundance of coarse-grained apatite and abundant development of an orange-coloured sphene.

Quartz usually constitutes between 5 and 20 per cent of the rock, giving a quartz syenite or, more rarely, quartz monzonite composition. A few members of the suite have more than 20 per cent quartz and thus are alkali granite.

The mineral assemblage and textures alone are consistent with assignment to the peralkaline rocks in the nomenclature of Shand (1949, p.229) and the ekeritic suite as described by Barth (1944, p.88-91; 1962, p.198); however, in the few samples which have been chemically analyzed the alkali:alumina ratio is marginally low for proper classification in either of these groups. Still, on the basis of low abundance of quartz and development of alkaline mafic minerals, the suite is mildly alkaline.

The few analyses of alkaline rocks from Fitzgerald Peaks (Lewis and Gower, 1978) and the Sir Samuel sheet (Bunting and Williams, 1976) show that despite the development of alkaline pyroxene and amphibole, the agpaitic ratio (molecular $\frac{Na_2O + K_2O}{Al_2O_3}$) is less than unity. This is in common with many generally accepted alkaline rocks, including 11 of the 32 peralkaline granites listed by Murthy and Venkataraman (1964). Yet the agpaitic ratio is higher (Fig.3) than in associated subalkaline rocks. The alkalinity, measured by agpaitic index or total alkalies, along with relatively low silica, measured by analyzed silica or low values for modal quartz, gives the suite much of its distinctive character.

The unique character of the alkaline suite among felsic rocks of the area is suggested by petrography, but the limited chemical data (Figs 2 and 3) provide even better evidence that the alkaline suite does not form a compositional continuum with the subalkaline rocks. In particular, the plot of agpaitic index versus solidification index (Fig.3) suggests both a divergence of trend and a compositional gap between the alkaline and subalkaline granitoids. The geographic spread of sample localities suggests that the two trends represent two sets of physical conditions or modes of origin of diverse materials rather than two simple crystallization series from two discrete magmas.

The plot of alkalies versus silica in Figure 2 distinguishes the alkaline and subalkaline rocks less powerfully than the plot of agpaitic index versus solidification index in Figure 3. However, in the data from Davy (1976a and 1976b) it is possible that samples 33864, 33815, 33818 and 33835 are in fact also alkaline, as data on silica and alumina, and petrographic data are not available.

The alkaline suite includes both granitic and porphyritic felsitic rocks. With increasing proportion of phenocrysts the felsites grade texturally into granitic rocks. The porphyritic felsites seem clearly igneous and there is little reason to doubt the igneous origin of most of the alkaline granitoids; however, some of the alkaline granitoids, notably certain of the Peak Charles samples and rocks near Twin Peaks, Edjudina

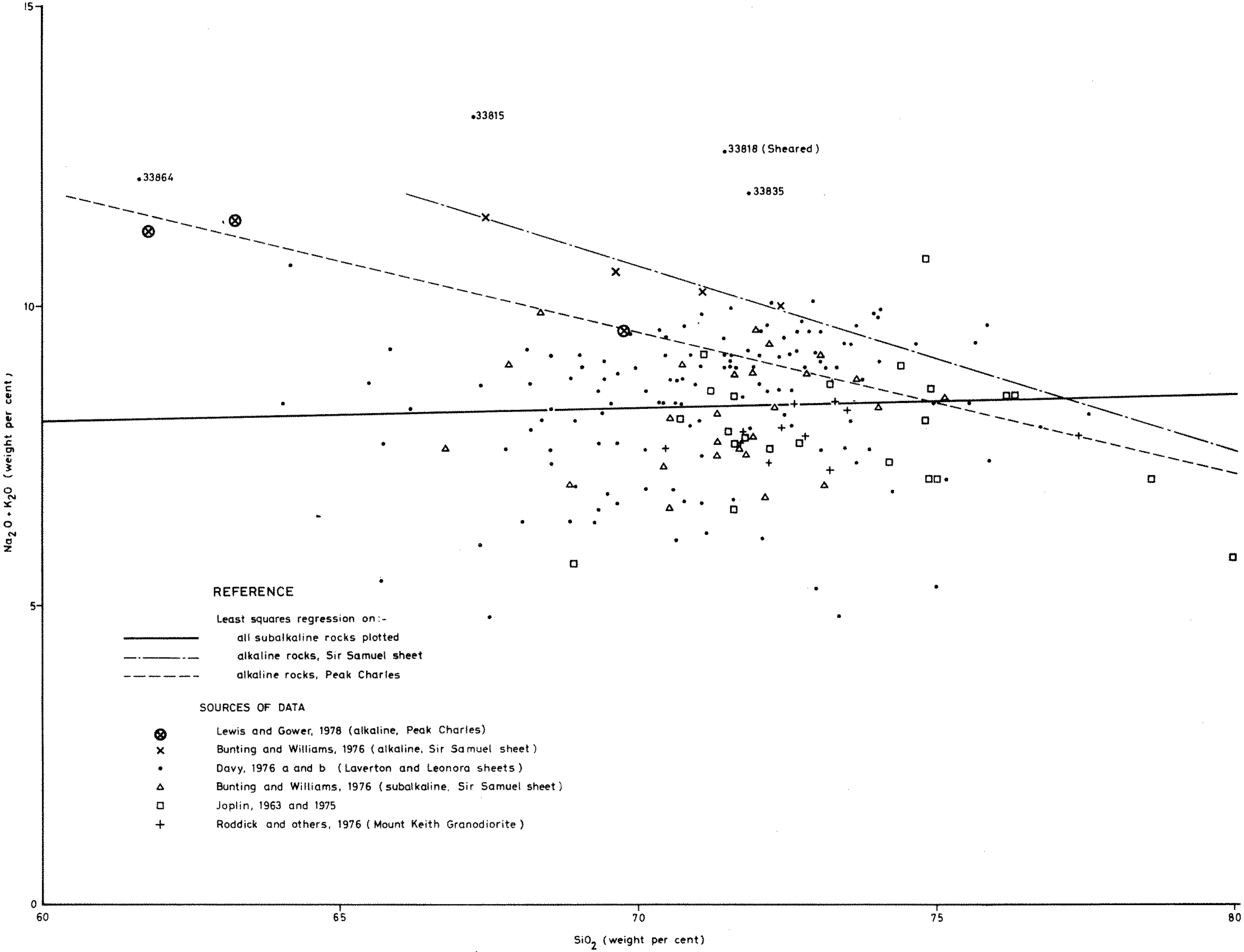

Figure 2. Total alkalies versus silica (weight per cent) for alkaline and subalkaline rocks of the Eastern Goldfields Province (GSWA 17328)

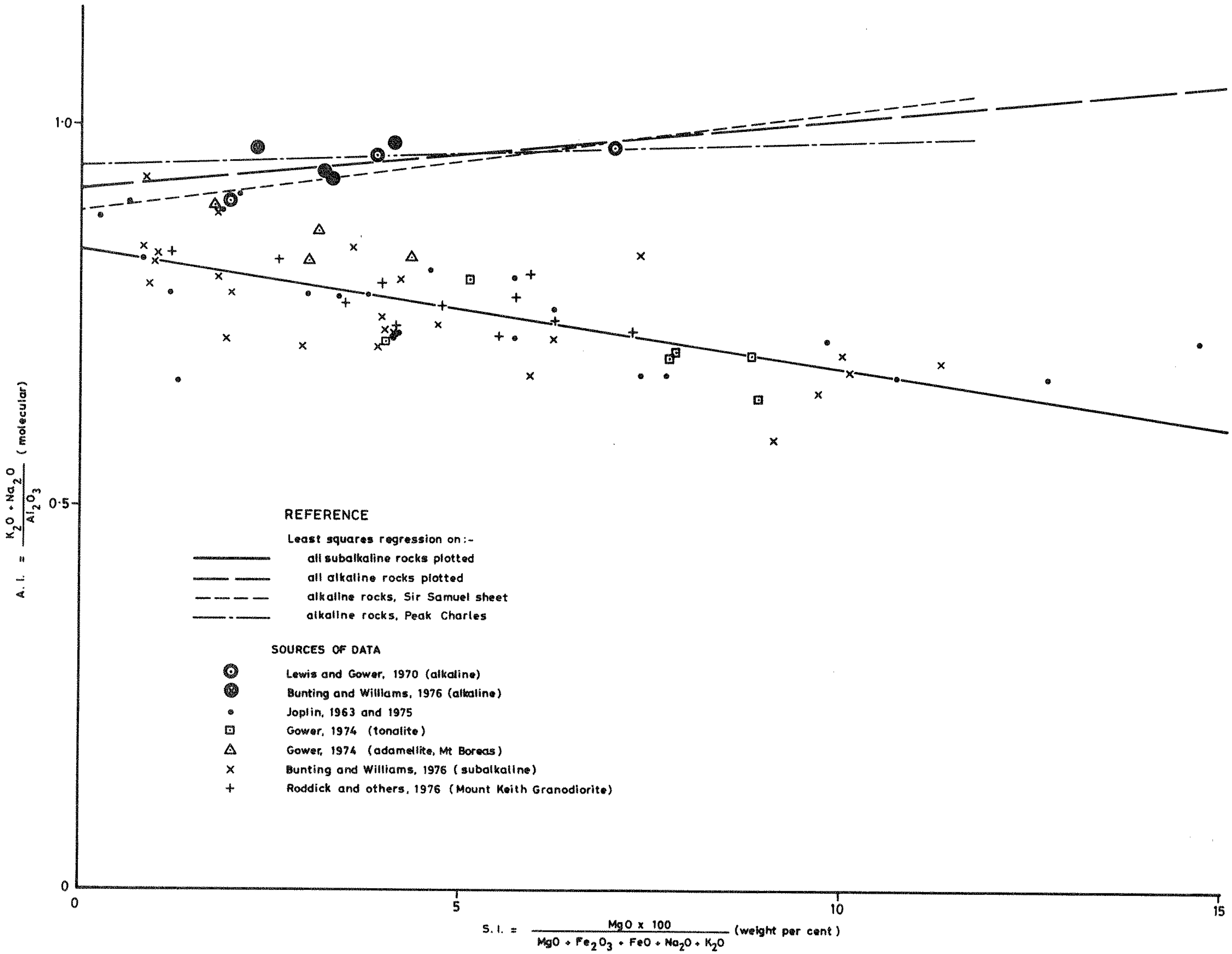

Figure 3. Agpaitic Index (A.I.) versus Solidification Index (S.I.) for alkaline and subalkaline granitoids of the Eastern Goldfields Province (GSWA 17329)

79306-9

sheet, have crystalloblastic texture, pronounced mineral grain orientation, and weak compositional layering. These may have retained their igneous alkaline character during metamorphism. Some of the alkaline bodies are heterogeneous with pods, streaks and lenses rich in mafic minerals set in the generally felsic body of the rock (Lewis and Gower, 1978).

REGIONAL DESCRIPTION

THE MAIN BELT

Within the main belt most samples of the alkaline suite are mesoperthitic (Plates I and II), with alkaline amphibole and pyroxene being the characteristic mafic minerals. Many samples have less than 20 per cent quartz and several contain orange sphene.

Pyroxene, without including three samples of doubtful affinity, seems to range from diopside to aegirine. The diopside and the pyroxenes which are optically intermediate between diopside and aegirine are length fast with a moderate extinction angle, a large optic axial angle and a positive optic sign. They range from colourless to green. The aegirine is length slow with a small extinction angle and a large, negative optic axial angle; its colour is yellow-green. Pyroxene with full optical properties of aegirine is restricted to three samples (2346, 6893 and 11099) from the Kurnalpi sheet and two samples (6522B and 6589) from the Widgiemooltha sheet, although pyroxenes with properties between aegirine and diopside (presumably aegirine-augite) are much more widespread. Pyroxene from Fitzgerald Peaks has been analyzed as aegirine-augite (Lewis and Gower, 1978). Sodic pyroxene is illustrated in Plates VI, VII and VIII.

Two granitoid rocks, samples 41475 (Boorabbin sheet) and 29906 (Laverton sheet), contain a green pyroxene but have no other properties of the alkaline suite. Optical properties of this pyroxene are consistent with diopside and the textures of the rocks are coarsely crystalloblastic. The rocks are pyroxene gneisses of doubtful affinity with the alkaline suite, although gradation of hedenbergite granite into peralkaline granite (for example, Bowden and Turner, 1974, p.336) leaves the question of relation to the alkaline suite open.

Amphibole in the alkaline suite of the main belt has a wide range of optical characteristics. In some samples amphibole is pale blue-green and probably is hornblende or actinolite; in other samples it is deep green with a small optic axial angle and strong dispersion, and probably is arfvedsonite. Deep blue to violet-blue riebeckite is abundant in samples 6522A and B from the Widgiemooltha sheet and sample 2346 from the Kurnalpi sheet. Sample 26690 from the Edjudina sheet carries flecks of secondary riebeckite. Alkaline amphibole is illustrated in Plates IV and V.

Pyroxene and/or amphibole is the principal mafic mineral in all but one of the quartz-poor samples of the main belt. The exception is sample 38674 from the east-central part of the Laverton sheet. This is a biotite syenite with dominant potash feldspar, about 40 per cent plagioclase near An_8 and no quartz. This, and the similar (hornblende-) biotite monzonite-syenite from Lake Shaster (Thom and others, 1977) in the Proterozoic Albany-Fraser Province, are the only biotite-rich rocks of syenitic affinity recognized in this study.

The opaque minerals in the alkaline and quartz-poor rocks of the main belt are black under oblique reflected light (?magnetite) except where oxidized to hematite or limonite, probably due to weathering. Apatite seems more abundant than in average granitoid rocks of the Eastern Goldfields Province. The apatite is coarse-grained and forms stubby prismatic crystals or irregular masses. Epidote is a minor secondary mineral in most samples but is abundant in a few. Fluorite was identified in a few samples (for example 24831, Edjudina sheet). Zircon was identified in slightly more than half of the samples, and in some samples it is very coarse grained and anhedral. In some cases it is metamict.

Although six samples contain no quartz and many others have little quartz, no feldspathoids were recognized.

Many samples from the main belt of alkaline rocks are porphyritic, with groundmass ranging from fine to medium-grained. With coarsening of the matrix and increase in the proportion of phenocrysts the porphyritic texture increasingly resembles granitic texture, apparently reflecting textural gradation from alkaline felsites to quartz syenites. This suggests that the porphyritic rocks are closely related to the coarse, even-grained rocks. Probably both are shallow intrusive bodies though some of the felsites may be extrusive. Porphyritic rocks seem absent from the two most heavily sampled areas of alkaline rock - the Fitzgerald Peaks on the Lake

Johnston sheet and in the vicinity of Twin Peaks on the Edjudina sheet.

Four small syenite bodies in the main belt were examined by I.R. Williams in the course of preparation of the Edjudina 1:250 000 sheet (Williams and others, 1976, and personal communication). A body at McAuliffe Well was described earlier by Jutson (1915) and Honman and others (1917). The location of each syenite body is shown on Figure 4. Three of the bodies, at Hamdorf Bore, Tassy Well, and Twelve Mile Well are within a heterogeneous, mainly adamellitic, complex, the Menangina Batholith. The syenites are in the outer margin of the complex in a zone which has an involved history of multiple intrusion. The zone contains igneous rocks ranging from diorite to alkaline granite and a variety of basic rafts and xenoliths in various stages of assimilation. The remaining alkaline body, at McAuliffe Well, is about 5 km northwest of the batholith.

Mesoperthite is the dominant feldspar in samples 26649 and 26690 from McAuliffe Well and 24831 from Hamdorf Bore, but is rare in 26650 and 26689 from Tassy Well and is absent in 24821 from Twelve Mile Well. The soda and potash feldspars of samples 24821 and 26689 possibly represent further unmixing of hypersolvus anorthoclase beyond the mesoperthite stage. There is no direct petrographic evidence for such unmixing, though in sample 26689 it could be explained by stress attending severe cataclasis. The total alkaline feldspar (microcline and albite) is greatly in excess of more calcic plagioclase (oligoclase) in all samples. The greatest proportion of oligoclase seen, in sample 24831, is less than 9 per cent of the rock.

The mafic mineral in sample 24821 is pale green amphibole; in sample 26689 both green amphibole and nearly colourless clinopyroxene are present. The principal mafic mineral in samples 26690 and 24831 is aegirine or aegirine-augite, accompanied in 24831 by secondary alkaline amphibole and minor biotite. Aegirine-augite and possible aegirine form both discrete grains and rims around pale green (?diopsidic) pyroxene. The rare amphibole and biotite also may be discrete or associated with the rims of dark green pyroxene.

The main accessory minerals at the four localities are sphene, apatite, opaques and quartz. The samples from Tassy Well and Twelve Mile Well are syenitic, with very little quartz, but have few other mineralogical characteristics of the alkaline suite.

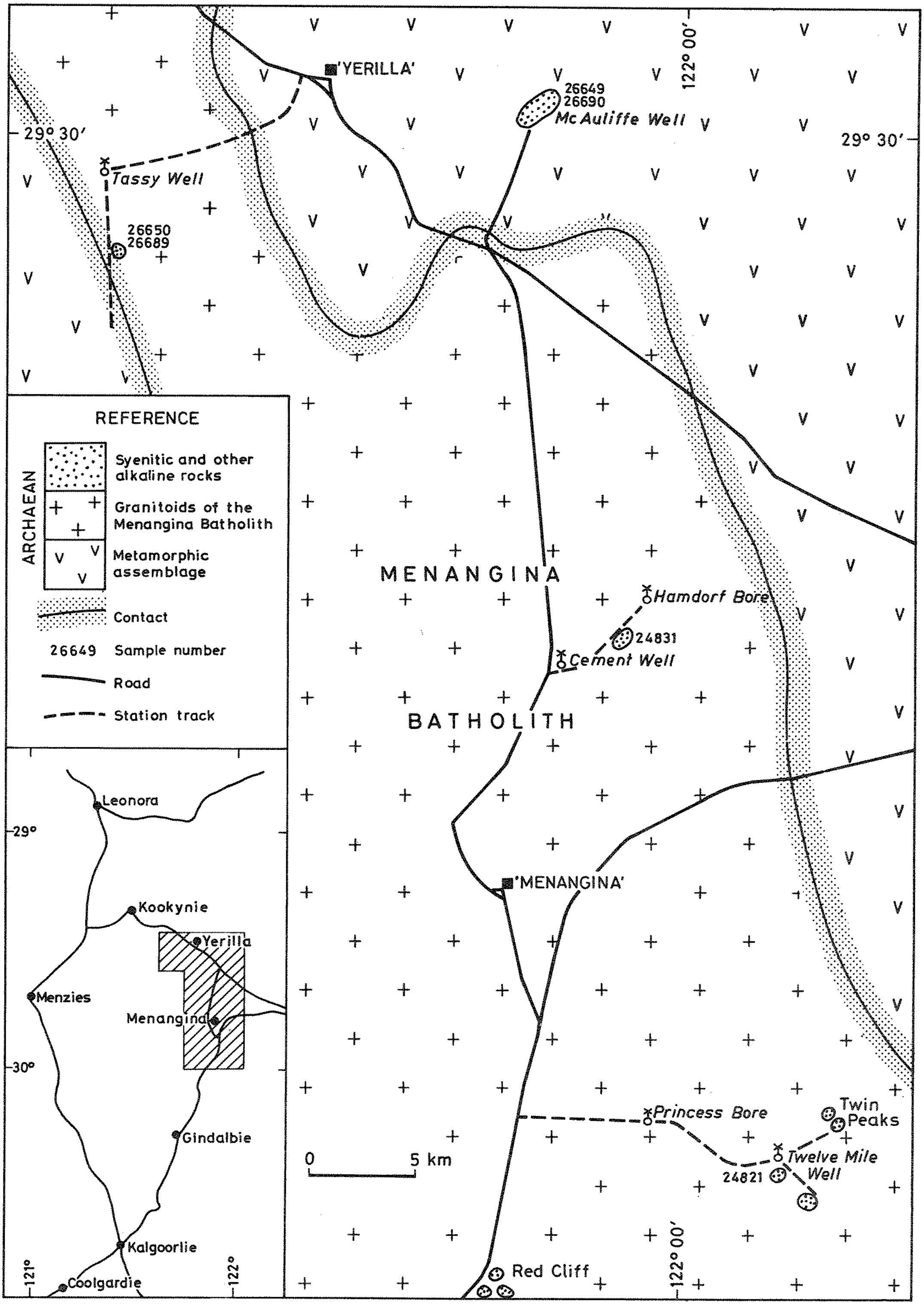

Figure 4. Locality map of Archaean syenites and other alkaline rocks in the Yerilla-Menangina region (GSWA 17330)

Three localities in the eastern part of the Laverton and Edjudina sheets (identified in Figure 5 as Linden syenite, carbonatite, and 38674) possibly should not be included in the main belt due to isolation from other members of the suite; or, perhaps, these constitute a bifurcation of the main belt. Sample 38674 is from a long, dyke-like body east of Laverton. It is low in quartz and has mesoperthitic, hypersolvus textures. The carbonatite is shown on the Kalgoorlie 1:1 000 000 geological series map (Williams, 1976) about 30 km south-southeast of Laverton. Samples were not available from the carbonatite or from the locality at Linden which Berliat (1956, p.24) has described as "... quartz-poor, syenitic varieties (of granite) ... east of Linden, in the vicinity of Lake Carey ..." on the Edjudina sheet.

A survey of scattered alkaline rocks on the continuation of the main belt north of the limit of the study area at latitude 28°S shows that aegirine-rich pyroxene is the characteristic mafic mineral in a suite variously deficient in quartz (with respect to granite) and in part carrying riebeckitic amphibole and hypersolvus alkaline feldspar.

FITZGERALD PEAKS

The pyroxene-quartz syenite of the Fitzgerald Peaks on the Lake Johnston sheet is described in an accompanying article (Lewis and Gower, 1978). Two phases of granitoid are recognized, a biotite adamellite to granodiorite and a pyroxene-bearing quartz syenite to pyroxene granite.

The biotite-rich rock is considered by Lewis and Gower (1978) to be intermediate between the pyroxene-quartz syenite and the regional porphyritic adamellite. Mesoperthite in some samples of the adamellite, and orange sphene suggest an affinity with quartz syenite, but quartz is not notably less than in an average granitoid. Alkaline mafic minerals are missing and in most samples plagioclase is oligoclase.

The pyroxene-quartz syenite is typical of the alkaline suite, varying from pyroxene syenite to pyroxene granite with a range in quartz from nil to about 30 per cent.

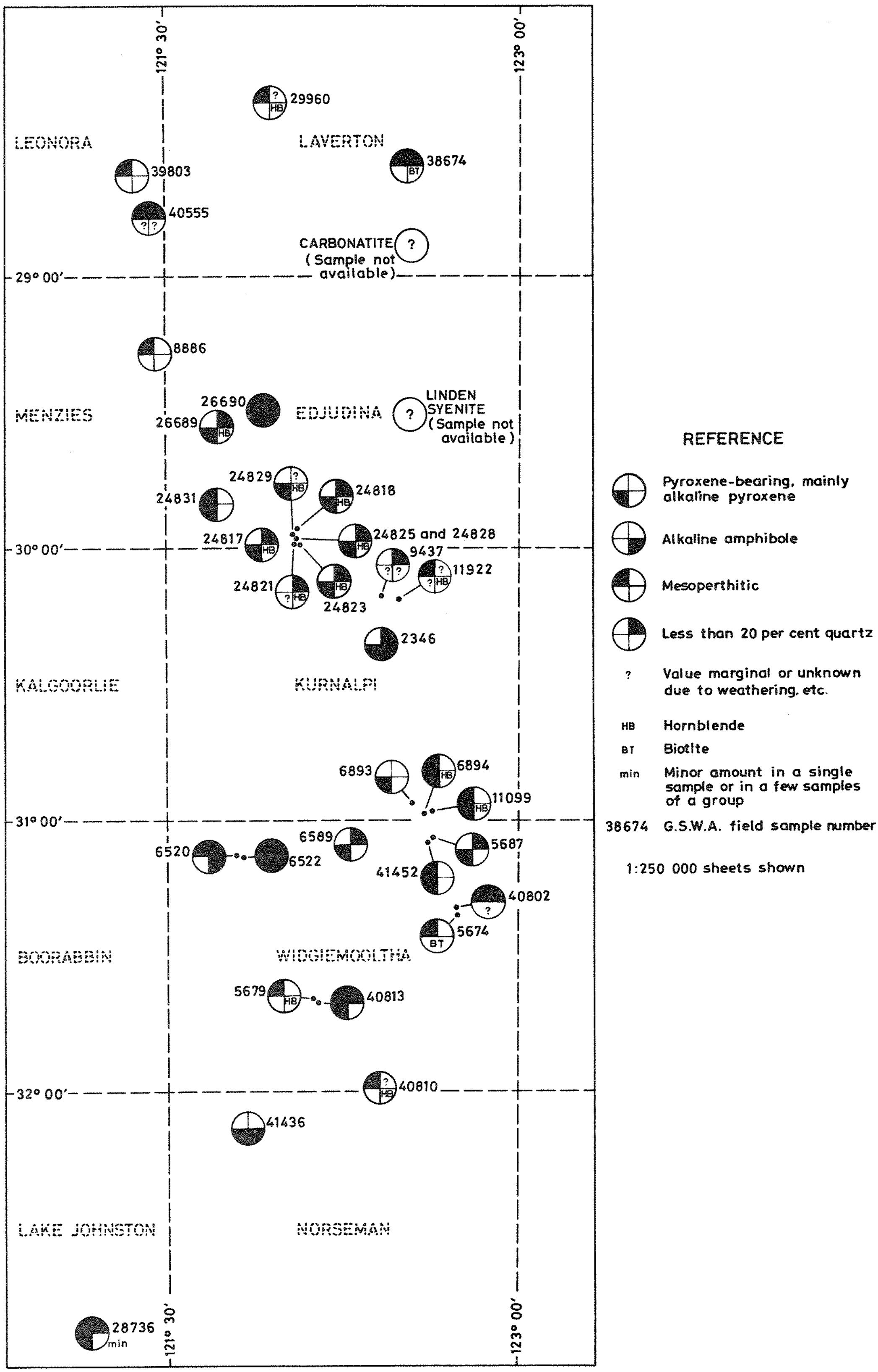

Figure 5. Distribution of rocks of the alkaline suite (GSWA 17331)

Feldspar commonly is mesoperthitic though proportions of sodic and potassic components are variable. Where feldspar phases are separate, plagioclase is albite. Pyroxene is aegirine-augite. Coarse-grained sphene with patchy orange pleochroism is common. Hypersolvus crystallization is implied by the texture of alkali feldspar.

LOCALITIES OUTSIDE THE YILGARN BLOCK

Three localities of alkaline rock well outside the main belt, in the Proterozoic Albany-Fraser Province may be unrelated to the alkaline suite of the Yilgarn Block. At Bobbies Point (Fig.1), on the Neale sheet, a sheared and partly recrystallized porphyritic rhyolite contains abundant minute groundmass needles of riebeckite. These rocks were discussed by van de Graaff and Bunting (1975).

At Lake Shaster, west of Esperance on the Ravensthorpe sheet (Fig.1), a hornblende-biotite-andesine monzonite is clearly alkaline but is of doubtful affinity with the alkaline suite of the Eastern Goldfields Province.

Chemical data in preparation for publication indicate that the monzonite ranges from silica saturated to slightly nepheline normative. The rocks have been described by Thom and others (1977), who also described an additional occurrence of syenite from the Proterozoic mobile belt, near Shamba Kappa homestead (Fig.1), mentioning a similarity between the syenite at Shamba Kappa and the quartz syenite at Fitzgerald Peaks.

FINE-GRAINED AND SERIATE ALKALINE ROCKS

Most of the alkaline rocks of the Eastern Goldfields Province are phaneritic but a few samples, especially from the Widgiemooltha sheet, have a fine-grained matrix, and others have an irregular grain size distribution which distinguishes them from normal phaneritic rocks. The special problems associated with these rocks seem to merit consideration apart from the phaneritic samples.

TEXTURE

Subtle differences in texture are important in interpreting the alkaline suite and in differentiating it from the subalkaline felsic suite. As terminology for the inequigranular rocks has not always been consistent, some common terms are defined here as used in this work. The term porphyritic is applied to rocks with apparently an igneous texture in which euhedral or subhedral grains (phenocrysts) are set in a finer groundmass. The phenocrysts (for example, plagioclase) must be represented in the groundmass by the same mineral (plagioclase), though the composition may be different (for example, andesine versus oligoclase). The phenocrysts must not grade regularly from coarse to fine; that is, the size distribution is bimodal, not seriate.

Inequigranular is the general term for rocks characterized by a wide range in grain size and includes porphyritic and seriate textures as well as texture in which relatively coarse grains of a mineral are set in a groundmass free of that mineral. In rocks with seriate texture one or more minerals grade through a substantial range of sizes without prominent clustering around one or two sizes.

The texture of rocks of the alkaline suite are systematically different from the textures of the more abundant subalkaline rocks in the Eastern Goldfields Province. The distinction between phenocrysts and matrix is less clear and matrix textures can be less easily classified than those of the porphyries of more normal composition (cf. Libby, 1978a). The origin of the porphyritic texture in the alkaline suite probably is different from that in the subalkaline rocks.

The textural variation among fine-grained rocks of the alkaline suite is quite remarkable. In sample 5764 (Widgiemooltha sheet) the size of albite and strongly perthitic microcline grains ranges evenly downward from about 3 mm. In sample 6522A (Widgiemooltha sheet), very coarse grains of mesoperthite are set in a matrix of medium or coarse-grained perthite with interstitial quartz, riebeckite and fine-grained feldspar. Sample 6893B from the Kurnalpi sheet is a medium-grained quartz-microcline-albite rock with green clinopyroxene and riebeckite. It has a texture which strongly suggests severe recrystallization. In sample 9138 from the Kalgoorlie sheet plagioclase phenocrysts and finer feathery, bluish amphibole grains are set in a microlitic and microgranular groundmass. Although very little of the suite is micrographophyric, an exception is sample 9143 (Kalgoorlie sheet). Here, small phenocrysts (about 1 mm) of quartz and alkali feldspar are set in a micrographophyric groundmass with complex spheroidal felsic masses and rather idiomorphic but intergrown (?perthitic) alkali feldspar. In sample 40555A from the Leonora sheet phenocrysts of mesoperthitic alkali feldspar are set in an unusual even-grained (about 1.5 mm) irregular intergrowth of alkali feldspar. Minor brecciation and fine granulation follows many small fractures.

Thus, variety in texture is perhaps a characteristic of the alkaline suite.

RELATION BETWEEN PHENOCRYSTS AND MATRIX

The distinction between phenocrysts and matrix in many rocks of the alkaline suite is not clear. Phenocrysts constitute 90 per cent of some of the alkaline rocks (samples 40802 and 41428 from the Widgiemooltha sheet) other samples (6522A, Widgiemooltha sheet) have a matrix with a grain size (1 to 2 mm) intermediate between coarse phenocrysts and very fine-grained groundmass; still other samples (6520 and 41452 from the Widgiemooltha sheet; 11099, Kurnalpi sheet; 24831 and 26689, Edjudina sheet) are seriate, having a broad but evenly graded range in grain size.

Commonly, where the distinction between phenocrysts and groundmass is clear, the rock has been disturbed. Sample 5586 (Widgiemooltha sheet) has a good size contrast but a mylonitic matrix. Another sample (6520, Widgiemooltha sheet) which seems initially to have good contrast is in fact seriate. Again, in sample 26689 (Edjudina sheet) very coarse-grained potassium feldspar and coarse-grained plagioclase are set in a fine-grained groundmass, but the amphibole, which probably is secondary, is strongly oriented. Sample 41427 (Widgiemooltha sheet) is a more typical porphyritic felsite but still the contrast between phenocrysts and matrix is less clear than in the common (subalkaline) felsites of the area.

Most typically there is only one phase of feldspar among the phenocrysts and this is mesoperthite. In the matrix, however, the alkali feldspars commonly are differentiated into discrete albite grains and microcline grains which are not perthitic. These may be unmixed or, more likely considering the perthitic character of the phenocrysts, have crystallized in the two-feldspar field. Again, there are exceptions in which groundmass feldspar is a single phase or in which there are two phases among the phenocrysts.

Samples 6522B, 40813 and 41427 (Widgiemooltha sheet) are typical of the suite. In sample 41427 coarse-grained mesoperthite and green clinopyroxene are set in a matrix of anhedral and in part intergrown microcline and albite. On a fine scale matrix grains are intergrown with the margins of the phenocrysts, a relationship typical of this suite. In contrast, albite is present among the phenocrysts in several samples. In samples 6589, 6599, and 41428 (Widgiemooltha sheet) albite phenocrysts are dominant but strongly perthitic phenocrysts of potassium feldspar are present. In sample 40802 (Widgiemooltha sheet) there are scattered albite phenocrysts among dominant mesoperthite phenocrysts, but more common are albite rims on the mesoperthite phenocrysts. Locally, the interface between mesoperthite core and albite rim is rounded, as though the mesoperthite had been partly resorbed prior to crystallization of albite as a separate phase.

As with textures as a whole, generalizations about matrix-groundmass relationships are difficult, but crystallization of phenocrysts at temperatures above the solvus seem characteristic though not universal in the alkaline suite, whereas hypersolvus crystallization of the matrix seems less common.

AGE

Little evidence of the age of the alkaline suite is available. Most plutonic ages in the Eastern Goldfields Province are in the vicinity of 2 600 m.y. Only one date is from a unit which may belong to the alkaline suite. Turek (1966, p.59) reported a Rb:Sr age of 1 670 m.y. with an initial ratio of 0.7473 from a two-point microcline - whole rock isochron on a microcline-quartz rock. The sample is from Peak Charles, one of the Fitzgerald Peaks, on the Lake Johnston 1:250 000 sheet. Much of the rock at the Fitzgerald Peaks is pyroxene-quartz syenite (Gower and Bunting, 1976; Lewis and Gower, 1978). Thus the dated sample may be from the alkaline suite. The date was dismissed by Turek as being affected by loss of ^{87}Rb

on field evidence that the rock is Archaean. However, acceptance of the possibility of a Proterozoic age for the alkaline suite in the Yilgarn Block would remove the Archaean constraint. Preliminary recent (de Laeter and Lewis, 1978) Rb:Sr dating of the Peak Charles syenitic rocks indicates a date near 2 500 m.y.

North of the study area, on the Sir Samuel 1:250 000 sheet, quartz syenitic rocks have been found to be intruded by potassic adamellite of the Mount Boreas type (Bunting and Williams, 1976, p.18-19). The Mount Boreas adamellite has been dated on the Laverton sheet at 2 480 $\pm$ 30 m.y., suggesting an Archaean age for the alkaline suite.

Monzonite at Lake Shaster and pyroxene-bearing quartz-syenitic rocks near Shamba Kappa on the Ravensthorpe sheet (Thom and others, 1977) would be included in the main belt if a major province boundary were not between these localities and the main belt, suggesting that the main belt may in fact be continuous into the Albany-Fraser Province and thus be of Proterozoic age.

Bunting (personal communication) has indicated that syenite typical of the alkaline suite crops out in the circular Lake Teague structure a few kilometres north of the north limit of general Archaean outcrop on the Nabberu sheet. It either cuts Proterozoic rocks or has been elevated from Archaean rocks which can be expected to be at modest depth in the area. A programme of dating rocks of the Lake Teague structure is in progress.

The riebeckite rhyolite at Bobbies Point in the Proterozoic Albany-Fraser Province has provided a single-point, whole rock model age of 1 190 m.y., assuming an $^{87}Sr/^{86}Sr$ initial ratio of 0.703 (Bunting and others, 1976, sample 40598A). However, this rock probably is unrelated to the alkaline suite of the main belt in the Yilgarn Block.

Data on the age of the alkaline suite of the Eastern Goldfields Province is ambiguous and evidence is contradictory. The age of the suite may or may not be homogeneous and may be Archaean or Proterozoic.

SUMMARY

A belt less than 100 km wide and more than 500 km long through the Eastern Goldfields Province is characterized by widely scattered bodies of fine to coarse-grained felsic rock with alkaline pyroxene or amphibole, generally less than 20 per cent quartz and commonly with hypersolvus alkali feldspar. Hypersolvus feldspars, alkaline mafic minerals, and chemical trends divergent to those of associated subalkaline rocks suggest a history distinct from that of the regionally dominant subalkaline granitic and felsitic suites.

It is probably too early to decide whether the alkaline suite has originated by local contamination at high crustal levels, deeper contamination and magmatic evolution, in association with deep fracturing, or by other means. It is also premature to suggest whether the suite may have been associated with late Archaean rifting, though the dimensions of the belt do not preclude such an origin. Further field and chemical data are being collected in an attempt to answer some of these broader questions.

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APPENDIX

LOCATION OF SAMPLES

Samples are located according to 1:250 000 sheets and the Australian Transverse Mercator Grid, in yards. The first digit of each coordinate indicates hundreds of thousands of yards. Four-digit coordinates have a precision of 100 yards, three-digit coordinates, 1 000 yards. Accuracy is less. Letter suffixes on sample numbers have been omitted.

BOORABBIN	
41475	445-/436-
EDJUDINA	
24817	4970/2869
24818	5142/2937
24821	5115/2880
24823	5130/2881
24825	5123/2897
24828	5123/2897
24829	5110/2911
24831	4764/3049
26649	Not available
26650	Not available
26689	478-/339-
26690	497-/347-
KALGOORLIE	
9138	393-/295-
9143	395-/247-
KURNALPI	
2346	242-/550-
6893	563-/173-
5894	563-/173-
9437	550-/264-
KURNALPI (cont.)	
11099	571-/167-
11922	557-/262-
LAKE JOHNSTON	
28736	417-/936-
LAVERTON	
29960	5025/4826
38674	564-/456-
LEONORA	
39803	4390/4510
40555	447-/434-
MENZIES	
8886	450-/372-
NORSEMAN	
41436	502-/026-
WIDGIEMOOLTHA	
5586	4880/1215
5674	5823/1230
5679	5181/0852
5687	5719/1570
6520	483-/149-
WIDGIEMOOLTHA (cont.)	
6522	Not available
6589	5344/1545
6599	4607/1252
40802	4607/1252
40810	5460/438-
40813	520-/084-
41427	520-/084-
41428	573-/145-
41452	570-/155-
NEALE	
40598A	258-/408-

P L A T E S

PART III

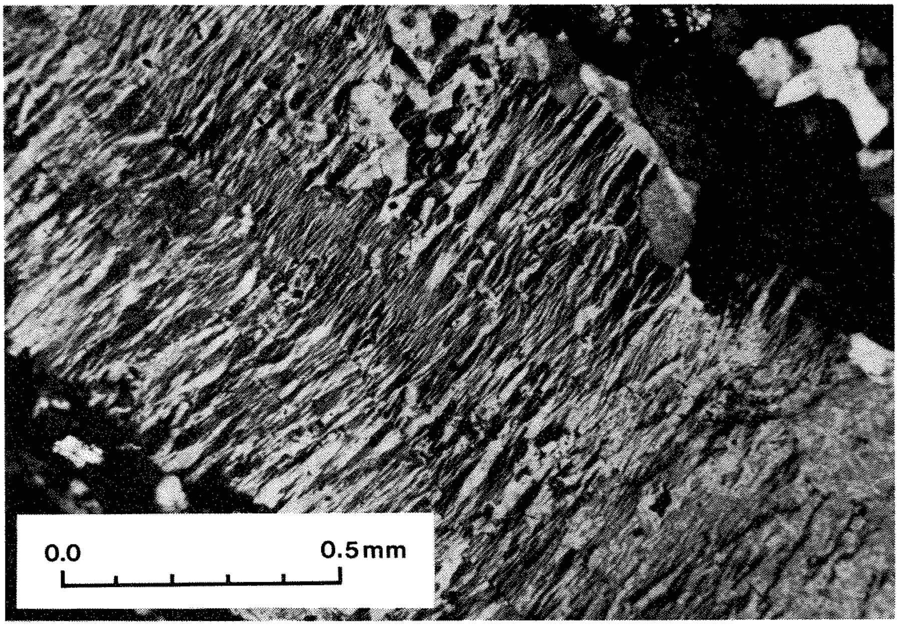

Plate I. Mesoperthite.

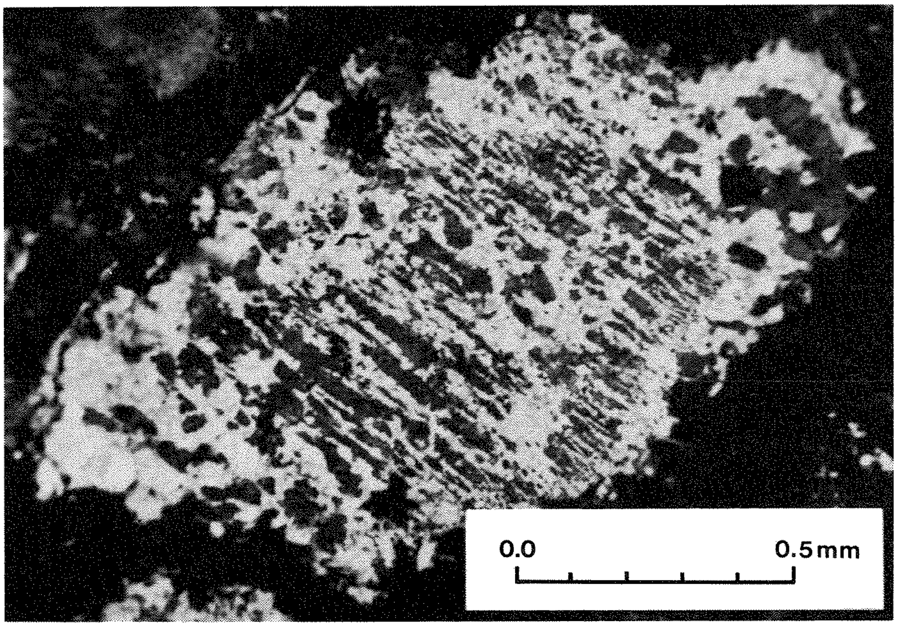

Plate II. Mesoperthite.

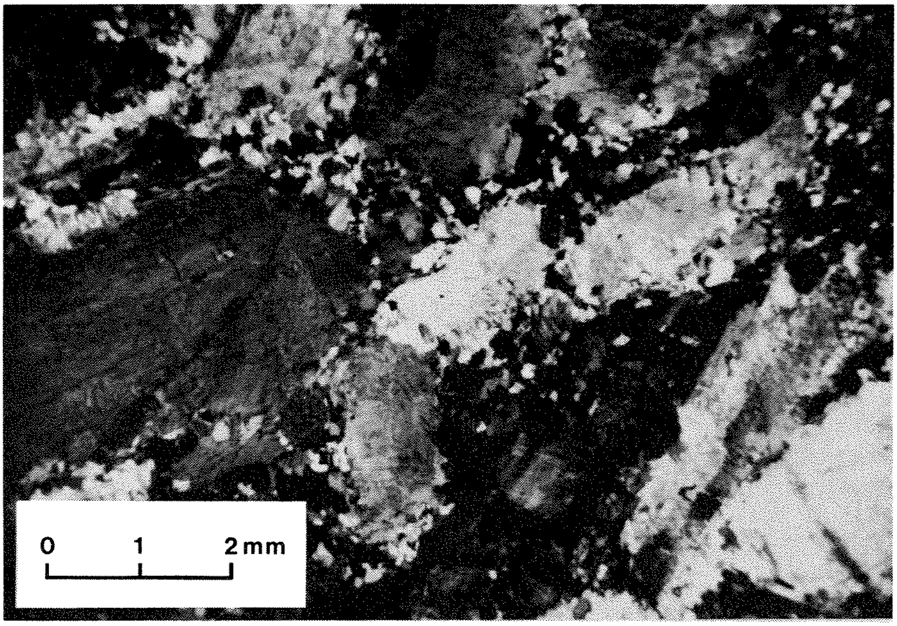

Plate III. Matrix-phenocryst relations in an alkaline rock.

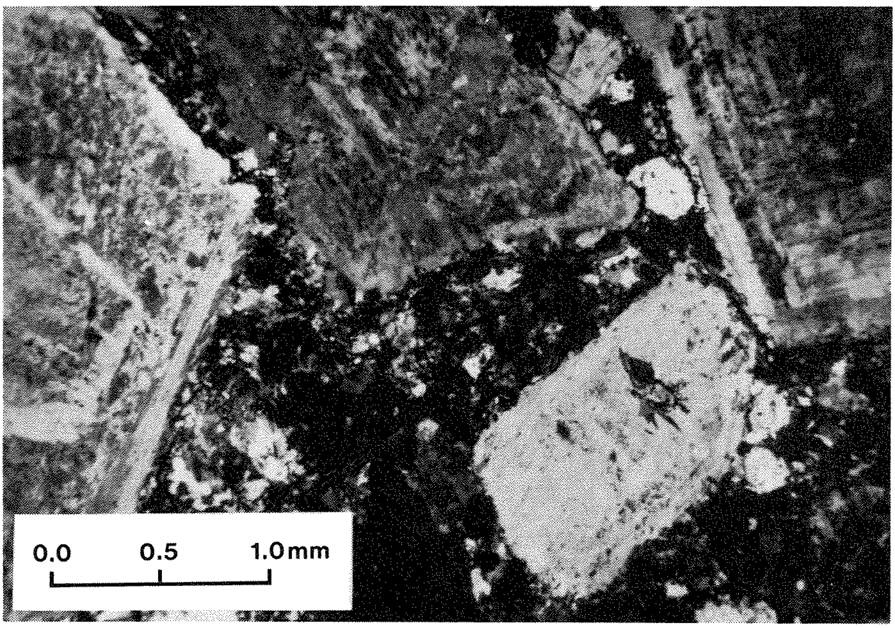

Plate IV. Alkaline amphibole interstitial to phenocrysts in porphyritic alkaline rock.

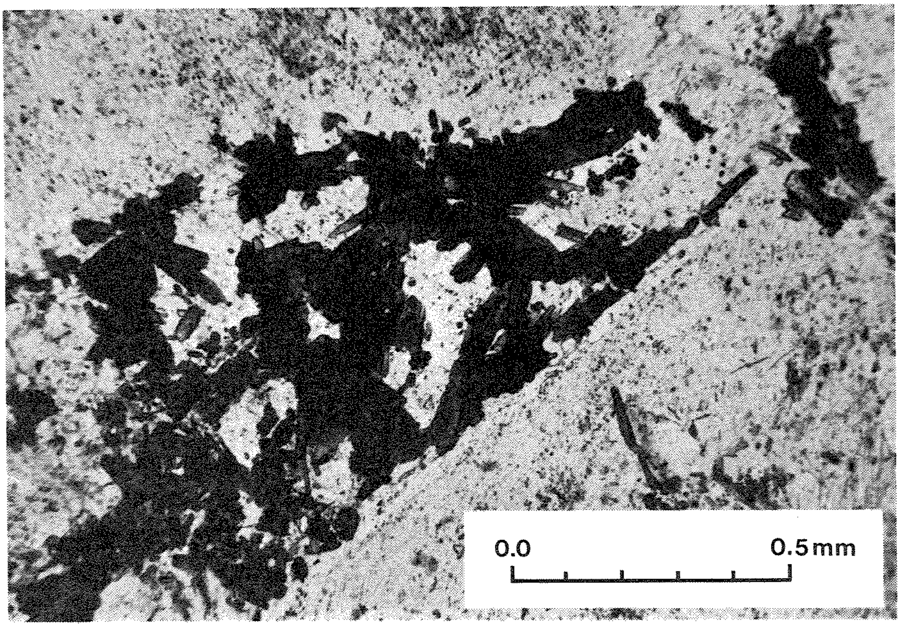

Plate V. Alkaline amphibole, probably secondary, interstitial to feldspar in alkaline rock.

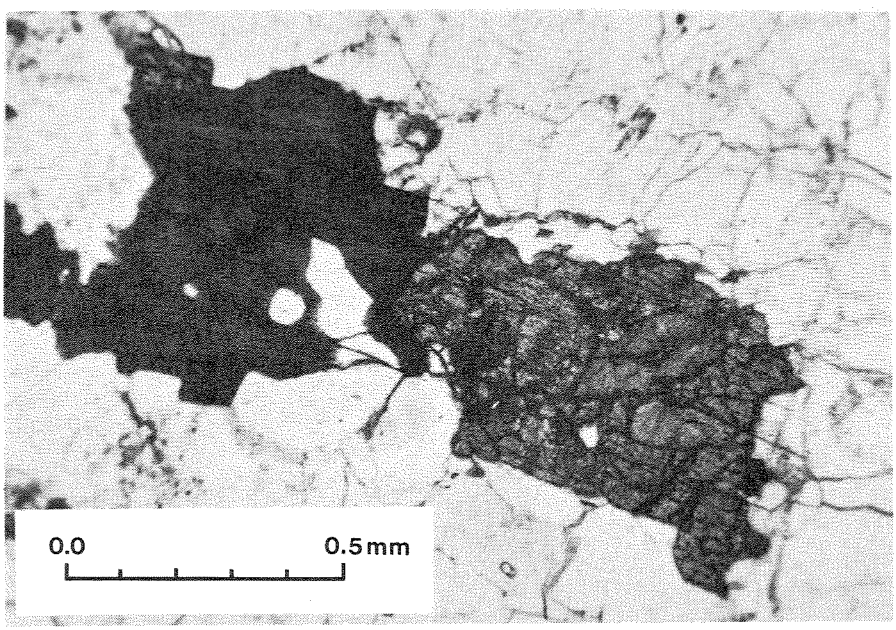

Plate VI. Sodic pyroxene in an alkaline granitoid.

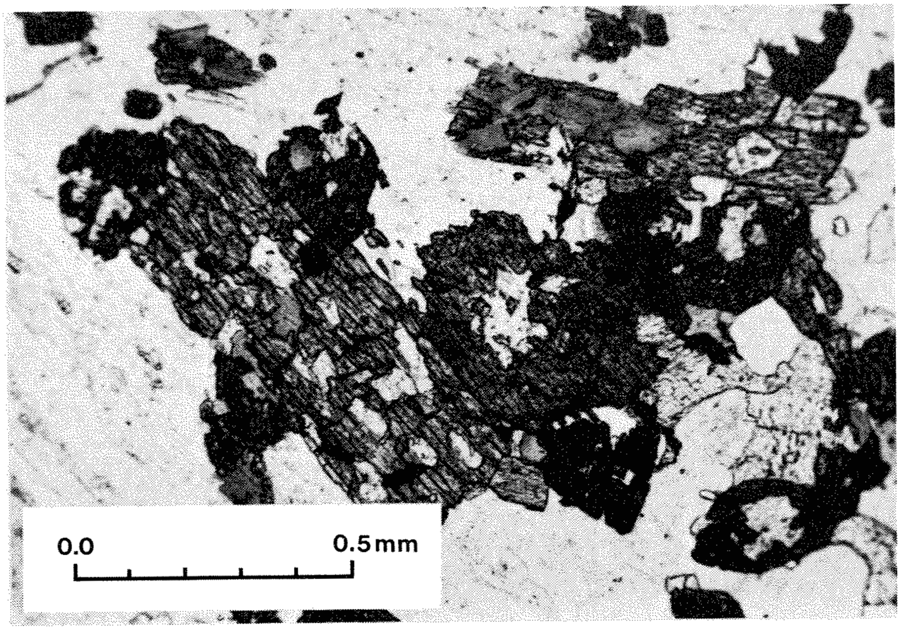

Plate VII. Sodic pyroxene in an alkaline granitoid.

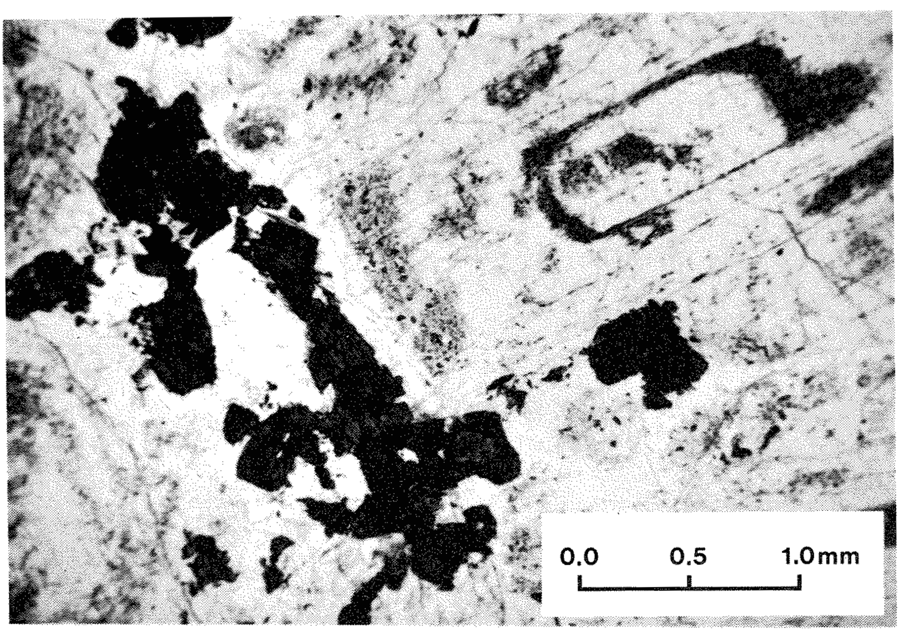

Plate VIII. Sodic pyroxene in an alkaline granitoid.

P A R T   I V

SYENITIC ROCKS OF THE FITZGERALD PEAKS, NEAR NORSEMAN

SYENITIC ROCKS OF THE FITZGERALD PEAKS, NEAR NORSEMAN

by

J.D. Lewis and C.F. Gower*

ABSTRACT

The Fitzgerald Peaks, about 96 km south-southwest of Norseman are formed by an isolated mass of syenite, quartz syenite and alkali granite intruded into a major Archaean batholith. The regional geology and petrology are described, and four complete chemical analyses are given. The syenites contain aegirine-augite for which full chemical, mineralogical and X-ray data are tabulated. The Fitzgerald Peaks Syenite is a high level diapir, probably of anatectic origin, and Proterozoic in age.

INTRODUCTION

The Fitzgerald Peaks are a prominent group of hills located about 96 km south-southwest of Norseman, in the southeastern part of the Lake Johnston 1:250 000 sheet. Peak Charles, 658 m high, is a roughly conical hill of bare rock which rises over 300 m above the Archaean granite plain and is visible for many miles. Peak Eleanora, 503 m high and 10 km to the south, is the other main peak of the group, and between these two prominences there are several lower hills.

During regional mapping of the Lake Johnston area (Gower and Bunting, 1976) it was recognized that the Fitzgerald Peaks were formed by an intrusion of syenitic and alkalic granitic rock which contrasted with the

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porphyritic biotite granodiorites of the surrounding region. More recently, several other alkalic intrusions have been discovered in the Eastern Goldfields Province but the only earlier report of syenites was of a small plug at Yerilla, about 100 km north of Kalgoorlie (Honman, 1917). The Fitzgerald Peaks remains the largest syenitic body known in Western Australia and the present report will deal with its regional setting and petrography, with particular reference to the sodic pyroxene present in the rock.

REGIONAL GEOLOGICAL SETTING

The granitic rocks immediately surrounding the Fitzgerald Peaks area are principally porphyritic biotite granodiorites grading to porphyritic biotite adamellite. These form part of a large Archaean batholith which occupies the eastern third of the Lake Johnston 1:250 000 sheet and extends onto the adjacent Boorabbin, Norseman and Ravensthorpe sheets. The batholith covers an area in excess of 5 000 km^2 and is most commonly a porphyritic biotite adamellite; the only variation is in the proportion of perthitic microcline phenocrysts. The Fitzgerald Peaks are located in the southwest corner of this batholith and comprise the only alkalic rocks found within the granite mass.

The western margin of the batholith is in contact with migmatites about 8 km west of Peak Eleanora, and is clearly delineated by a low, positive aeromagnetic anomaly trending north to northeast. Shearing structures can be seen at the boundary south of Dog Rock, suggesting that the contact is faulted. The migmatites exhibit schlieren and nebulitic structures which trend northeast and are truncated by the porphyritic adamellite.

South of the Fitzgerald Peaks the batholith extends a further 16 km until it is truncated by the northeast-trending Proterozoic migmatites of the Albany-Fraser Province.

In the southern half of the batholith the porphyritic adamellite shows distinct banding or minor variations in mineral concentrations. The strike of the banding is variable and the dip is often less than 30°. Further north the banding is absent and foliations are parallel to the north-northwest Archaean trend. South of the Fitzgerald Peaks the adamellite has a northeasterly foliation, possibly reflecting a Proterozoic influence.

THE FITZGERALD PEAKS

Apart from their topographic expression the rocks of the Fitzgerald Peaks are distinctive in being non-porphyritic and containing a bright-green pyroxene, although locally biotite or amphibole may become dominant. The rock types vary from an almost quartz-free syenite to quartz syenite, granite and adamellite. The rock types, with the possible exception of the biotite adamellite, do not form clear cut mappable units but grade imperceptibly into one another.

Since, apart from one small area, outcrops of the surrounding porphyritic adamellite are absent in the vicinity of the Fitzgerald Peaks the outline of the syenitic rocks can only be inferred from aeromagnetic data (Wells, 1962). The alkalic rocks probably form a roughly crescent shaped mass (Fig.1), although it is possible that an unexposed east-northeast dextral shear passing between Peak Charles and Peak Eleanora has offset what was originally an elliptical body. Numerous foliation measurements were recorded but these fail to give a convincing indication of the three-dimensional form of the body. In general, however, it would seem that the body narrows downward, as foliations on the eastern side dip westwards whereas those on the western side dip eastward. In addition an indistinct banding which dips south at about 25° to 30°, can be seen on Peak Charles, and a similar effect on the north side of Peak Eleanora dips north. It seems likely that the body is a high level diapiric structure which intrudes the porphyritic adamellite and granodiorite of the batholith.

Banding in the syenitic rocks is caused both by variation of the aegirine-augite content and by partially assimilated xenoliths of mafic rocks. Pods, streaks and lenses rich in aegirine-augite are present in all rock types and indicate an inhomogeneity in the original magma. In addition there are pegmatitic veins and pods, some consisting almost entirely of potash feldspar, and others containing large euhedral pyroxene laths. In the larger pegmatites the pyroxene crystals are up to 100 mm long and are elongated perpendicular to the vein walls. Thin stringers of almost pure pyroxene, often only a few millimetres wide, are common and maintain uniformity over several metres.

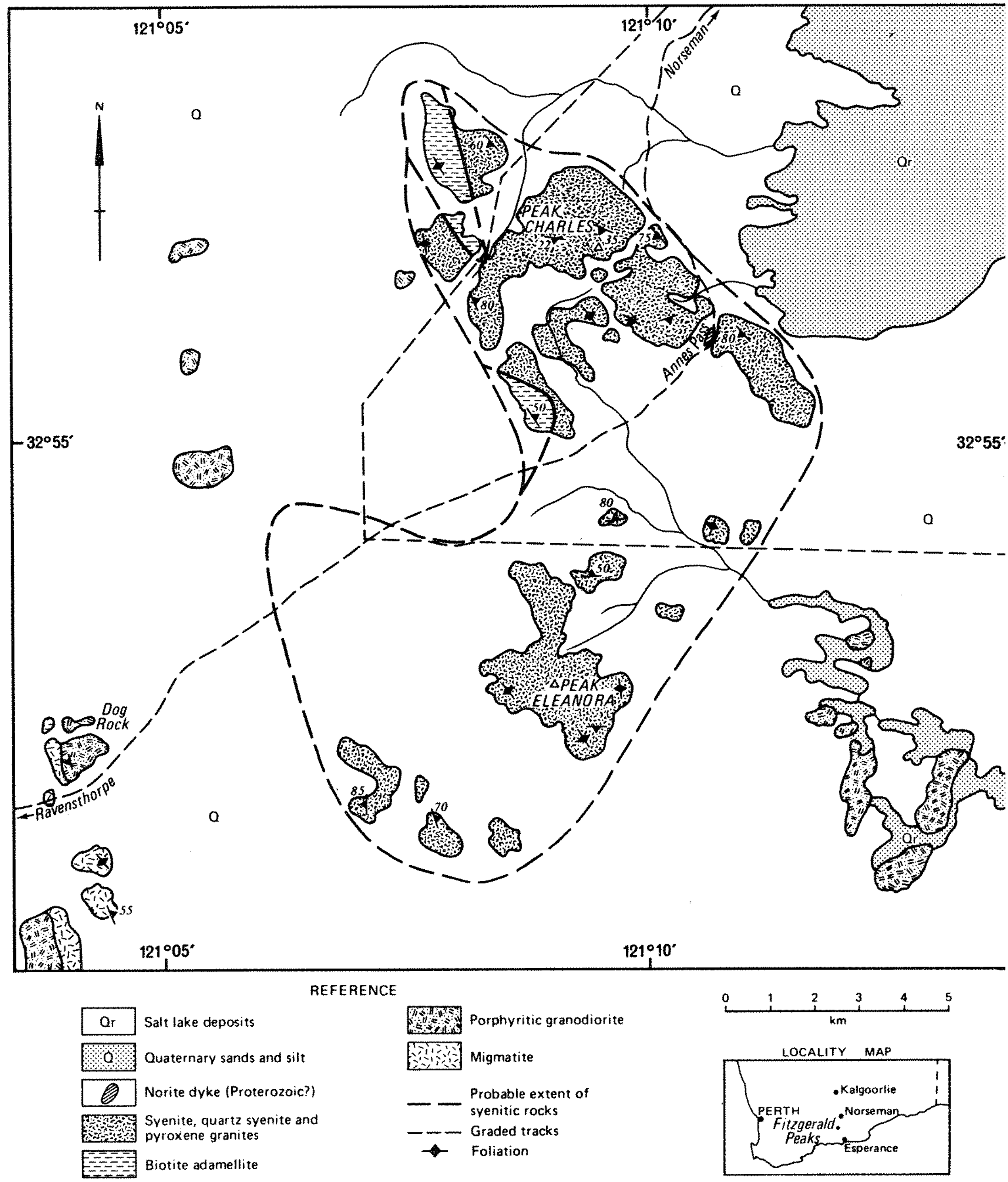

Figure 1. Sketch map of geology of Fitzgerald Peaks area (GSWA 17332)

Xenoliths of mafic rock vary from ghostlike, diffuse patches, through discontinuous pods and lenses, to continuous bands several metres long, which often have sharply defined parallel sides. The lenticular form of some xenoliths is clearly due to minor faulting of an originally continuous band. One such mafic band that has been sectioned (29804) revealed a fine-grained basic granulite containing equal proportions of green hornblende, pale green diopside, and calcic oligoclase (An_{26}). Granitic veins traversing the rock contain bright-green aegirine-augite, and plagioclase bordering the veins has been completely sericitized. The mafic bands could have been early basalt or dolerite dykes which have been remobilized. Later basic dykes also cut the syenites and granites, and appear to occupy pre-existing joint directions. The dominant dyke trends are east-northeast, northeast and northwest, but the dykes are poorly exposed and it is possible that unexposed dykes occupy many of the major fractures in the syenite.

PETROGRAPHY

The Fitzgerald Peaks are composed principally of pyroxene-bearing rocks which range continuously from granite with about 20 per cent modal quartz to syenite with less than 1 per cent quartz. Small areas of medium-grained biotite granodiorite to biotite adamellite are also present. These lack the distinctive pyroxene but have other features which resemble the main syenitic mass. Both rock types are easily distinguished from the porphyritic biotite granodiorite into which they are intruded.

Modal analyses of the main rock types are given in Table 1 and chemical analyses in Tables 4 and 5. Chemical and mineralogical data for the pyroxene of the Fitzgerald Peaks rock are given in Tables 2 and 3.

PORPHYRITIC BIOTITE GRANODIORITE

Specimens collected from scattered outcrops around the Fitzgerald Peaks are of a fairly uniform, coarse-grained, directionless biotite granodiorite (Tables 1 and 5; samples 28861, 28862, 28864).

TABLE 1. Modal analyses of rocks from the Fitzgerald Peaks area

Sample no.	28861	28862	28864	29805	29809	29831	29818	29821	28736
Quartz	32.3	29.3	41.1	21.6	19.7	14.5	6.4	1.0	0.7
Microcline	13.1	50.0	13.2	))15.6	30.7	) -)	-	-	-
Perthite	-	-	-	)		)77.5	81.5	85.4	69.0
Plagioclase	48.9	17.6	37.3	47.6	38.3	-	-	-	-
Biotite	5.2	2.6	6.8	9.8	8.2	-	-	-	-
Pyroxene	-	-	-	-	-	5.9	9.8	11.3	24.1
Sphene	-	-	-	1.9	0.9	0.9	0.7	1.0	1.0
Apatite	-	-	0.8	0.7	1.0	0.6	1.3	0.7	2.3

28861-62-64 Biotite granodiorite, major batholith surrounding Fitzgerald Peaks

29805-09 Biotite adamellite/granodiorite, part of Fitzgerald Peaks

29831 Pyroxene granite, SW of Peak Charles)
29818 Quartz syenite, SE of Peak Charles) Fitzgerald Peaks
29821,28736 Syenite, E of Peak Charles)

The proportion of microcline, however, is variable; and particularly where phenocrysts are common, the rock grades to an adamellite. The rock is fresh and consists principally of large anhedral crystals of plagioclase and quartz up to 8 mm across, lesser amounts of microcline and a few per cent biotite. Accessory minerals are small prismatic crystals of apatite, zircon and opaque iron oxide. A few small flakes of muscovite are present, either as a late stage mineral or as an alteration product of plagioclase.

The plagioclase is poorly twinned sodic oligoclase with a little untwinned myrmekite. Microcline often encloses small, early formed oligoclase crystals; it is only rarely perthitic, although the plagioclase sometimes contains exsolved patches of antiperthitic microcline.

The biotite present is a dark red-brown variety, strongly pleochroic to pale orange-brown, and is found as small flakes up to 0.5 mm long, lying along crystal boundaries or associated in clots with the accessory minerals.

Texturally the rock is typically granitic and, apart from a little chlorite and sericite, unaltered.

BIOTITE ADAMELLITE

Parts of the small hills to the northwest of Peak Charles are composed of a biotite adamellite which is allied to the main syenitic mass but which has a different mineralogy and texture. The rock is medium grained with a normal granitic texture and consists of anhedral crystals of oligoclase, microcline and quartz with a few per cent biotite, and accessory sphene, apatite, zircon and opaque iron oxide. The plagioclase is usually well twinned, only rarely myrmekitic, and is sodic oligoclase of composition An_{12-15}. In some specimens the oligoclase has a narrow marginal zone of albite. The microcline is usually only slightly perthitic but on occasion the proportion of exsolved albite rises to nearly half the crystal and its appearance approaches that of the syenitic rocks. Flakes of brown biotite up to 1 mm across are scattered randomly throughout the rock, and in some specimens outline a crude foliation.

Modal and chemical analyses of the biotite adamellite are given in Tables 1 and 4 and a photomicrograph in Plate III. Despite the differences in mineralogy and texture, the similarity between this rock and the syenitic mass is shown in the chemical analysis and by various minor mineralogical features. Some specimens contain perthite similar to the main mass, and all contain numerous small lozenges of a distinctive orange-brown sphene which are lacking in other granitic rocks of the area, but which are characteristic of the syenites. The association is further emphasized by pods of biotite adamellite within the main mass, which are similar in texture to sample 29809 but which also contain corroded grains of aegirine-augite (sample 29822) and arfvedsonitic amphibole (sample 29828).

PYROXENE GRANITES AND SYENITES

The major portion of the Fitzgerald Peaks is composed of medium to coarse-grained nonporphyritic granitoid rock containing variable amounts of quartz and green sodic pyroxene. Modal and chemical analyses of a selection of these rocks are presented in Tables 1 and 4. The common characteristics of the mass are the presence of a large proportion of perthitic (or anti-perthitic) feldspar, and lesser amounts of pyroxene and sphene. The proportion of quartz in the rock varies from about 20 per cent to almost nil in a continuous series, and division into granite and syenite is arbitrary. Neither are the varieties distinguishable in the field and, although from thin section evidence certain areas proved to be more syenitic than others (for example, the summit area of Peak Charles), no pattern emerged for the distribution of rock types.

PERTHITE

The principal mineral of rocks from the Fitzgerald Peaks is perthite which in leucocratic varieties can account for almost the whole rock. The mineral is always anhedral, and the crystal margins are usually highly sutured (Plate VII). Most of the perthite is a coarse, streaky variety with about equal proportions of microcline and untwinned sodic plagioclase, but the composition is variable and examples are common of antiperthite containing only small blebs of microcline. Similarly the internal texture of the perthite is variable (Plates V, VI and VII), from varieties with small orientated spindles of plagioclase to those with broad irregular veins of finely twinned plagioclase. In one specimen (Plate V, 26680) there appear to be two potash feldspar phases present in the one crystal. An orientated mesh of fine albite veins has a matrix of well-twinned microcline, and superimposed on this are orientated spindles of poorly twinned microcline. The final degree of exsolution of plagioclase from the perthite occurs when the crystal breaks down to a mosaic of individual albite and microcline crystals. Where optically determinable the composition of the plagioclase is albite (An_{5-10}).

AEGIRINE-AUGITE

A bright-green aegirine-augite is a constant component of the rock and ranges in amount from a few scattered grains up to 25 per cent of the rock. The crystals are usually anhedral to subhedral prisms, 1-4 mm long, often corroded, and sometimes mantled by amphibole. Many pyroxene crystals contain small blebs of quartz so that even the most extreme syenitic varieties are not entirely quartz free. Pleochroism in the aegirine-augite is from X=Z=bright green to Y=yellow green, but the depth of colour is variable. From a moderately saturated colour in most specimens the colour varies to a pale apple-green in others, whereas a few have a deeper colour than usual. It is probable that with a decrease in colour intensity, there is a decrease in the Na content of the pyroxene. The analyzed specimen (Table 2) is of average colour and comes from a pegmatitic lens containing about 70 per cent aegirine-augite as acicular crystals up to 50 mm long, and interstitial quartz and perthite. When compared with analyses of other aegirine-augites presented in Deer and others (1963, vol.2, p.82-84), the Peak Charles material differs only in having a low Al_2O_3 and TiO_2 content, and a slightly higher than average MnO content. The optical properties given in Table 2 were made on single grains mounted on a spindle stage (Bloss and Light, 1973) by the method suggested by Joel (1963). Density was determined by the method of Ellsworth (1928). The results fit reasonably well with the graphs drawn by Deer and others (1963, vol.2, p. 87) for an aegirine-augite containing approximately 24 per cent of the aegirine molecule.

TABLE 2. Chemical and mineralogical data for aegirine-augite

			No. of ions on basis of 6 (O,OH.)	
SiO_2	52.02			
TiO_2	0.15	Si	1.997	2.00
Al_2O_3	0.76	Al'	0.003	
Fe_2O_3	8.15	Al	0.030	1.02
FeO	8.36	Fe^{3+}	0.235	
MgO	8.12	Fe^{2+}	0.268	
CaO	17.67	Mg	0.464	
Na_2O	3.17	Ti	0.004	
K_2O	0.05	Mn	0.023	
H_2O^+	1.33	Ca	0.727	0.97
H_2O^-	0.10	Na	0.236	
P_2O_5	0.04	K	0.002	
MnO	0.72			
Total	100.64			

Specimen 29816: Pegmatite rich in pyroxene from Peak Charles
Analyst: N. Marsh, Government Chemical Laboratories

1. Cell dimensions:
   $a = 9.751 \pm 0.052$ Å, $b = 8.949 \pm 0.044$ Å, $c = 5.258 \pm 0.034$ Å,
   $B = 105.91^\circ \pm 0.24^\circ$, axial ratios: a:b:c = 1.090:1:0.588
   unit cell volume: 441.25 $Å^3$
2. Refractive indices:
   $\alpha = 1.710$, $\beta = 1.722$, $\gamma = 1.735$ (all $\pm$ 0.002)

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TABLE 2 - continued

3.	2V = 82°, Extinction angle X∧c = 30°
4.	Pleochroism: X = bright green, Y = yellow green, Z = bright green. dispersion: r>v (moderate).
5.	D = 3.4395 ± 0.0002.

TABLE 3. Aegirine-augite X-ray diffraction data

I	$d_{obs.}$	d_{calc}	hkl	I	$d_{obs.}$	hkl	I	$d_{obs.}$	hkl
27	6.495	6.474	110	5	2.111	$42\bar{1}$	3	1.587	530
7	4.701	4.689	200	3	2.043	$32\bar{2}$	3	1.564	600
14	4.476	4.474	020	3	2.020	240	16	1.551	350
3	3.360	3.355	$12\bar{1}$	2	1.954	141	3	1.528	$62\bar{1}$
95	3.235	3.237	220	2	1.899	$51\bar{1}$	3	1.508	$61\bar{2}$
43	2.996	2.996	$22\bar{1}$	4	1.860	331	6	1.488	123,124
100	2.952	2.951	310	10	1.836	$42\bar{2}$	18	1.424	531,450
13	2.901	2.836	$31\bar{1}$	3	1.776	421	5	1.409	152
13	2.571	2.571	$31\bar{1}$	16	1.754	$50\bar{2}$	5	1.332	252,$61\bar{3}$
14	2.534	2.534	$20\bar{2}$	2	1.675	042	10	1.325	512
12	2.521	2.518	221	10	1.627	$53\bar{1}$	3	1.283	323,522
3	2.349	2.344	400	16	1.617	440	3	1.262	$64\bar{2}$
3	2.306	2.303	311						
2	2.221	2.217	112						
2	2.205	2.205	$22\bar{2}$						
28	2.158	2.158	330						
29	2.136	2.136	$33\bar{1}$						

The powder X-ray data, Table 3, were measured from diffractometer traces. A parameter refinement using the CELFIT program described by Pryce (1970) gave a = 9.751 Å, b = 8.949 Å, c = 5.258 Å and β = 105.91°. The pattern was initially indexed from the data of Frondel and Ito (1966) for an aegirine-augite of similar aegirine content but with a considerable manganese and zinc content. The resulting cell parameters for the Peak Charles material show some variation from the zincian aegirine-augite, particularly in the angle β. When compared with a more 'normal' aegirine-augite from Canada containing 77 per cent aegirine (Nickel and Mark, 1965) the differences in all parameters are considerable. Little information exists on the variation of cell dimensions with composition for the series aegirine - aegirine-augite, but a study of the synthetic series aegirine-diopside by Nolan and Edgar (1963) indicates that the dimensions a and b decrease whereas c and angle β increase with increasing aegirine content. Using the data of this paper and that found by Nickel and Mark there is a suggestion that, although the absolute values differ considerably, the same relationship holds for a, b and c in the natural material whereas the angle β moves in the reverse direction. The reason for this deviation is not known.

AMPHIBOLE

The aegirine-augite is commonly altered to a blue amphibole, pleochroic from a pale straw yellow to varying shades of blue grey. Invariably the amphibole is charged with octahedra of magnetite and blebs of quartz (Plate IV) which indicate that, even in specimens without pyroxene present, the amphibole is an alteration product of aegirine-augite. The patchy colouring probably indicates a variation in composition, but because of the granular nature of the amphibole it is difficult to determine optically. Some of the darker patches of amphibole have a strong dispersion and anomalous birefringence and are possibly arfvedsonitic in composition.

SPHENE

Sphene is a constant and distinctive minor component of all rocks from the Fitzgerald Peaks; it is rarely absent from a thin section and is commonly present at about the 1 per cent level (Table 1). Its form varies from anhedral rounded blebs to well-formed lozenges and tabular shaped crystals up to 2 mm long. The distinctive features which separate it from sphene found in the surrounding granite batholith are its colour and alteration. In hand specimens sphene can sometimes be seen as orange-brown crystals although in thin section the mineral is pale brown and patchily zoned to orange-brown. The crystals are moderately pleochroic in shades of orange-brown, and the birefringence is noticeably lower than normal sphene.

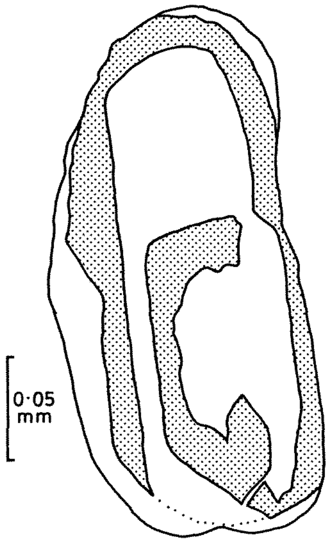

Figure 2. Zoned metamict sphene. Fresh sphene stippled, metamict zones clear. See also Plate VIII (GSWA 17333)

According to Deer and others (1962, vol.1, p.74) the lower birefringence and stronger colour can be correlated with a low Ti and high Fe_2O_3 content for the mineral. The orange hue might be due to the presence of significant amounts of rare earths in the sphene. In most specimens the larger sphene crystals show some degree of alteration, marginally or along cleavages and fractures, to a dark red-brown iron-stained material, but in a few the alteration is to a yellow or orange-brown high relief material which is isotropic or nearly so. In the specimen illustrated (Fig.2 and Plate VIII; sample 29818) there is a narrow outer zone of orange sphene with a zone of pale coloured sphene, and a core of nearly isotropic orange material and sphene. Specimen 29836 shows a large crystal of sphene which has been altered to needles of an opaque oxide, areas of isotropic semitransparent material, and areas of colloform transparent orange material. Sahama (1946, p.116) describes similarly zoned and altered sphene from Finland the analysis of which contained significant amounts of rare earths. X-ray photographs by Sahama also revealed the presence of anatase in the altered material. No mineral identifiable as anatase was seen in the Fitzgerald Peaks rocks but it is probably present in a finely divided state in the altered sphene.

ACCESSORIES

Accessory minerals include magnetite, apatite and zircon. All occur in the small amounts usual for granitic rocks; but in a few specimens apatite, as prisms up to 2 mm long, forms 2-3 per cent of the rock. Apart from the amphibole derived from aegirine-augite and the material derived from the breakdown of sphene, the only secondary minerals present are a little carbonate and rare fluorite.

CHEMISTRY

TABLE 4. Chemical analyses of rocks from Fitzgerald Peaks

Sample no.	29809	29831	29818	29821	A
SiO_2	62.17	69.82	63.18	61.67	61.68
TiO_2	0.85	0.13	0.27	0.57	0.58
Al_2O_3	16.85	14.90	15.93	16.23	16.91
Fe_2O_3	1.79	0.72	0.83	1.15	2.32
FeO	2.71	1.14	2.19	1.85	2.63
MgO	1.35	0.23	1.09	0.58	0.96
CaO	2.72	1.18	2.48	2.61	2.54
Na_2O	4.58	5.27	5.40	5.74	5.46
K_2O	4.18	4.29	6.03	5.56	5.91
H_2O^+	0.73	0.52	0.66	0.58	0.53
H_2O^-	0.60	0.06	0.14	0.08	-
CO_2	0.00	0.00	0.00	0.00	-
P_2O_5	0.32	0.06	0.38	0.31	0.19
MnO	0.02	0.05	0.09	0.12	0.11
Total	98.87	98.37	98.67	97.05	100.00

TABLE 4 - continued

C.I.P.W. norm

Q	11.62	19.67	3.25	2.53	
C	0.61	-	-	-	
Or	24.69	25.35	35.61	32.86	
Ab	38.75	44.59	45.69	48.57	
An	11.41	4.32	1.44	2.11	
Di	-	1.00	6.97	6.35	
Wo	-	0.49	3.50	3.19	
En	-	0.15	1.64	1.44	
Fs	-	0.36	1.83	1.73	
Wol	-	-	-	0.50	
Hy	5.51	1.43	2.30	-	
En	3.37	0.42	1.09	-	
Fs	2.15	1.02	1.22	-	
Mt	2.59	1.05	1.20	1.66	
Il	1.61	0.25	0.52	1.08	
Ap	0.75	0.14	0.89	0.73	

Analyst: N. Marsh, Government Chemical Laboratories. CO_2, H_2O and FeO by chemical methods, remainder by X.R.F.

28909 : Biotite adamellite

28931 : Aegirine-augite granite

29818 : Quartz syenite

29821 : Syenite

A : Average alkali syenite (Nockolds, 1954)

TABLE 5. Partial chemical analyses of rocks from the Fitzgerald Peaks area

Sample no.	28861	28862	28864	29803	29817	29835
MgO	0.53	0.26	0.57	0.19	0.46	0.24
CaO	2.28	0.70	2.06	0.96	1.31	1.66
Na_2O	4.17	3.10	4.25	4.17	5.80	4.05
K_2O	2.75	5.10	2.90	4.44	4.30	3.40

28861-62-64 : Porphyritic biotite granodiorite and adamellites, major batholith surrounding Fitzgerald Peaks

29803-17-35 : Pyroxene granites, Fitzgerald Peaks.

The essentially similar nature of all the rock types from the Fitzgerald Peaks is shown by the chemical analyses of Table 4. Soda and potash values are high in each of the analyzed specimens, and the only significant variations are in the SiO_2 values which decline with falling modal quartz (Table 1), and Al_2O_3 which rises with total modal feldspar. The analysis of sample 29821, a syenite with only 1 per cent modal quartz is similar to Nockolds' (1954) average for an alkali syenite in all except iron content. A strict comparison of the norms of Table 4 and the modes of Table 1 is not possible due to the presence of a soda-bearing pyroxene in the rock, but the most notable omission from the norm is sphene which although present in small amounts is so prominent in the rocks.

The similarity of the biotite adamellite to the main mass of the Fitzgerald Peaks is also shown by the analyses where it is seen that a slightly lower alkali content is the only distinctive chemical feature of the adamellite.

DISCUSSION

The Fitzgerald Peaks Syenite is a diapiric body intruded into an Archaean granite. Foliation and banding in the rock indicate that the intrusion probably narrows downward, and the presence of modal aegirine-augite suggests a high level intrusion. Beyond these generalized and tentative conclusions problems arise because the uniformity of the rock types and the isolation of the intrusion within a 'sea' of granite, allow no more than speculation as to the origin of the magma or its age. No structures within the surrounding granite were observed which could be connected to the intrusion of the syenite, but perhaps the presence of basic dykes within the mass and their absence from the granite give an indication. As noted above the dykes vary from normal, parallel-sided post-syenite intrusions to highly metamorphosed and streaked out rafts. It appears possible that, at the time of intrusion of the Fitzgerald Peaks mass, a local 'hot spot' had developed which allowed both the intrusion of basic dykes and the development of the syenitic magma. Early dykes were metamorphosed and partially absorbed as the magma was emplaced at higher levels, whereas later dykes remain. On this scheme the origin of the syenitic magma was anatectic, although to produce such an alkali-rich and quartz-poor rock a considerable degree of differentiation must have taken place. Assimilation of basic material from early dykes, although locally demonstrable, cannot have a great overall importance as no mixture of normal acidic and basic material would produce the chemistry observed.

From the contrast between the rock types and topography of the Fitzgerald Peaks with those of the surrounding Archaean granites, and the nearness of the Proterozoic Albany-Fraser Province, it is tempting to assume a Proterozoic age for the syenitic rocks. No structures within the syenite or surrounding granites provide evidence for this hypothesis, and there are no similar rock types known within the area of Proterozoic rocks. There is a small outcrop of quartz-poor rocks at Lake Shaster, about 70 km east-southeast of Ravensthorpe, but this is a biotite monzonite having an entirely different texture; the Fitzgerald Peaks Syenite more closely resembles the syenites found further north within the Archaean shield. Radiometric data reported by Turek (1966) support a Proterozoic age, but are open to various interpretations. Based on one whole-rock analysis and a feldspar separate from the same sample, Turek reported an age of 1 670 m.y. with the very high initial $^{87}Sr/^{86}Sr$ ratio of 0.7473. Assuming the data were correct, they not only indicate a Proterozoic age for the Fitzgerald Peaks, similar to ages found in the nearby Albany-Fraser Province (Arriens and Lambert, 1969, p.380), but also show that the magma must be of anatectic origin. Alternative interpretations (W. Compston, written communication) which would allow an Archaean age for the Fitzgerald Peaks rocks involve the assumption either of technical errors in the analysis, or the resetting of the feldspar during the Proterozoic. The only field evidence which suggests an age older than 1 670 m.y. is the presence near Annes Pass of a small exposure of norite (sample 29838). This appears to be part of a dyke which cuts the syenite and which might be related to the major east-west dykes dated by Turek at 2 420 $\pm$ 30 m.y.

Apart from the small intrusion at Yerilla noted by Honman (1917) recent regional mapping of the Eastern Goldfields Province by the Geological Survey has found numerous small, isolated bodies of alkalic rocks. These vary from porphyry dykes at Norseman and Widgiemooltha to larger bodies of syenite and quartz syenite in the Sir Samuel area. All these intrusions are characterized by the presence of aegirine-augite, often altering to an arfvedsonitic amphibole. These bodies are sparsely scattered over an area several hundred kilometres long and do not outline a definite alkalic province within the major greenstone belt of the Eastern Goldfields Province, nor can they be compared with the Fitzgerald Peaks rocks.

However, it is perhaps significant that no syenites are known from the other greenstone belts of the Yilgarn Block, and that within the Wiluna-Norseman belt the alkalic rocks are confined to a relatively narrow central zone.

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P L A T E S

PART IV

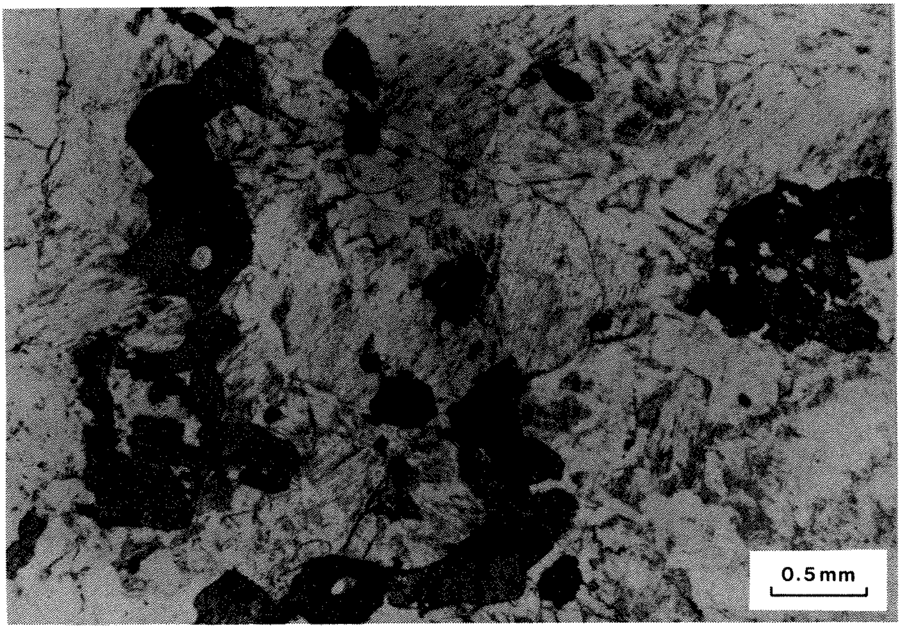

Plate I. 29833: Quartz syenite, Peak Charles. Anhedral aegirine-augite and subhedral sphene in a feldspar matrix (plane polarized light).

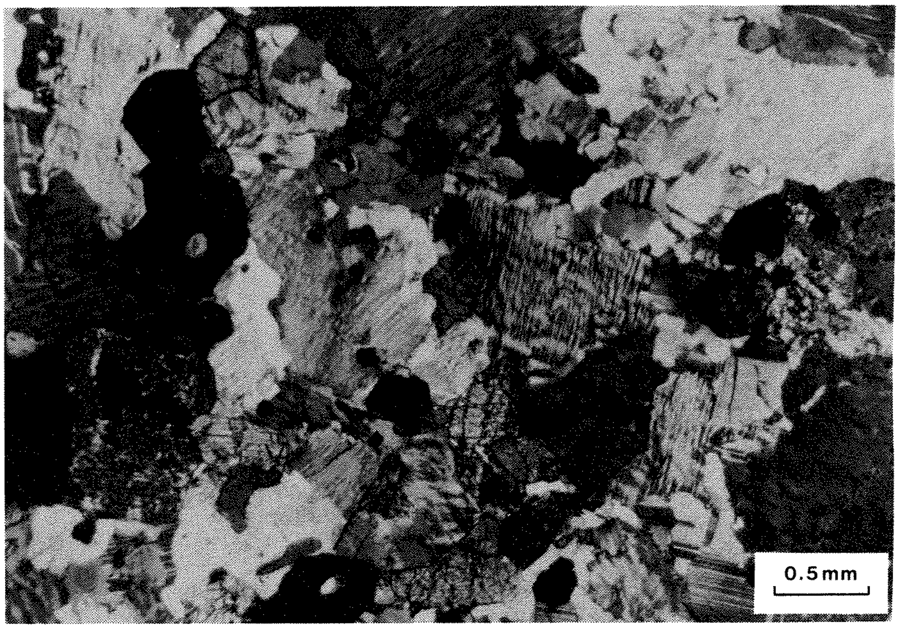

Plate II. 29833: Quartz syenite, Peak Charles. Note the predominance of perthitic microcline, but also the presence of finely twinned and myrmekitic albite (crossed polarizers).

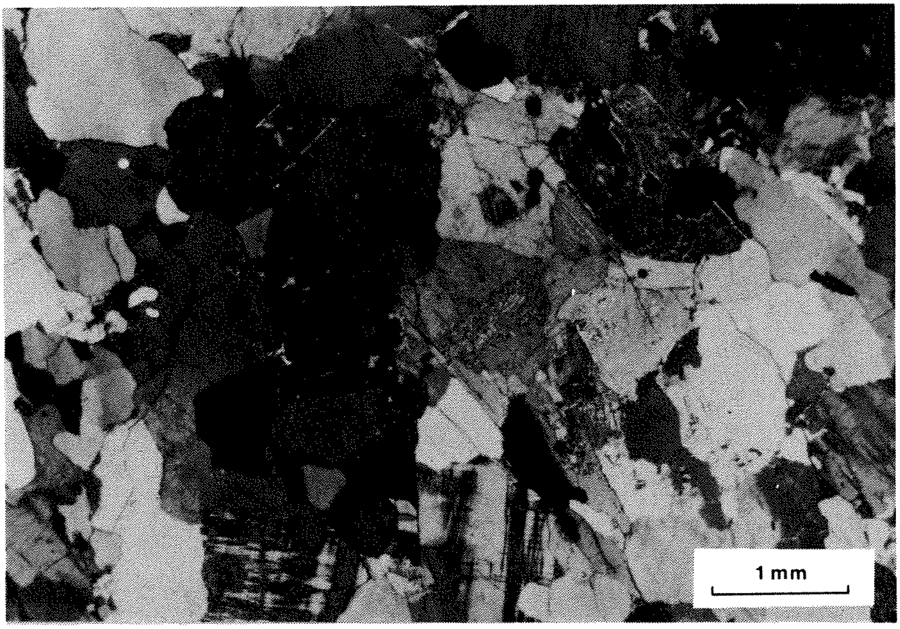

Plate III. 29809: Biotite adamellite, northwest of Peak Charles. Microcline and sodic oligoclase as separate phases and biotite as the principal mafic mineral (crossed polarizers).

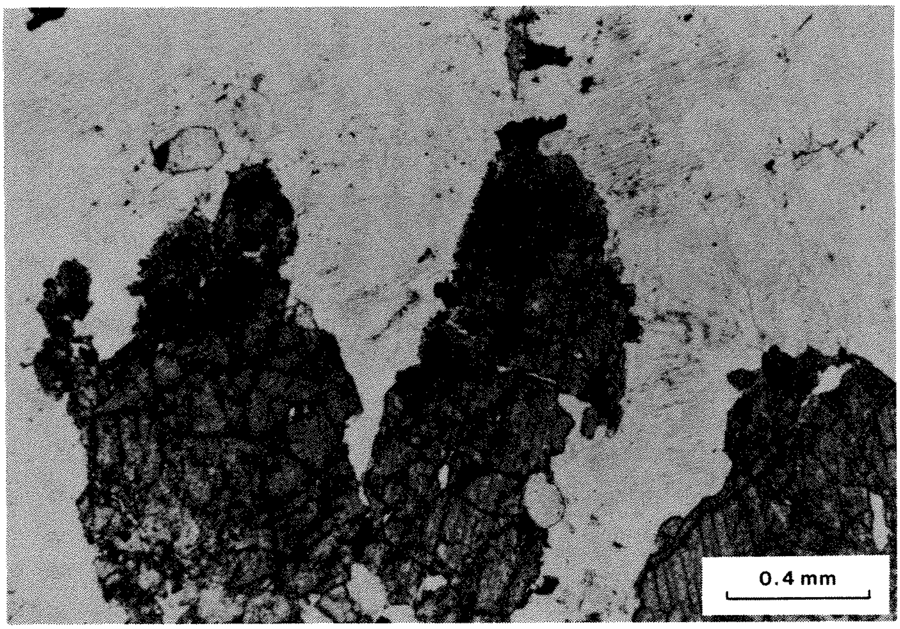

Plate IV. 29821: Aegirine-augite altering marginally to arfvedsonitic amphibole charged with granular magnetite (plane polarized light).

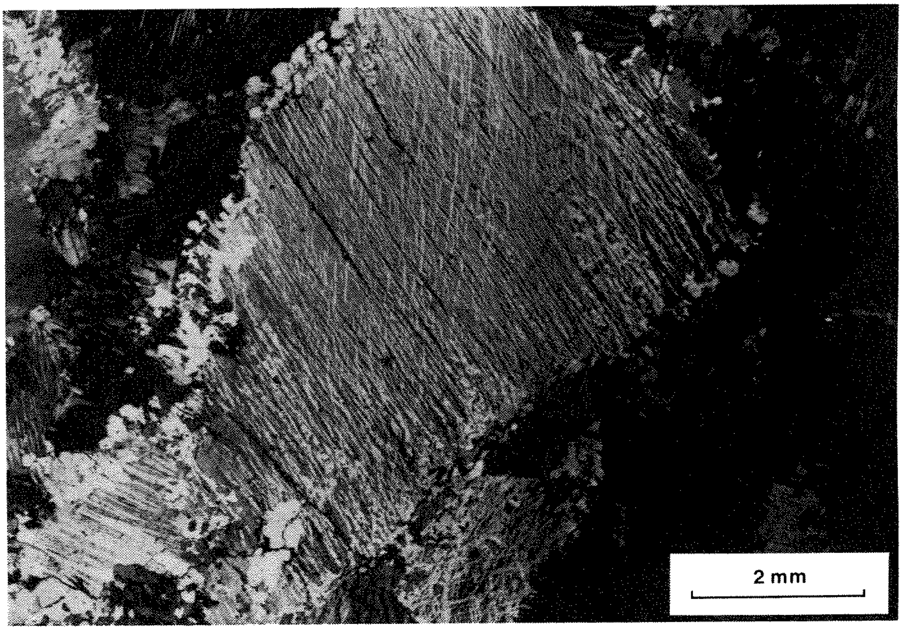

Plate V. 26680: Large perthite crystal with exsolved meshwork of albite and secondary spindles of microcline (crossed polarizers).

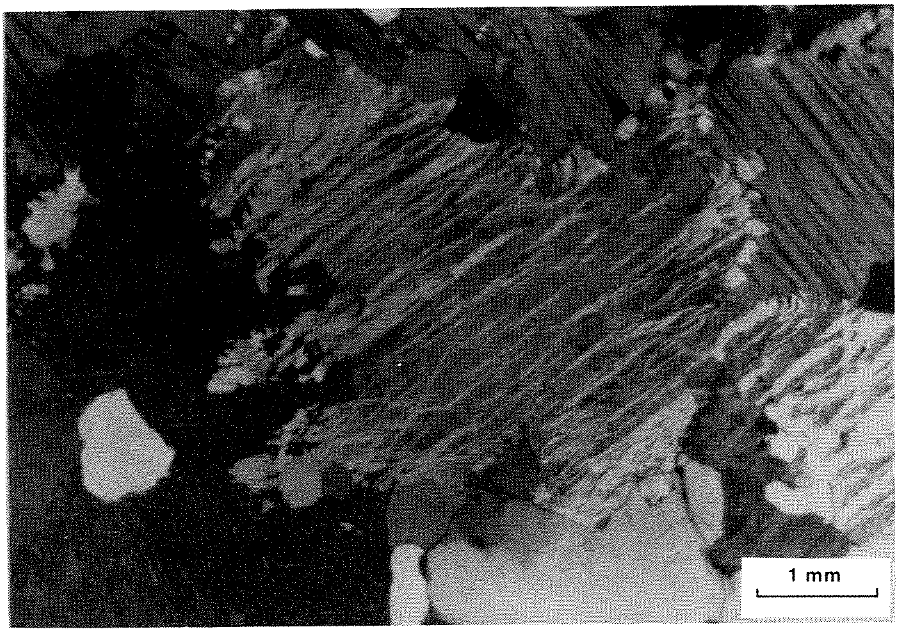

Plate VI. 29812: Perthite with highly sutured lobate margins towards adjacent perthite crystals (crossed polarizers).

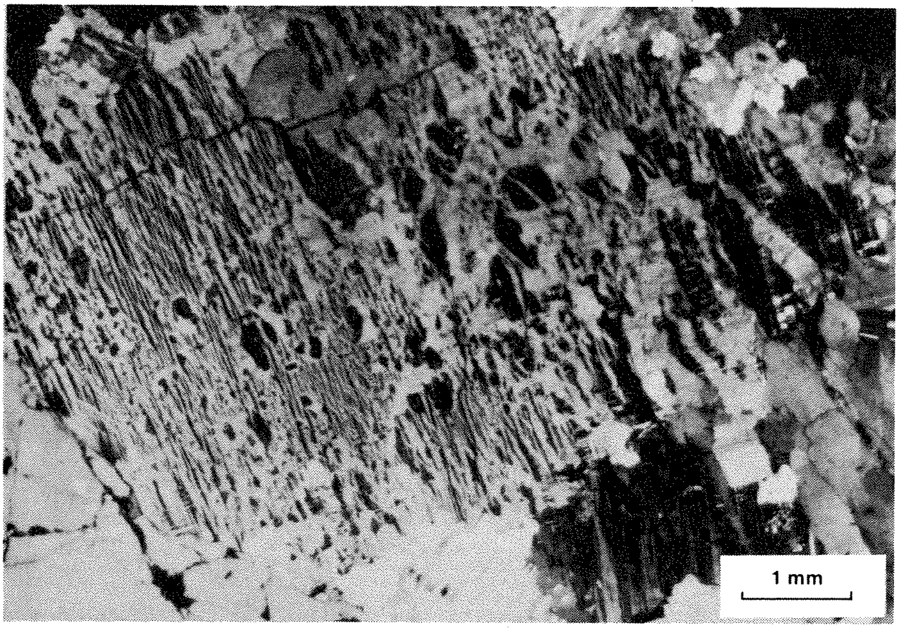

Plate VII. 29815: Perthite showing variations in single crystal from oriented spindles of albite to irregular exsolution veins. The albite is twinned perpendicular to the veins (crossed polarizers).

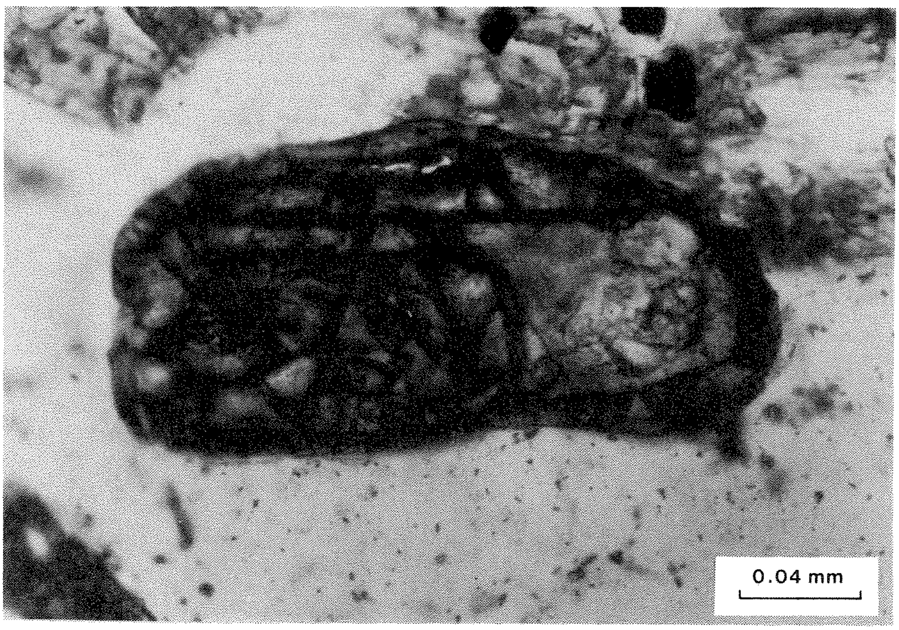

Plate VIII. 29818: Zoned metamict sphene (see also Fig.2).

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