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THE UNIVERSITY OF ADELAIDE

THE GEOLOGY OF THE HINCKLEY RANGES, W.A.

by Peter C. Smith (B.Sc.)

Honours Thesis, 1970.

THE GEOLOGY OF THE HINCKLEY RANGES, W.A.

A thesis presented

by

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ABSTRACT

The Hinckley Range is situated on the South Australia and Western Australia border between coordinates, latitude 26°05'S to 26°10'S, longitude 128°42'E to 129°05'E.

Lithological units include granulite facies rocks (mafic and felsic), granitoid intrusives, Giles Complex (meso gabbros, olivine meso gabbros, meso norites) and three distinct dolerite sets. All the above rock types have undergone severe cataclasis during the development of the Hinckley Mylonite Zone.

A sequence of events together with hypotheses for the genesis of the "mafic granulites" are proposed. These have been accomplished using field relations, structure, petrology, X-ray Diffraction (on the Giles suite rocks) and comparisons with similar provinces in other parts of the world.

INTRODUCTION

The Hinckley Range straddles the border between Western Australia and South Australia about 10 miles south of its junction with the Northern Territory border. (See locality map, Figure 1). Mafic granulites intruded by acid granulites with charnockitic affinities are separated from the Giles Complex gabbros by the Hinckley mylonite zone.

The area mapped covers approximately 100 square miles and lies 2 miles south of I.N.A.L.'s Wingellina camp. At its widest point the Hinckley Range is about 6 miles wide by approximately 25 miles long.

Isotope dating by Arriens and Lambert (1969) places an age of 1,380 ± 120 m.y. on the granulites of the Musgrave Ranges. It is assumed that the granulite facies metamorphism affecting the Hinckley Range is of the same age. The best age available for the Giles intrusion is 1,100m.y. (Oliver, et.al., 1969).

The present study was undertaken primarily in order to elucidate the genesis of the mafic granulites. Although this aim was not altogether satisfied some possible mechanisms have been postulated.

Finally it should be noted that this report can only be considered as a preliminary investigation of the area. The time available coupled with the relatively large area to be mapped prohibited the collection of a large amount of detailed information. Thus it is hoped that this paper will stimulate further interest which will lead to a more detailed approach to the problems of the area.

PREVIOUS INVESTIGATIONS

Although many papers have been written in recent years on other intrusions of Giles Complex material into the granulite and amphibolite facies country rock, little work has been undertaken specifically on the Hinckley Range. Daniels (1966) described the Hinckley Range gabbro as "occupying a syncline with N-NW axis whose southern limb thins to the west". Little or no igneous banding was observed until the thickness reached approximately 3,000 feet. Daniels interpreted the mafic granulites as contaminated Giles material, "transgressive sheets into the granitic and granulitic country rock". However there is reasonable evidence for the converse i.e. the granitic (charnockitic) rock is intrusive into the mafic granulite. (See Plate 1A).

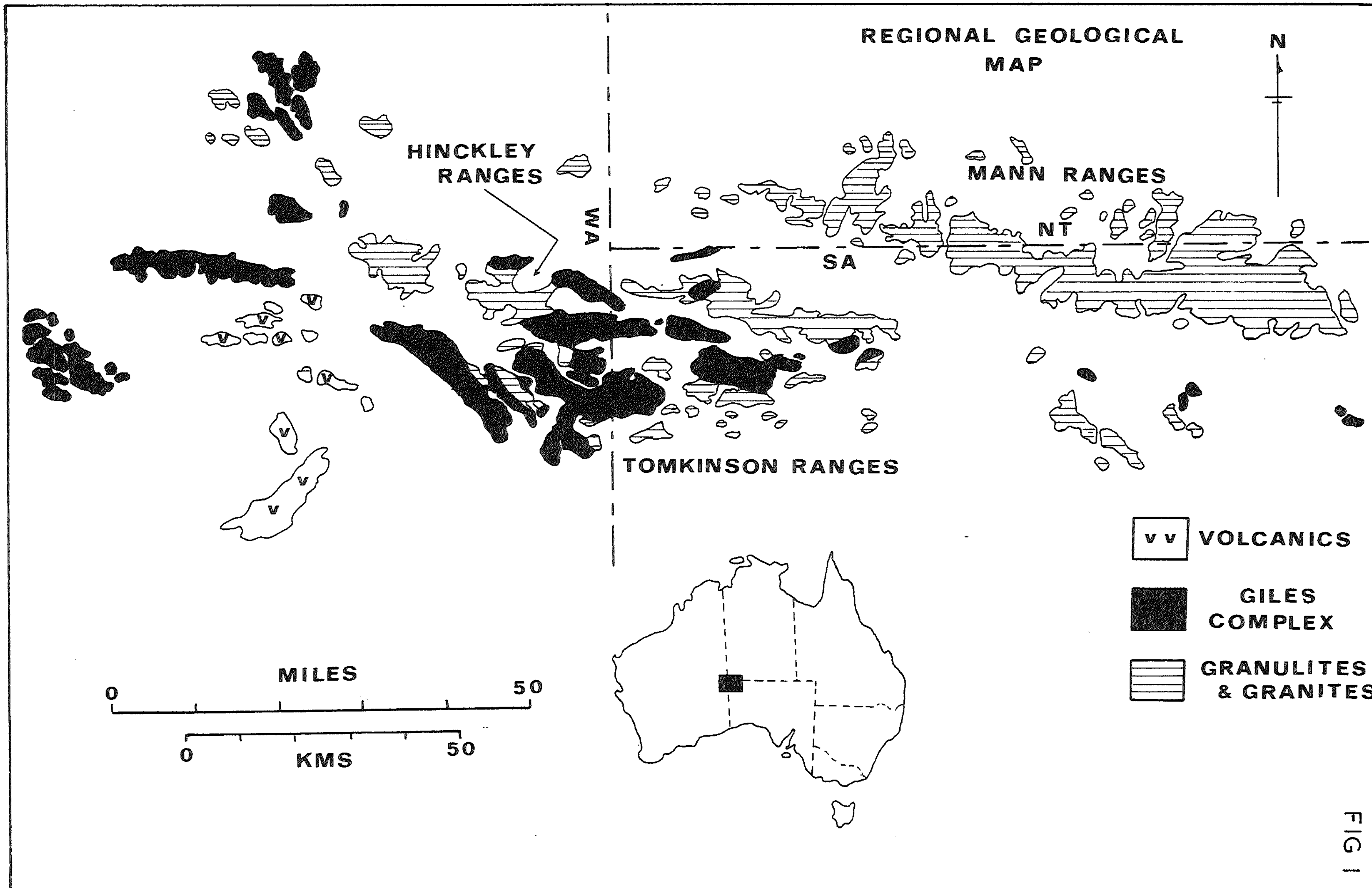

REGIONAL GEOLOGICAL
MAP
N
HINCKLEY
RANGES
WA
MANN RANGES
NT
SA
TOMKINSON RANGES
v v
VOLCANICS
GILES
COMPLEX
GRANULITES
& GRANITES
MILES
0
50
0
KMS
50

FIG I

Although most of the work done on the Hinckley Range by South West Mining Ltd. (now I.M.A.L.) between 1954 and 1957 was confined to the area north of the Gunbarrel Highway, i.e. the Northern Hinckleys, some large scale mapping of the area studied by the author was also undertaken. South West Mining Ltd. were naturally more interested in the highly weathered ultra-basic lenses of picrite and dunite which now outcrop as a nickeliferous ochre. It is interesting to note that no such ultrabasic lenses occur in the Hinckley Range but are confined to the cores of folds. They probably represent a later discordant intrusion.

Nesbitt and Talbot (1965) collected 19 samples from a traverse almost due south from Wingellina camp, some of which have since been described by the author. They recognised the Hinckley mylonite zone which was mapped by Thompson, (1964 Davies 1 mile, Geological Survey of S. Aust.) on the eastern side of the border. Primary dips measured by them pointed to a northerly facing for the Hinckley Range gabbros. This observation is supported by the author.

PHYSIOGRAPHY

Daniels (1966) describes the Giles Complex rocks and associated high grade metamorphics outcropping as "a series of monad-nocks in sand plain country". This definition succinctly describes the outcrop pattern of the Hinckley Range.

The hills themselves rise quite steeply out of the sand plain, particularly on the NW side, where felsic granulites define sharp ridges which parallel the regional strike of the range. The felsic granulites are well-jointed and weather to rounded tor-shaped boulders which in some places sit precariously on small ledges. Exfoliation was observed on a number of the more exposed felsic granulite boulders. (See Plate 1B).

The mafic granulites within which the felsic granulites intermittently outcrop, generally define steep-sided hills with plano-convex slopes. Soil cover on these hills is relatively light, with sporadic scrubby trees and patchy spinifex clumps as the only vegetation.

Most of the large stream beds run in a N-S direction, this being the direction of major shears dissecting the granulites. Tributary stream courses in a predominantly E-W direction contribute to the larger N-S trending creeks.

Flow along these water courses only occurs during periods of intense or prolonged rain.

Dolorite dykes define easily observed NW linear trends on the aerial photographs. These dykes were used as markers during field work by the author, as most of the hills of the range have little to differentiate them from their neighbours.

However the gabbros can be easily differentiated from granulites by their mode of outcrop. Whereas the granulites define plano convex slopes, the Giles material commonly outcrops as angular ledges which are apparent on observation of the aerial photographs. It was also noted in the field that the spinifex had a definite preference for the more magnesian soil associated with the weathering of the gabbroic rocks. The low frequency of shears in the Giles material is manifested in the paucity of stream courses within the gabbros.

Climate of the region is arid, with day temperatures during the time of mapping reaching 90-95°F, while night temperatures probably dropped below 50°F. Rainfall is extremely intermittent and irregular. However precipitation is very rapid and heavy when thunder-storms move down from the NW. This violent and infrequent rainfall is probably the single most important factor in sculpturing the present land form.

PROBLEMS IN FIELD WORK

The greatest single problem in field work was to cover the area to be mapped efficiently in the time available. It was realised from the outset that owing to the relative inaccessability of the area, all work had to be completed within the time allotted. Thus in order to adequately map the area it was necessary to walk roughly N-S traverses across the strike of the body. Little or no contact mapping was attempted except about the contact of the Giles Complex with the granulite country rock. However the mylonisation of this contact presented difficulties in interpretation.

Another factor which made field work difficult was the initial inability of the author to distinguish Giles intrusives from the mafic granulites. However after several days the following criteria were used to discern the two lithalogies:

1) the "recrystallised" nature of the mafic granulites. This was probably a purely subjective criterion, but it can be argued that mapping itself is subjective.

2) the presence of "blebs" or schlieren in the mafic granulites, coupled with isoclinal intrafolial folds, defined by quartz-perthite layers (See Plates 2A, 2F).
3) typical blocky outcrop of the gabbroic rocks, together with their associated "unrecrystallised" appearance.
4) association of spinifex with the gabbroic rocks. This was used in places where other criteria were not evident.

The last factor is of a non-geological nature but nevertheless important considering the terrain in which the mapping was undertaken.

An electrical fault in the vehicle being used necessitated a relatively early return from fieldwork, as use of the vehicle's lighting system would have rendered it inoperable (which the author discovered during the return to Adelaide). Furthermore 3 days were lost because of heavy rain which made some sections of the area inaccessable.

REGIONAL GEOLOGY

Giles Complex basic and ultrabasic rocks outcrop as thick sheets and plugs throughout the Musgrave Block (See Fig.1). They intrude acid, intermediate, and basic rocks of both granulite and amphibolite facies. The regional strike of the whole block is roughly E-W, with significant outcrop in S. Aust. W. Aust., and N.T. Structurally, the long axes of the various intrusions are parallel to the regional strike.

The Giles Complex parent magma probably had tholeiitic affinities as all of the ultramafic cumulates are dominated by orthopyroxene and olivine. (Nesbitt, et.al., 1969). The most common texture of the basic and ultrabasic intrusives is cumulative, with individual intrusions displaying well-developed fractionation. Because of the relatively thin lenticular nature of the Hinckley gabbro, primary igneous banding is not as well developed as it is in Mt. Davies, to the east, which has been well-studied and documented. (Nesbitt and Talbot 1966). The method of intrusion of the Giles material is thought to be in the form of a series of sheets emplaced at different structural heights within the Proterozoic crust.

Granulites and their charnockitic associates have been documented by Wilson (1954), and more recently by the various Geology Surveys conducted by S. Aust. and W. Aust. Both "metamorphic" and "magmatic" charnockites have been reported. However on further investigation it could possibly be shown that both may be of sedimentary origin, but have undergone different degrees of mobilisation during granitisation or anatexis.

Throughout the whole of the Musgrave Block NW trending dolerite dykes define linear features which can be easily observed on aerial photographs (as noted in a previous section). A tentative correlation can be made with similar NW trending dykes reported in the Middleback Ranges, based on the petrology and magnetic properties of both sets. Nesbitt, et.al. (1969) subdivided the dolerites into four distinct sets on the basis of petrology and orientation.

On either side of the Musgrave Block lie younger sediments, to the north the Amadeus Basin, and to the south the Officer Basin.

STRUCTURAL GEOLOGY

Although structural information was gathered at regular intervals during traverses, the interpretation given below should only be regarded as preliminary. The nomenclature used is that adopted by Nesbitt et.al., (1969) and Oliver et.al., (1969) for the granulite facies rocks of the Musgrave Block. Most structures defined by this scheme have been recognised in the granulites of the Hinckley Range.

S_0 - discontinuous compositional layering represented by alteration of acid and basic lenses ranging in scale from a few millimetres e.g. Slide 333-28 to several tens of metres e.g. ridges of felsic granulite as described above. (See Plates 2D and 2E).

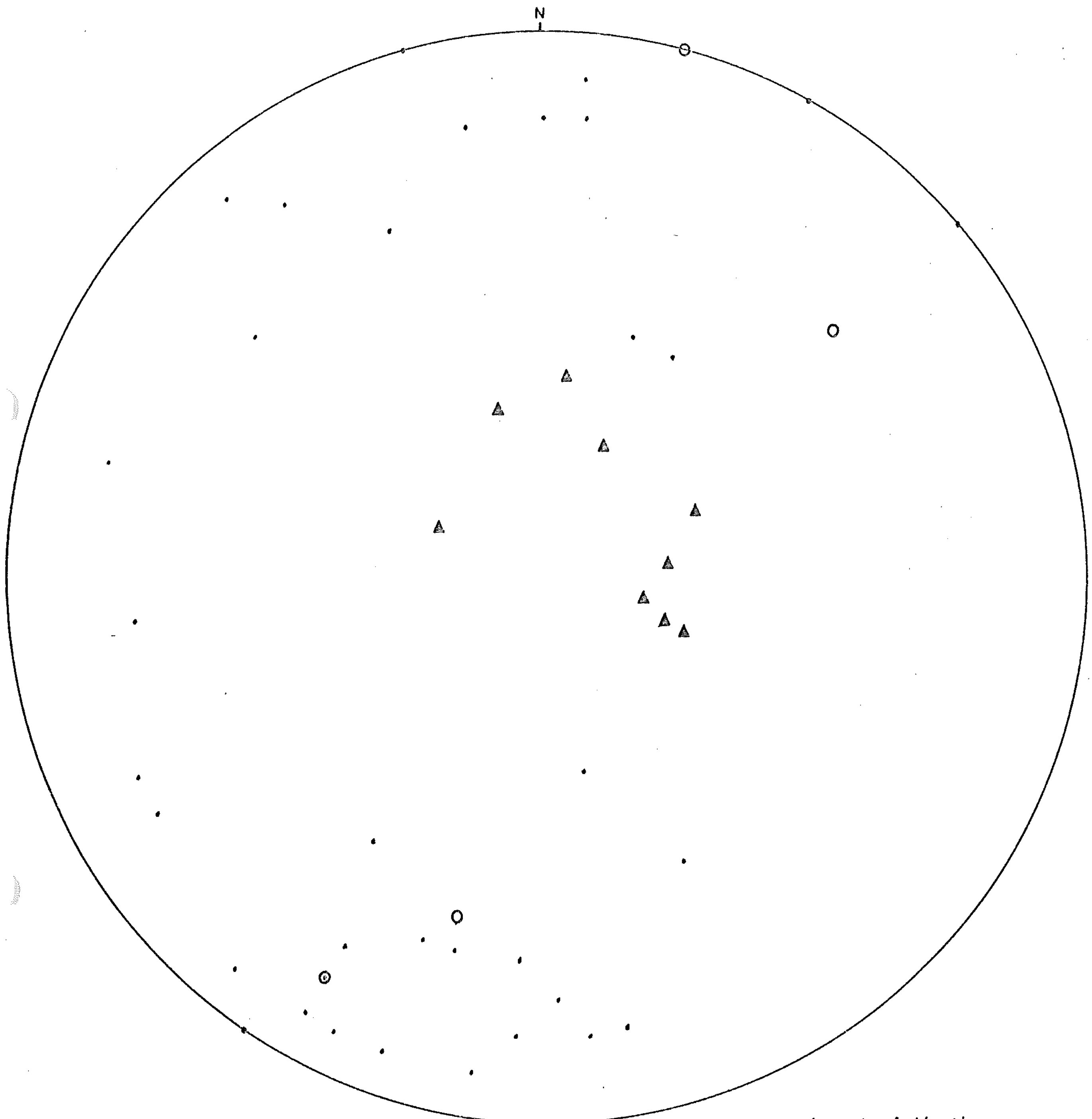
S_1 - foliation (schistosity generally parallel to the compositional layering S_0) imposed during the gneissic deformation. (See Plate 2F).

F_1 - tight, isoclinal, similar intrafolial folds as a result of D_1 deformation. (See Plates 2B and 2F).

L_1 - mineral elongation (streaking out of quartz in felsic lenses) in the direction of plunge of mesoscopic F_1 intrafolial folds.

S-Surfaces and Folds. Nesbitt et.al., (1969) have described "quartz rich laminae within some F_1 fold hinges which appear to have been deformed into very small rootless folds, producing a rodded linear structure containing remnant fold hinges. With further flattening these rootless folds degenerate into flat rodded structures". The further flattening probably occurred during the gneissic deformation. (See Plate 2A). This mechanism is proposed by the author for the formation of the felsic (quartz-feldspar) "blebs" or schlieren described in the mafic granulites.

FIG 2



• poles to foliation

▲ lineation (mafic granulite)

o poles to bedding (GILES)

Another hypothesis which has been put forward to explain the "blebbing" is contamination of Giles material by felsic granulites, the so-called mafic granulites actually being interpreted as contaminated and recrystallised Giles. However the reported F_1 intrafolial folds defined by small-scale quartz-feldspar bands within the broader mafic bands invalidate such an hypothesis, because the F_1 deformation predates the intrusion of the Giles mafic and ultramafic suite of rocks. (Nesbitt et.al., 1969).

The S_o banding between the felsic and mafic granulites is possibly an indirect reflection of the original layering within the sediments which has subsequently been metamorphosed and transposed by later deformation. The large scale regional banding i.e. ridges of felsic granulite within the mafic granulite, probably represents original stratigraphic distribution. The finer-scale compositional variation possibly represents metamorphic processes of segregation and differentiation. (Moore, 1970).

Within the felsic granulites (which include rocks with charnockitic affinities) foliation is defined by streaking out of quartz grains and the development of feldspar augen. (See slide 333-1). In the hand specimen preferred orientation of ferromagnesian minerals (pyroxene, opx or cpx, hornblende and biotite) plus opaque defines the plane of foliation. Although the structural data is limited there is some evidence to show that the foliation within the felsic granulites parallels that in the mafic granulites ie felsic granulites and mafic granulites have both undergone gneissic deformation, producing S_1 foliation surfaces. See Fig. 2.

Daniels (1967) described the Hinckley Range gabbro as the southern limb of a syncline with N-NW trending axis. The Northern Hinckleys define the northern limb of this syncline. However no correlation can be made between these two limbs as the northern limb was not studied by the author. It occurs with associated weathered ultrabasics (in the form of a nickeliferous ochre) on I.N.A.L.'s nickel leases. The gabbros display only primary dip surfaces, defined by variation in the ratio of ferromagnesian minerals to felsic minerals, plus the superimposed gneissic deformation surface S_1. Poor examples of graded bedding were observed approximately 200 yards south of sample location point 333-39. F_1 generation folds are entirely absent within the Giles Complex, thus supporting the contention that the D_1 deformation (responsible for F1 intrafolials) predated the intrusion of Giles mafics and ultramafics.

? Do they really ?

PLATE 1

A

Intrusive contact of felsic rock with mafic granulite. Near sample point 333-31.

B

Exfoliation from a felsic boulder. Sphenoids are of included mafic granulite fragments.

C

Primary breccia. Zenoliths of mafic granulite. Indicating intrusive nature of the leucocratic material.

D

Agmatite. Fragments of mafic granulite within felsic intrusive.

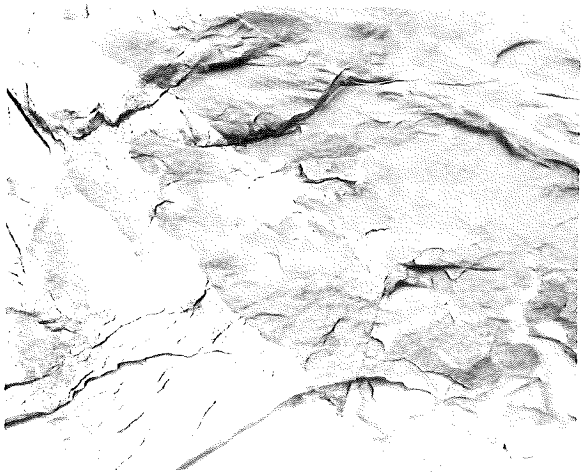
E

Agmatite. Fragments of "felsic granulite" included by mafic granulite. Illustrates original igneous nature of the mafic granulite.

F

Local development of migmatite near sample location point 333-100. Example of a "hybrid rock type".

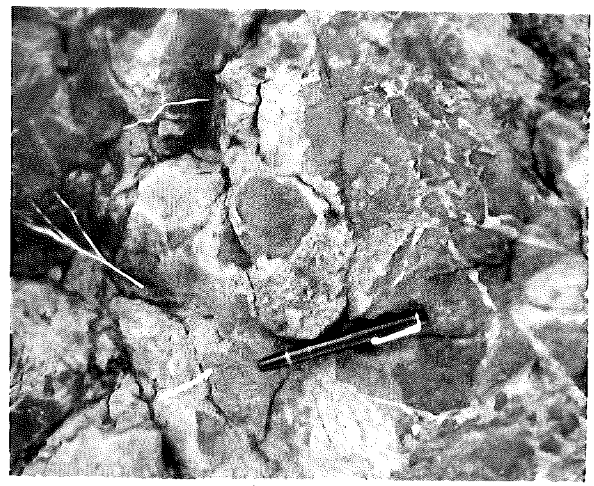
PLATE 1



A

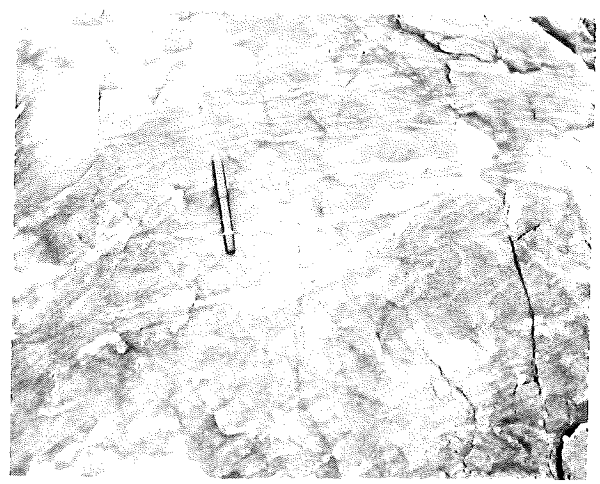
B

C



D

E



F

PLATE 2

A

Partial transposition of F1 intrafolial folds to form the blebs (schlimen) of quartz-feldspar.

B

Intrafolial F1 folds defined by both acid and basic bands.

C

A poor example of the F2 fold style showing the more open type. Rapidograph in the direction of the axial plane.

D

So - discontinuous compositional layering. Note lensing out of mafic bands.

Mylonite ?

E

So discontinuous compositional layering. In the approximate centre of the photograph note F1 intra folial define by a mafic lens.

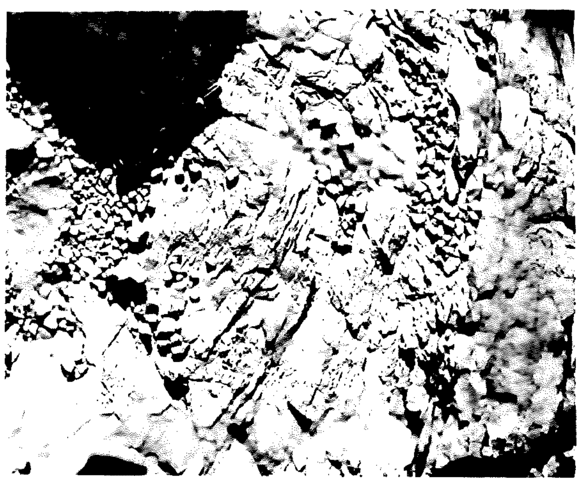
F

F1 - intrafolial folds. Note attenuation of fold limbs parallel to the S1 plane.

PLATE 2

A

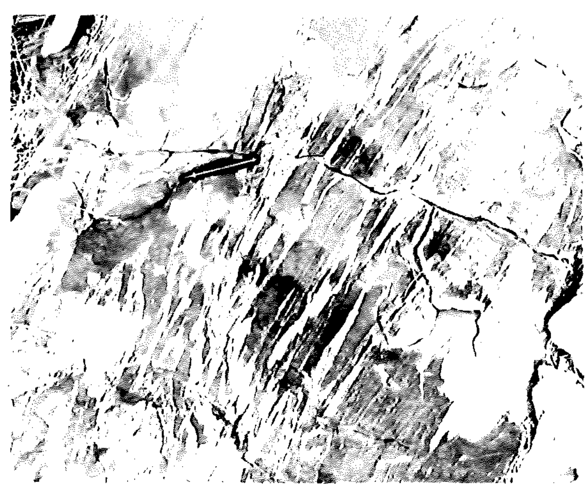
B



C

D

E



F

Although for the greater part, the strike of foliation within the Giles Complex basics is orientated in a WNW direction, there is some indication that the foliation direction changes to NW toward the western end of the intrusion. This folding is probably indicative of the F_3 deformation which broadly warped the Giles material and granulite country rock.

D_2 deformation (manifested as F_2 folds) was observed only infrequently in the field. (See Plate 2C). The F_2 fold style is easily differentiated from the F_1 intrafolials by openfold style coupled with a more weakly developed foliation. "In S-layered rocks the development of an F_2 axial foliation tends to be very weak". (Nesbitt et.al., 1969). The overprinting relations between F_1 and F_2 fold styles as described by Moore (1970) were not observed in the granulites of the Hinckley Range.

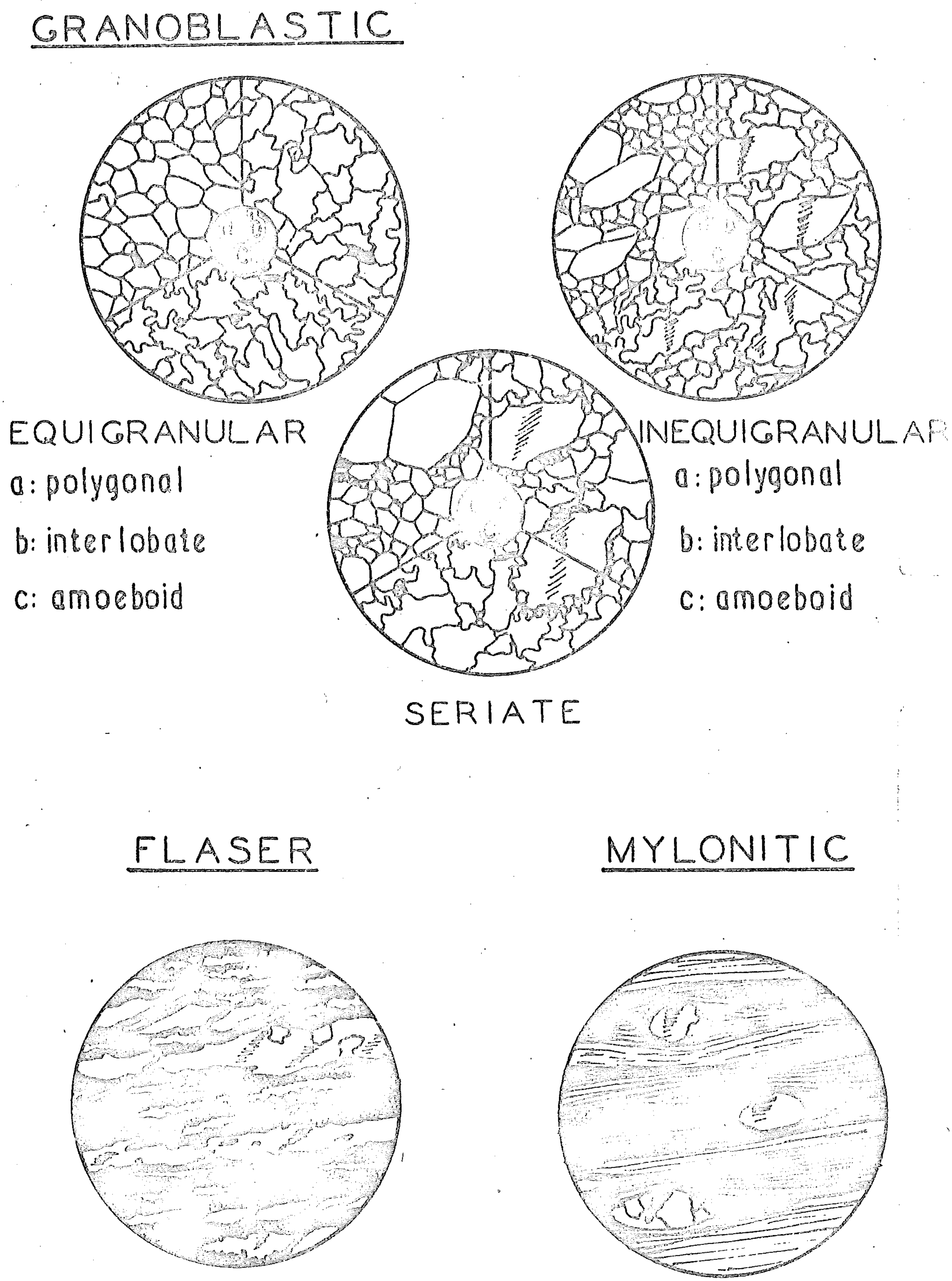
Lineations within mafic granulites were observed in the proximity of sample location points 333-86 and 333-28. The lineations are defined by streaking out of both felsic and mafic minerals in the plane of the S_1 foliation. A number of measurements were taken but because of the local nature of the readings, predictions on regional significance seem undesirable. The plunge of mesoscopic F_1 fold axes locally parallels the direction of mineral streaking. From the limited data taken, it would appear that the direction of plunge of the F_1 fold axes is approximately 70° in a NNE to NE direction.

<u>Faults, Shears, Mylonites and Pseudotachylites</u>

The most striking manifestation of "brittle fracture" within the Hinckley Range is the Hinckley Fault. This could be more correctly termed the Hinckley Mylonite zone, as it defines quite a broad strip (approximately half a mile wide) through the gabbros and a small section of the mafic granulites. Associated with the cataclastic deformation produced by the mylonite, are numerous very local developments of pseudotachylite. The extreme cataclastic texture of all the Hinckley Range rock types is very apparent on examination of thin sections. Undulose extinction, formation of secondary twinning and kinking of exsolution lamellae can all be observed.

In the field the mylonite zone can be readily identified - within the plane of the mylonite is a well-developed lineation which probably defines the direction of movement. At sample location point 333-25 the strike of the mylonite is essentially E-W while the "foliation plane" dips at 50° toward the north with a lineation pitching at 80° toward the east. This data was confirmed further east along the strike of the mylonite.

FIG 3



After Moore 1969

As mentioned above, pseudotachylites are locally developed in all rock types, including some dolerites. In thin section (See Plate 3F) the pseudotachylite is manifested as a dark grey-green coloured "glass", within which can be observed drawn out "augen" of partially vitrified minerals.

Small shears are common throughout the mafic granulites, but a marked decrease in occurrence was noted within the Giles Complex lithologies. They are readily apparent on aerial photographs and often provide planes of weakness for the courses of streams. The dominant shear direction is NNE, and may define an axial plane structure associated with the regional folding of the granulites. Supplementary shear directions were recognised approximately normal to the major NNE trending shears. N-S shears cut the mylonite zone near the contact of mafic granulites with Giles intrusives, and therefore must be the youngest deformation.

Three dolerite dyke suites corresponding to the type A, B and D subdivisions of Nesbitt, et.al. (1969) were recognised on petrological and geographic orientation criteria. These minor intrusives will be dealt with in a subsequent section.

Conclusions

Two fold styles have been recognised, F_1 with its tightly appressed, isoclinal introfolials and F_2, a more open structure. The S_1 foliation plane is parallel or sub-parallel to the S_0 compositional layering.

Both brittle and "flow-type" (mylonitic) faults exist, the former type probably being the last deformation to affect the area.

It is tentatively proposed by the author that the granulites and gabbros underwent F_2 deformation separately, and were later faulted into juxtaposition, probably prior to the Hinckley Fault. This is suggested because S_1 foliation in the granulites has been folded around a near-vertical NNE plunging fold axis (?), whilst the gabbros show no such structure.

PETROLOGY (GRANULITES)

a) Nomenclature

The terminalogy used to describe the textures of the granulite suite of rocks is that proposed by Moore (1970) in an attempt to standardise nomenclature. (See Fig. 3). The terms used are generally without genetic connotation i.e. essentially descriptive.

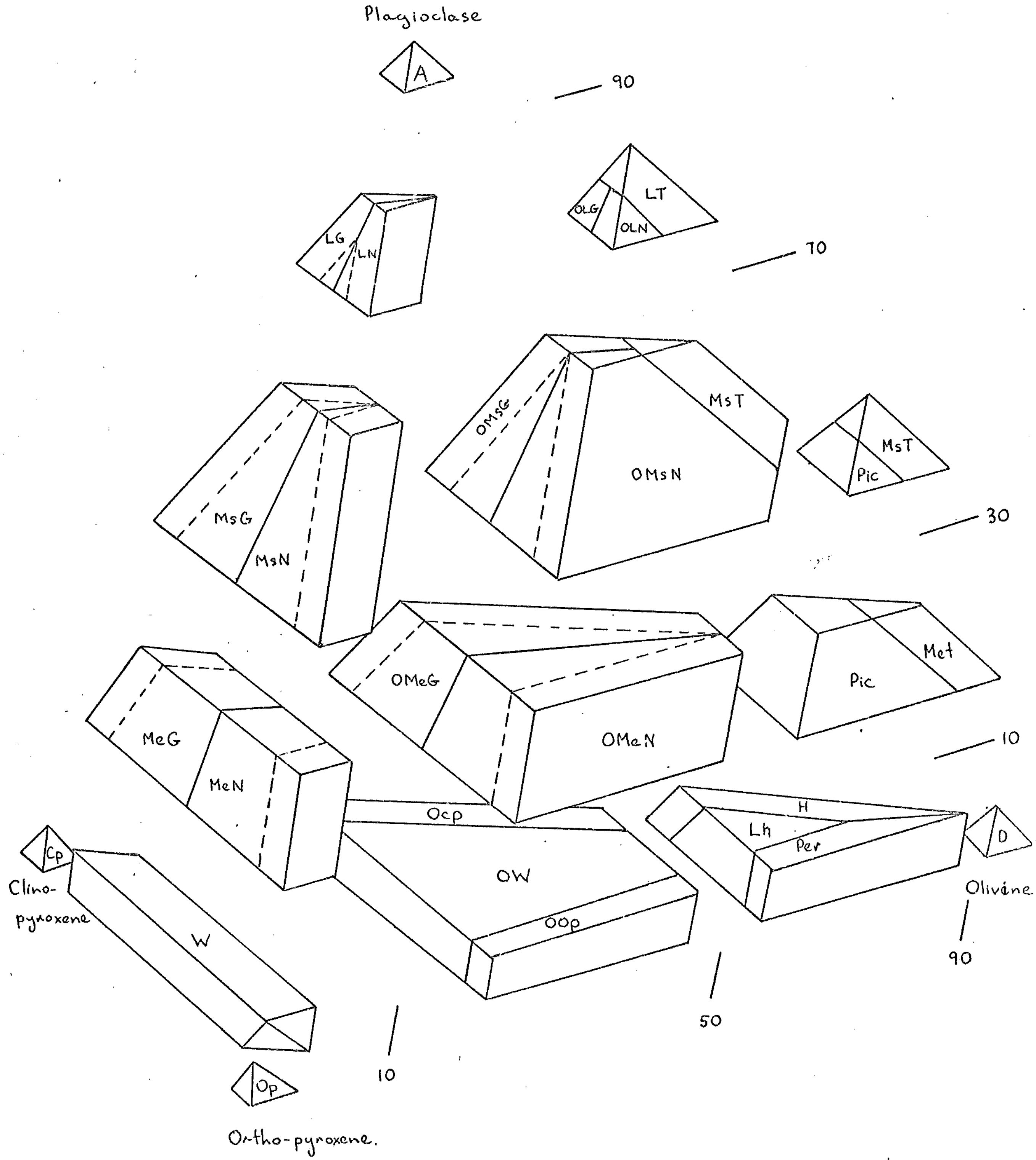
Explanation of Figure 4.

Opx - Cpx - Ol - Plag. Tetrahedron exploded at 10, 30, 70 and 90% critical plagioclase modes and 10, 50, and 90% olivine critical modes. Dashed divisions at 10% orthopyroxene and 10% clinopyroxene critical modes.

Abbreviations:

O = olivine
Op = ortho pyroxenite
Cp = clino pyroxenite
L = leuco-
Ms = meso-
Me = mela-
A = anorthosite
N = norite
G = gabbro
D = dunite
Pi = picrite
Per= peridotite
H = harzburgite
Lh = lherzolite
T = troctolite
W = websterite

FIG 4



After Goode (1970)

A system of classification proposed by Goode (1970) was used for the Giles Complex gabbroic rocks. (See Fig. 4). Goode found this system to be particularly successful in the naming of layered intrusives. Textural nomenclature used is that of Toplin (1964).

b) Mafic Granulite Petrography

Texturally these rocks have polygonal grain boundaries and display characteristic recrystallisation or annealing (Moore, 1970), and cataclasis. Generally they can be described as granublastic, equigranular, polygonal, but in some specimens porphyroblasts of perthitic K-feldspar, can be found. The occurrence of K-feldspar possibly suggests potassium metasomation during the emplacement of the "remobilised felsic granulites - charnockites". (Cooray, 1969). In some specimens, primary biotite defines crude foliation within the S_0/S_1 plane. Blebs (schlieren) of quartz-feldspar are also drawn out in this direction in a few specimens (e.g. 333-14, 333-33, 333-10 and 333-9). A doleritic type texture can also be observed in which the plagioclase grains are lath-like and extremely well zoned. The significance of this texture will be discussed in a later section.

The minerology of the mafic granulites is remarkably consistent. The essential minerals are antiperthitic plagioclase, diopsidic hedenbergite - augite (as the clinopyroxene), and hypersthene - bronzite (as the orthopyroxene). (See Plate 3A). Magnetite is the essential opaque. Accessory minerals are zircon, apatite, biotite, minor quartz, and brown-green hornblende. Myrmekitic intergrowths were recorded in some specimens. The above mentioned anhedral porphyroblasts of perthitic K feldspar occur intermittently (e.g. slide 333-14), and "porphyroblasts" of plagioclase (multiple twinning and zoning) with smaller subhedral grains of multiple twinned, zoned plagioclase enclosed within were also observed (e.g. slide 333-82). Plagioclase - this mineral is generally in the form of anhedral to subhedral grains which define triple point junctions with other plagioclase grains as well as the ferromagnesian minerals. Within each specimen (except for the plagioclase porphyroblasts) the size

PLATE 3

A

333-46 Mafic granulite.
Note polygonal texture.

- pl - plagioclase
- opx - onthopyroxene
- cpx - clinopyroxene
- bi - biotite
- oq - opaque. X63x.n.

B

333-73 "Felsic granulite".
Development of myrmekite between two perthitic K-feldspars.

- my - myrmekite
- per - perthite
- bi - biotite. X108x.n.

C

333-78 "Felsic granulite".
Note amoeboid texture with myrmekite development.

- or - orthoclase
- hb - hornblende
- bi - biotite
- my - myrmekite
- bi - biotite
- oq - opaque X108 x.n.

D

333-50 "Felsic granulite".
Amoeboid to interlobate texture.

- qt - quartz
- on - onthoclase
- oq - opaque
- hb - hornblende

X63 x.n.

E

333-101 Development of mylonite in "felsic granulite". Note augen development of partially vitrified grains within the mylonite band.

- mt - mylonite
- pl - plagioclase
- qt - quartz. X63x.n.

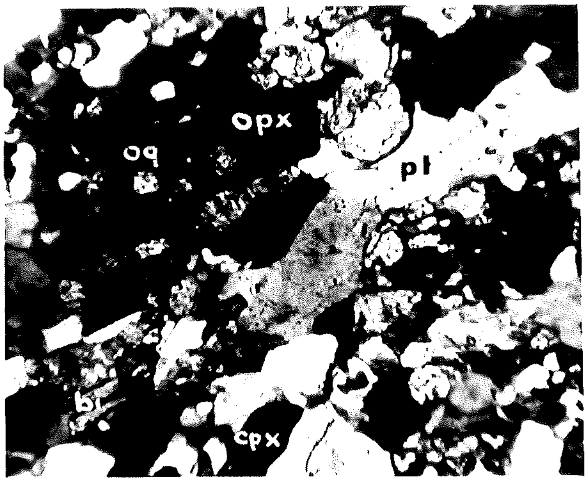
F

333-2 Development of pseudotaclylite within dolerite.

- pl - plagioclase
- oq - opaque
- ps - pseudotachylite
- cpx - clinopyroxene
- bi - biotite

X63 x.n.

PLATE 3



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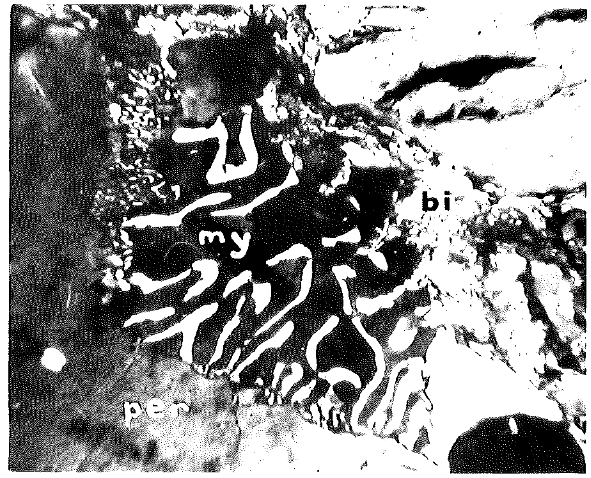

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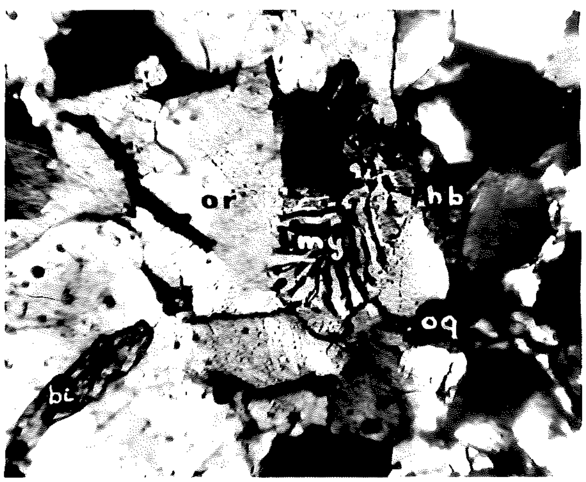

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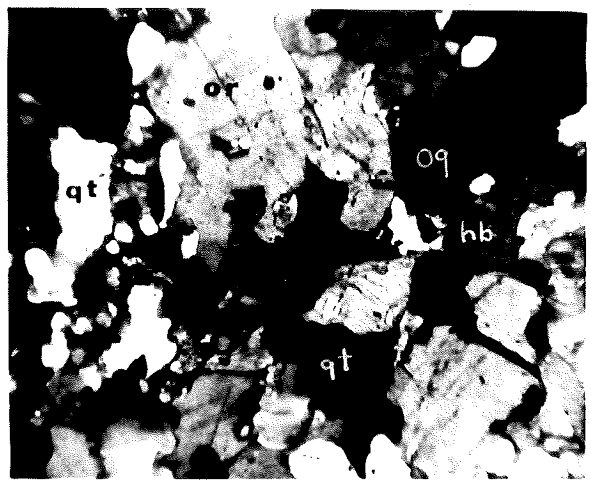

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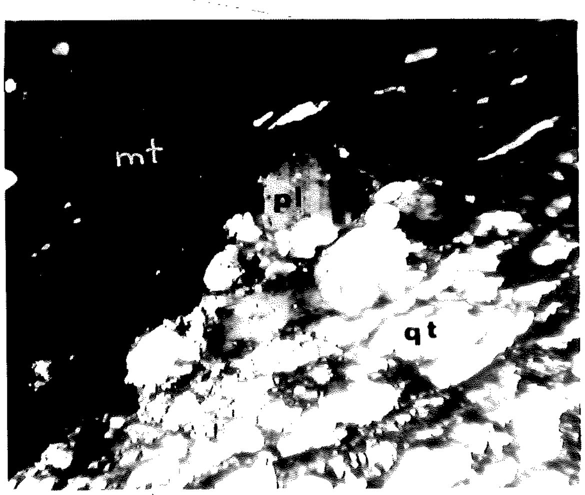

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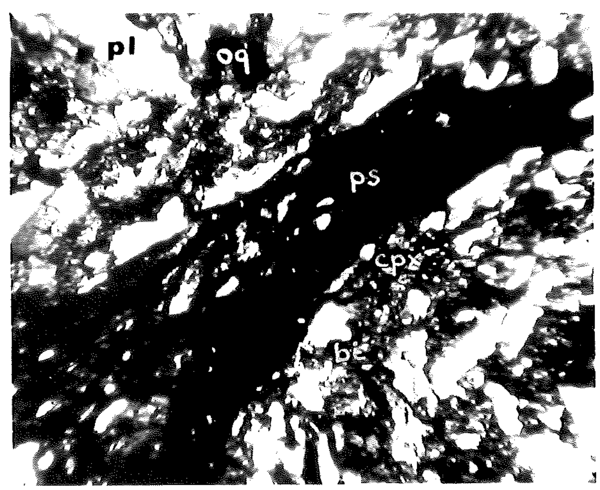


F

range is moderate, but from sample to sample grain size changes appreciably. It ranges from approximately 0.1mm - 1.5mm in the more or less equidimensional anhedral grains, to 3mm x 1mm for the lath-like zoned plagioclases in the "pseudo-dolerite" type mafic granulites. "Porphyroblasts" of plagioclase, containing smaller, subhedral plagioclase grains, reach dimensions of 15mm x 6.5mm. (e.g. slide 333-82). Many grains contain "dustings" of fine opaques which in some cases are aligned in crystallographic direction, but in general their distribution tends to be random. In one of the "doleritic type" mafic granulites the opaque dusting is restricted to the core of a strongly zoned grain. The significance of this phenomenon will be discussed in a later section. Multiple twinning is common, but not displayed by all plagioclase grains. Simple twinning occurs in a number of thin sections, and along the twin bound-aries are rows of fine opaques. Most of the plagioclase grains are strongly antiperthitic. This K feldspar exsolution varies from anhedral curved rods to quite euhedral square patches, the former being more prevalent. As well as the inclusion of fine opaque grains, acicular apatites are extremely common, and their habit is significant in the genetic interpretation of the mafic granulites. The plagioclase composition is difficult to determine because of extreme cataclasis of the rocks, producing secondary twinning (Cannon, 1966) which cannot be taken as representative of the original composition. However, composition is thought to be intermediate to calcic i.e. of labradorite composition. Quite often the plagioclase - pyroxene grain boundaries are defined by clusters of fine opaques which could represent a reaction between the two phases. In "contaminated" mafic granulites plagioclase megacrysts are often embayed with a myrmekitic intergrowth.

Clinopyroxene - like the plagioclase, this mineral is usually anhedral in habit with cleavage often well developed. Grains are generally polygonal in outline and of widely differing grain size - from approximately 0.1mm - 1.0mm. In many grains there is a reaction rim between the clinopyroxene and plagioclase which is very narrow and only discernible under crossed polars. Criteria used to distinguish clinopyroxene from orthopyroxene are the higher birefringence of the former, lack of marked pleochroism and exsolution of opaques. There are many inclusions (as well as exsolutions) of opaques, but inclusions of small anhedral embayed plagioclase grains are rare. Compositionally the clinopyroxenes are diopsidic-augite, with 2V = 60°. However low 2V values have been observed which correspond to a composition move toward the augite end of the scale. Thin mantles of highly pleochroic dark green hornblende frequently envelope the clinopyroxene grains, and they are invariably associated with fine opaques.

Opaque exsolution is generally in the form of thin rods, parallel to the cleavage direction, but more anhedral, irregular opaques are contained within many grains. It is not known whether these are inclusions or an exsolution phenomenon. Occasional twinning was also observed.

Orthopyroxene - this occurs as anhedral grains varying in size from approximately 0.1mm - 1.0mm. Triple point junctions between the orthopyroxene and other minerals are the most common relationship. As with the clinopyroxene, small anhedral inclusions of opaques are ubiquitous, with an occasional inclusion of anhedral plagioclase. Exsolution lamellae are quite common, but less frequent than in the clinopyroxenes. The intense pleochroism (salmon pink α to pale green γ) of the orthopyroxene, coupled with a negative sign and relatively high 2V, classifies it as hypersthene. As with the clinopyroxene, small clusters of fine opaque (with a slightly greenish tinge) outline many of the grains. Some grains of hypersthene are overgrown with clinopyroxene (augite) and although the latter has a higher birefringence, they extinguish together.

Opaques - they are generally anhedral, and except for the fine dusting within plagioclase grains, are solely associated with the ferromagnesians. Grain size varies considerably, but is usually in the range 0.1mm-0.6mm. The small clusters of opaque have been mentioned above. Mineragraphy on thin section 333-52 proved the opaque to be magnetite, with possible haematite exsolution. A similar exsolution of haematite from titaniferous magnetite was recorded by Moore (1970) from Gosse Pile, approximately ESE of the Hinckley Range. Mantles of biotite were sometimes seen about anhedral opaque grains. Euhedral exsolution of opaque from both orthopyroxene and clinopyroxene occurs in many specimens.

Biotite - occurs possibly as a primary mineral, but more probably as a later alteration product of the pyroxenes or opaques in the presence of water. Many opaques display a mantle of biotite. Grain size is generally 0.5mm, while actual content of mica can be 5-10%. An increase in percentage was noted near contacts with the felsic granulites. Typical biotite pleochroism (α yellow, $\beta = \gamma$, dark reddish-brown) was also observed, although in some basal sections biotite displayed little apparent pleochroism but remained dark rusty-red on rotation of the microscope stage. Where biotite is present, preferred orientation of grains is pronounced, probably due to the gneissic foliation. Small biotite flakes are occasionally included in plagioclase megacrysts (e.g. slide 333-79).

Apatite - acicular grains of apatite are ubiquitous throughout the mafic granulites, and are restricted to plagioclase, where they occur as small clusters of up to 20 needles, with no preferred orientation. As well as the needles, small equidimensional grains occur, but with a lower frequency of incidence than the acicular form. In many cases the length of the needle was found to be up to 20 times its breadth Hollow needles, as described by Wyllie, Cox and Biggar (1962) were found in thin section 333-81. The significance of these apatites will be discussed later.

Zircon - occurs infrequently as small, rounded highly birefringent grains within the plagioclase. It is distinguishable from the apatites by its habit, higher relief, and interference colours. Rounded zircons in small groups were found in mafic granulites contaminated with felsic granulite. Their rounded nature is significant in the interpretation of the genesis of the felsic granulites (See Discussion). Grain size is generally less than 0.1mm, although some exceptionally large grains were recorded.

Hornblende - generally occurs as a secondary alteration product, due to instability of pyroxene in the presence of water. An excellent example of this appears in thin section 333-5 which is a mafic granulite contaminated with felsic material. The hornblende has marked pale yellow-brown α - yellow-brown β - greenish-brown γ pleochroism, and is thus readily distinguished from the pyroxenes.

The secondary nature is obvious from the inclusions of remnant pyroxene found ophitically enveloped in the hornblende. Small inclusions of anhedral opaques are common. Rims of hornblende about pyroxene are to be found in most specimens, but this is possibly due to weathering rather than the "retrogressive metasomatism" described above.

Myrmekite - as with hornblende, it is commonly found in mafic granulites contaminated with felsic granulites. These rocks generally have a granablastic interlobate to amoeboid texture rather than the polyganal fabric common to most mafic granulites (eg slide 333-81). Quartz is also a common phase in these "hybrid" rocks. Myrmekite intergrowths were frequently found as embayments into meso to crypto perthite or multiple twinned plagioclase grains. In some contaminated mafic granulites myrmekite intergrowths may constitute as must as 2-3% of the rock. It may therefore be tentatively used to indicate contamination by felsic intrusions.

Quartz - occurs only in the rocks contaminated by felsic material. Where present, it has anhedral form (amoeboid to interlobate) and displays pronounced undulose extinction. Grain size varies considerably, from approximately 0.4mm to porphyroblasts of greater than 10mm. Quartz is invariably associated with the presence of myrmekite.

c) Felsic Granulite Petrography

The author has made no attempt to subdivide these, although in mode of outcrop and mineralogy considerable differences were apparent. Generally they outcrop as rounded boulders (some exfoliated, See Plate 1B) with a greasy, vitreous weathered surface. Many hand specimens display augen development of feldspars which are aligned with long axes parallel to the S_1 foliation plane. Foliation is also defined by streaking out of quartz grains, elongation of ferromagnesians, and opaques. Quartz often displays a faint blue colour, while the feldspars appear buff to pink-brown. The field appearance of these rocks is similar to that described by Subramaniam (1959) within the type charnockite province near Madras. It is thought by the author that 2 distinct types of felsic granulite exist:

1) a sedimentary type metamorphosed to granulite facies more or less in situ.
2) a remobilised palingenetic type of felsic rock (variously described as charnockites or hypersthene - adamellites) which were intruded into the mafic granulites.

It is beyond the scope of this report to classify individual outcrops in any way, but the author feels that the prominent ridges on the NW side of the ranges are of the first type. However Plate A1 is an excellent example of the second type which occurs a few yards upstream from sample location point 333-31. Texturally it is difficult to separate the two types of felsic rock See Plate 3C. Both display granoblastic inequigranular, amoeboid to interlobate texture with cataclasis manifested by undulose extinction (particularly of quartz) and distortion of plagioclase multiple twins.

Augen development of feldspar (meso to crypto perthite) is common and is well illustrated in slide 333-1. Essential minerals in the felsic granulites are quartz, meso to crypto perthitic K-feldspar, minor plagioclase and opaques. The ferromagnesian minerals associated with the leucocratic constituents vary considerably. They include diopside, orthopyroxene (hypersthene), biotite and hornblende. However, in slide 333-95 sphene is the only non-felsic mineral associated with the opaques. Accessories include, zircon, apatite and the above mentioned sphene. Myrmekitic intergrowths are common.

Quartz - occurs as anhedral amoeboid grains of widely differing size ranging from 01. - 2.0mm. In some of the more porphyroblastic specimens elongate grains have the dimensions 5mm x 2mm. Most grains are clear with rows of very fine inclusions possibly delineating former grain boundaries before annealing. Undulose extinction of quartz is particularly obvious in all thin sections. Inclusions of zircon occur infrequently and are confined mainly to perthitic feldspar. Stringers of quartz grains with long axes up to 15 times the breadth were observed enveloping porphyroblasts of meso perthite in slide 333-13 illustrating the severe distortion associated with the gneissic deformation.

Perthitic potassium feldspar - within the felsic granulites K-feldspar is only present with perthitic exsolution. See Plate 3B. The form of this exsolution varies from small rounded blebs to the more frequently observed curved rods of exsolved plagioclase parallel to the long axes of individual grains. The latter form would be described as mesoperthite with some examples becoming so fine as to be termed cryptoperthite. Grain size varies markedly from less than 0.1mm to elongate porphyroblasts with dimensions 5mm x 2.5mm. Associated with many mesoperthites are myrmekitic intergrowths which Hubbard (1966) considers as forming contemporaneously with perthitization. Inclusions of opaque, zircon, sphene and hornblende are frequent. Possible remnant simple twins were observed which were highly distorted and thus could have been confused with strain shadows.

Plagioclase - The presence of this phase is variable and never forms more than about 2-3% of the modal composition of the rock. Grains are anhedral and small with dimensions usually less than 0.1mm. Multiples twinning is the only way in which plagioclase can be recognised in this section. Consequently untwinned grains may not have been recognised thus lowering the recorded plagioclase modal percentages.

Hypersthene - Orthopyroxene occurs in relatively few samples and when present is the only ferromagnesian phase. The fact that pink-green pleochroism is marked was the criteria used to distinguish it from clinopyroxene. Cleavage is generally well developed. Grain size was found to be relatively constant at approximately 0.7mm.

Diopside - The assemblage diopside - hornblende - biotite is particularly common in the felsic granulites. Diopside (little or no pleochroism) occurs as anhedral aggregates of grains with associated opaques. Well developed cleavage is characteristic whilst 2V was found to be approximately 45°. Mantles of hornblende commonly rim the diopside hence indicating secondary alteration. Grain size is generally constant at about 0.5mm or less.

Hornblende - of the ferromagnesians in the felsic granulites, hornblende is probably the most common. It is characterised by light green α, brown green β and dark green γ pleochroism. Grain size, as with most of the minerals in the felsic rocks is variable but is generally less than 0.5mm. Associated with hornblende are opaques as discrete grains or as inclusions. Minor hornblende occurs as thin rims about clinopyroxene. In well foliated specimens the long axes of hornblende grains are aligned parallel to the S_1 surface.

Biotite - characterised by typical pleochroism, mica is found in association with all the other ferromagnesians except hypersthene. Clusters of mica are frequently observed with long axes aligned in the S_1 foliation surface. Opaques are frequently contained within biotite flakes possibly indicating a retrogression of the opaque or reaction of the opaque with the enclosing potassium feldspar. Grain size is generally less than 0.3mm. but varies considerably from one specimen to another.

Zircon - This accessory is common to almost all the felsic granulites. Habit is in the form of well rounded anhedral grains which are easily recognised because of their high birefringence and relief. Grain size is generally of the order 0.05mm. The rounded form of the zircons as well as one instance (333-13) where a brownish core is overgrown with colourless zircon possibly indicates that the felsic granulites are regenerated sediments.

Apatite - Where observed, the apatites have anhedral essentially equidimensional form as distinct from the acicular apatite described in the mafic granulites. Grain size is generally less than 0.02mm. It is most commonly found in intergranular quartz, boardering ferromagnesian minerals.

Sphene - Sphene could be used to distinguish the granulite facies felsic rocks from the later intrusives using Turner's (1968) contention that sphene is not stable under granulite facies metamorphism. However the habit of sphene, as retrogressive rims around ilmenite, could be a post granulite facies feature. Where observed (See slide 333-95) sphene grains occur both as discrete grains and retrogressive (?) rims about ilmenite. It is distinguished from zircon by its colour, habit (less rounded grains) and predominant association with opaque. Grain size was recorded as approximately 0.3mm.

Myrmekite - myrmekite intergrowths are ubiquitous between K feldspar - K feldspar grain boundaries. They occur as embayments within perthitic grains. Shelley (1967) regards its occurrence as indicative of recrystallisation following deformation.

d) Local Lithalogies within the Granulites

The following rock types occur locally developed within the mafic granulites:

1) Agmatite - Plates 1D and 1E.
2) Primary "breccia" - Plate 1C.
3) Migmatite - Plate 1F.

Agmatites were readily recognised in the field. They are defined as mafic blocks, cross cut and included by intrusive felsic material. The occurrence of this rock type indicates violent intrusion of the felsic material without significant resorption of the country rock. Primary breccias were noted in the vicinity of one of the large NW trading dolerite dykes at sample location point 333-100. As with the agmatite, the intrusive nature of felsic material is indicated.

Migmatite is developed locally within the mafic granulites, the best exposure being in conjunction with the primary breccia at sample point 333-100. A possible explanation of this phenomenon is local reheating, thus "randomising" the orientation of former F_1 type folds to give the migmatite now observed.

Discussion

Significance of Petrography - The author has included the above rather exhaustive petrography in order that the reader may realise on what criteria the following discussion is based.

Mafic Granulites: Typical assemblage for the mafic granulites is plagioclase (labradorite) - orthopyroxene (hypersthene) - clinopyroxene (diopside augite) - magnetite (ilmenite) ± biotite ± hornblende, with apatite and zircon as accessories.

The occurrence of plagioclase as zoned, multiple twinned megacrysts presents the following theee possible interpretations:-

1) the plagioclase megacrysts are phenocrysts with primary zoning and twinning.
2) the megacrysts are porphyroblasts with secondary zoning and twinning.
3) a combination of 1) and 2).

The author favours the third interpretation. If one assumes the mafic granulites to be basic (perhaps doleritic) sills intruded concordantly into sediments which have subsequently undergone granulite facies metamorphism, interpretation 1) is valid. The simple twins observed can only be explained in this way, whereas multiple twinning can be the result of deformation producing glide twins (Gannon, 1966). Gannon described plagioclase (andesine) in which zoning, both reverse and normal, as well as secondary pericline twinning occurs, in amphibolites and granulites from Guiana. In most cases, the plagioclase grains from the mafic granulites in the Hinckleys display a well-twinned core with a zoned periphery untwinned. This indicates growth (possibly due to metasomatism) after the deformation which produced the multiple twins. Thus the author presents the following mechanism to explain the above phenomenon. The plagioclase nucleated as essentially free-growing crystals in a basic magma in which occasional crystals came together to form the simple twins now observed. Zoning of these crystals occurred as the grains fell through magma of different composition. [illegible] twinning possibly occurred during the D_1 deformation (which produced the F_1 interfolial folds). Following or during this deformation, secondary zoning of the plagioclase was imposed on the primary zoned megacrysts. If the zoning is of the reverse type, its secondary nature is almost beyond question. Gannon noticed increase in anorthite content of plagioclase with rise in metamorphic grade, particularly in high grade metamorphic reactions.

That the mafic granulites are of igneous origin seems indisputable. The occurrence of acicular apatite in conjunction with simple twinned porphyroblastic plagioclase supports this contention. Wyllie, Cox and Biggar (1962) state that the presence of acicular apatite implies igneous origin. Also there is a suggestion that the magma from which the apatite precipitated cooled at a moderate rate, thus preventing the apatite from assuming its euhedral form. Hence growth occurred predominantly in the fastest growth direction, thus resulting in acicular form.

Myrmekitic intergrowths, while ubiquitous in the felsic granulites, occur only in the mafic granulites as a contamination feature. Two divergent schools of thought attempt to explain the genesis of this phenomenon (Hubbard, 1966). The first considers myrmekite as a replacement feature resulting from replacement of orthoclase by sodium - rich plagioclase, or of plagioclase by orthoclase, viz:

$$2\ KAlSi_3O_8 + Na_2O \longrightarrow 2NaAlSi_3O_8 + K_2O$$

$$2\ KAlSi_3O_8 + CaO \longrightarrow CaAl_2Si_2O_8 + K_2O + 4SiO_2$$

The second considers that myrmekite is directly linked with perthite exsolution. This involves the assumption that the dissolved Ca component of an high temperature alkalic feldspar has a molecule of the form $(Ca(AlSi_3O_8)_2$ which, on reversal to "normal perthite" as a result of exsolution, would liberate free quartz:-

$$Ca(AlSi_3O_8)_2 \longrightarrow CaAl_2Si_2O_8 + 4SiO_2$$

Both possibilities may occur in the granulites of the Hinckley Range. Contemporaneous with the intrusion of the "charnockitic type" felsic rocks, potassium metasomatism may have occurred. Evidence for this is the presence of perthitic K feldspar porphyroblasts within the mafic granulites. On the other hand however, Hubbard places great emphasis on the association of perthite with myrmekite i.e. myrmekitic intergrowths are an extension of exsolution phenomena associated with deformation.

Opaque (haemetite) exsolution from pyroxene is also taken as indicative of igneous origin for the mafic granulites. The orthopyroxenes (as noted in the petrography section) are characterised by marked pleochroism. Howie (1964) attributes this phenomenon to high alumina content which is indicative of a high pressure of formation. High alumina content of pyroxene was also reported by Moore (1968) for the orthopyroxenes of Goose Pile. Experiments conducted by Green suggest such pressures are likely to occur between the mantle and upper crustal environments.

As regards the prevalence of antiperthite within plagioclase, Sen (1959) described increased potassium content with increase in metamorphic grade. Parameters thought by Sen to be significant in the occurrence of antiperthitic plagioclase in granulite facies rocks are:-

1) slow cooling after a temperature maximum.

2) monometamorphic rather than polymetamorphic "retrogression"

If Sen's contentions are correct, the granulite facies metamorphism affecting the Musgrave Block produced a temperature maximum which declined slowly in a single episode.

Felsic Granulites : The leucocratic rocks of the Hinckley Range can be divided into two broad groups[1].

1) a sedimentary type, metamorphosed to granulite facies more or less in situ.

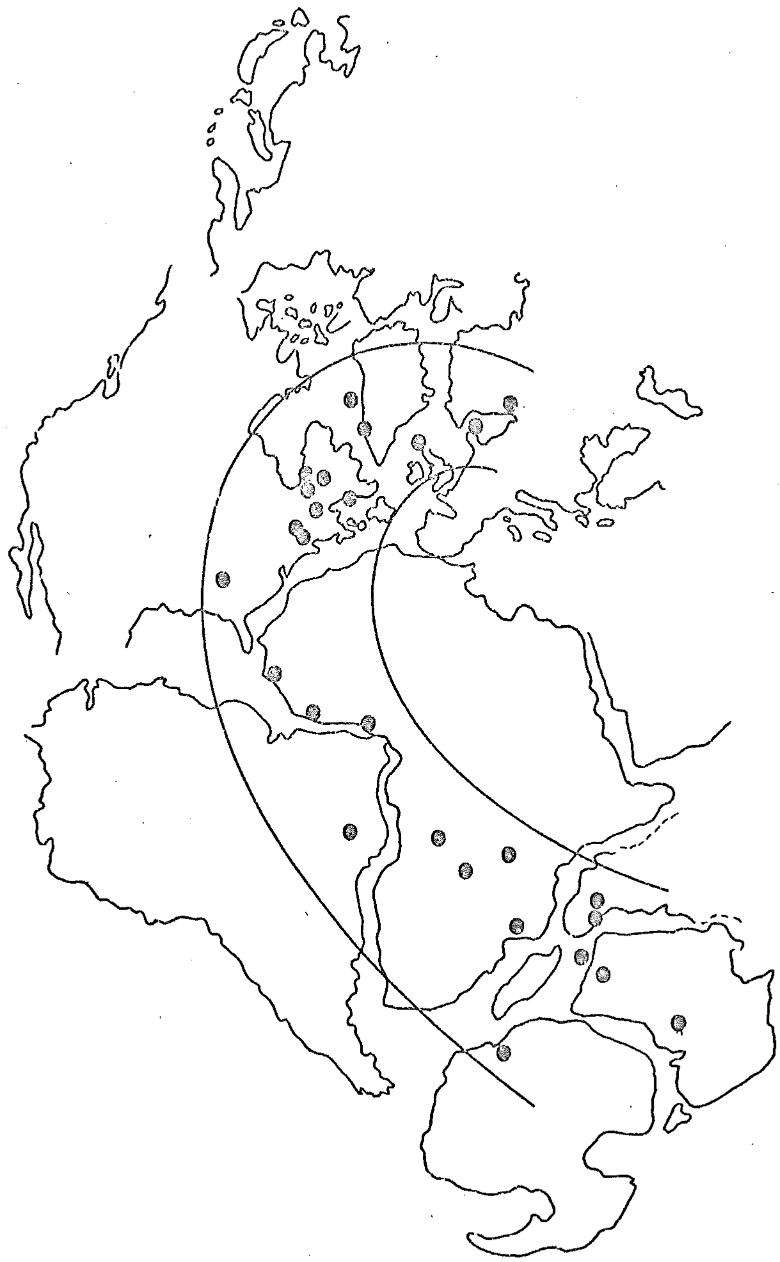
2) a remobilised palingenetic type of felsic rock (variously described as charnockite, or hypersthene adamellite, Wilson, 1954) which was intruded into the mafic granulites.

That the "felsic granulites" are of sedimentary origin is indicated by the following facts.

1) the mode of outcrop of the leucocratic rocks on the NW side of the range. Here the felsic rocks define lenticular ridges several tens of metres wide. The author feels that it would be difficult to produce this outcrop pattern by processes of metamorphic segregation and differentiation. Hence these felsic rocks would fall into category 1).

[1]It should be noted here that on the accompanying map no such subdivision is made because of the inability of the author to classify each outcrop of leucocratic rock individually. Thus on the map the terms "felsic granulite" and "acid gneiss" are synonymous.

FIG 5



After Hurley and Rand (1969).

2) rounded zircon grains. Moore (1970) used this criterion for inferring the sedimentary origin of the leucocratic granulites at Gosse Pile. In one case, a zircon with a round, brownish-pink core is mantled with clear colourless zircon. This possibly indicates secondary growth or a reworked detrital zircon grain. However this hypothesis may be incorrect as rounded zircons have been reported from alleged "magmatic granites".

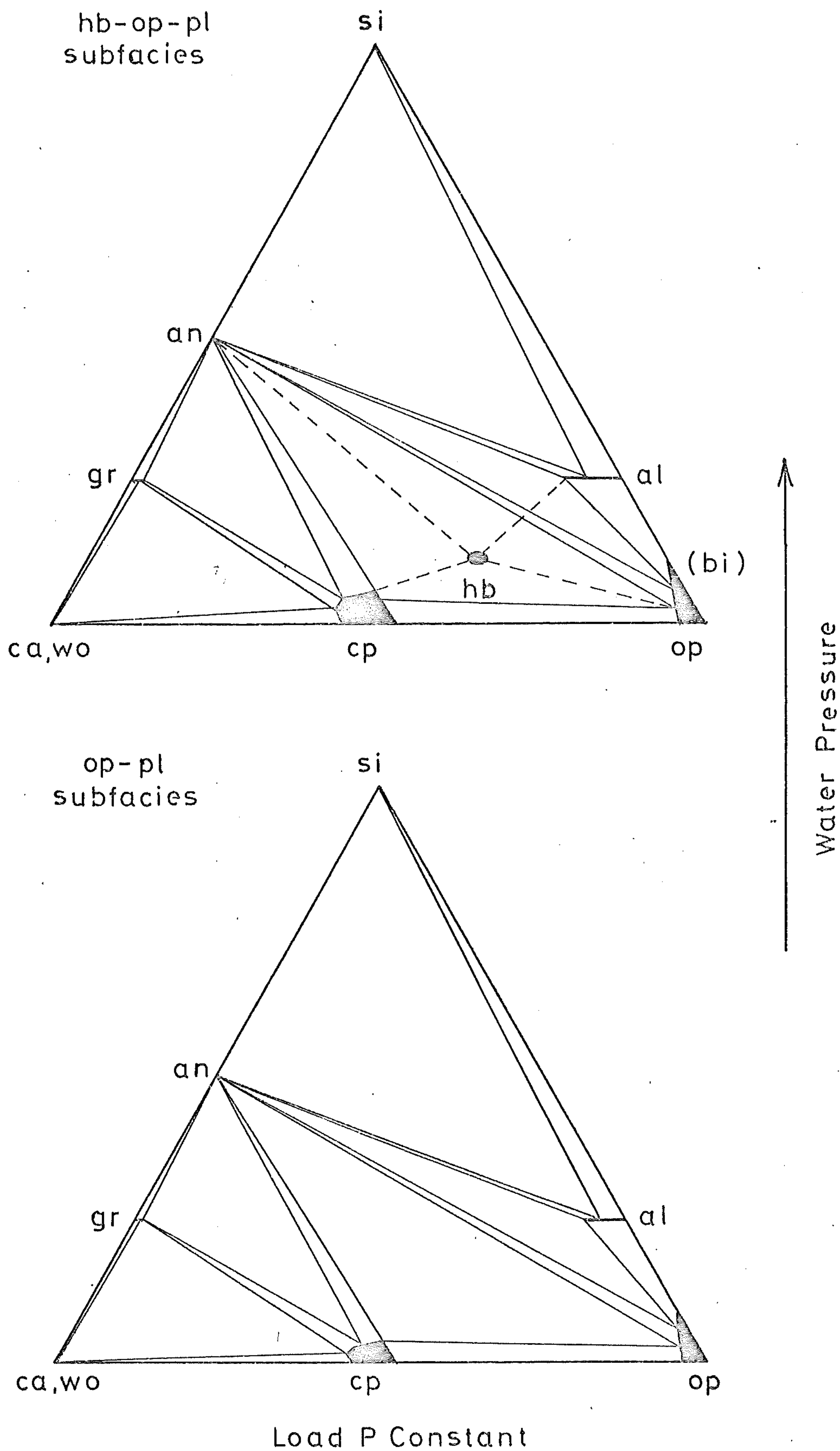
3) although somewhat dubious, the local inhomogeneity of the felsic rocks possibly suggests facies variations within the original sediments. This hypothesis neglects the migration of metasomatic "fluids" during metamorphism as well as local differences in PH_2O, temperature and pressure.

Intercontinental Correlations. - Because of the connatations associated with the word "charnockite", this term has not been used by the author in describing the leucocratic rocks of the Hinckley Range. However it would seem permissible to describe these rocks as having charnockitic affinites. The type charnockite area near Madras described by Subramaniam (1959) bears some remarkable similarities with Hinckley Range granulites. Factors in common include:-

1) similar appearance and mineralogy of the acid rocks.
2) acid, intermediate and basic rocks.
3) "unrecrystallised" lenses of basic rock of noritic composition.
4) migmatite, primary breccia, and agmatite.
5) similarities in the response to defeormation, e.g. streaking out of quartz grains, etc.
6) Hybrid rocks - probably contamination of an acid rock by a basic rock, or the converse.
7) cross-cutting dolerite dykes.

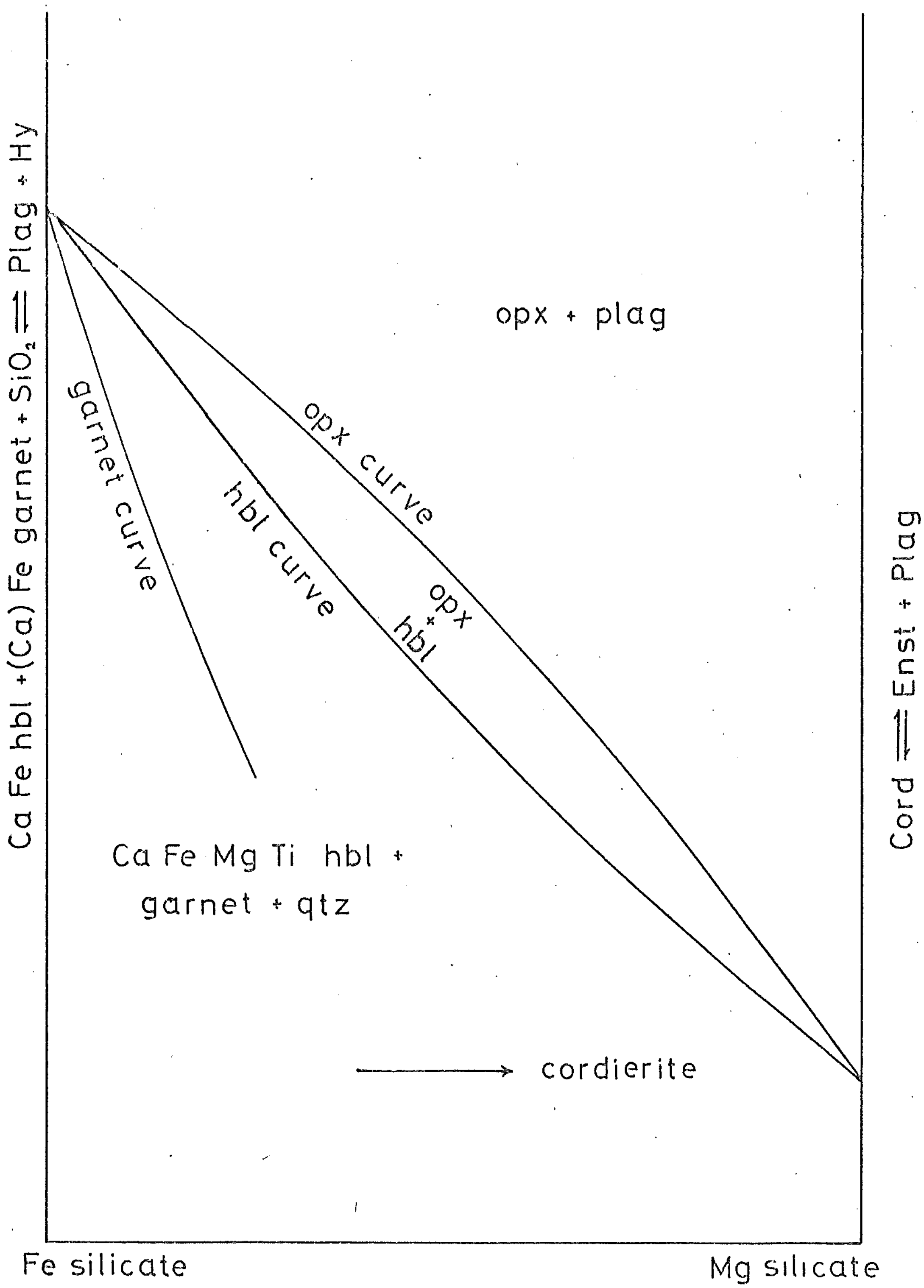
To the reader, it may seem undesirable to make correlations on the basis of purely petrological and field association data. However, using Hurley and Rand's (1969) precontinental drift reconstruction this correlation seems feasible. (See Figure 5). When platted an Hurley and Rand's reconstruction, similar lithological associations in India, Uganda, Adirondacks (U.S.A.) Greenland and Scandinavian countries describe a well-defined belt of granulite facies rocks (Cooray, 1969). However this is only a tentative correlation as the data is anything but conclusive.

FIG 6



After de Waard (1965)

FIG 7



After Ramberg (1949).

Metamorphic Facies - The mafic granulite assemblages of plagioclase - hypersthene - diopsidic augite - opaque ± biotite ± hornblende places them in either the orthopyroxene - plagioclase or hornblende - orthopyroxene - plagioclase subfacies of the granulite facies (de Waard, 1965). (See Figure 6). Local variations in the PH_2O explain the presence or absence of hornblende. With higher water vapour pressure hornblende becomes a stable phase at the expense of orthopyroxene. The nonoccurrence of garnet could possibly be explained by a fairly high Mg/(Mg + Fe^{2+}) ratio, the presence of hornblende and the relatively high Al_2O_3 content of the pyroxene (Green and Ringwood 1969).

The extremely local variation in PH_2O is shown in slide 333-98. In this slide, a thin band made up entirely of hornblende and plagioclase in a mafic lens is separated from diopside (in an acid lens) by less than 1mm. This also supports Ramberg's (1949) contention that hornblende is more stable in the basic assemblages than in the more leucocratic lithologies. However hornblende has an extremely wide stability range with respect to composition, pressure, temperature, and water vapour pressure. (See Figure 7).

For the leucocratic rocks ("Felsic granulites cum hypersthene adamellites cum charnockites") de Waard postulates a temperature of origin up to 800°C with very low water vapour pressure. Low PH_2O is required to explain the stability of hypersthene over hornblende and is compatible with granulite facies conditions. In rocks which contain hornblende and biotite as the stable ferromagnesians, two possibilities exist.

1) the PH_2O in the environment of formation was higher relative to those areas where orthopyroxene is the stable mafic material.
2) Subsequent retrogression of the once stable pyroxene has resulted, due to diapthoretic changes i.e. diopside - hypersthene - hornblende - biotite. (Cooray, 1969).

The author favours the former view to explain this phenomenon in the Hinckley Range granulites.

GILES COMPLEX INTRUSIVES

The following three reasons are put forward to explain the brevity of this section.

1) the aim of the project was to determine the genesis of the mafic granulites, hence only three traverses were walked across the strike of the Giles intrusives,

2) The inter sample point distances were too large to fully recognise on subsequent thin section descriptions any possible rhythmic units within the layered sequence.

3) Both geochemistry (because of incorrect technique) and X-ray diffraction of plagioclase failed to give a simple trend. The data obtained was insufficient to fully interpret the mode of intrusion. However some generalisations can be made.

4) Petrology - Plagioclase is the dominant mineral in the gabbro clan rocks of the Hinckley Range Giles Intrusives. All rocks described have at least 45% plagioclase and thus fit into the meso range of Goode's basic and ultrabasic classification (See Figure 4).

Texturally the rocks vary from hypidiomorphic granular to alletriamorphic with most specimens displaying cataclasis to some degree. Within the mylonite zone, primary minerals are impossible to recognise, due to the almost complete vitrification of the original assemblage, e.g. slide 333-25. Where cataclasis is only weakly manifested, the cumulative origin of some mineral phases is apparent. Plagioclase in particular displays subhedral form, the former euhedral shape having been modified by adcumulus growth (Jackson, 1961).

Mineralogically the gabbroic rocks contain between 45 - 60% plagioclase, whilst the ferromagnesian phases of olivine, orthopyroxene and clinopyroxene are extremely variable. Opaques occur as discrete grains as well as an exsolution product from pyroxene. Hornblende and biotite are common constituents, and myrmekite was also found in some thin sections. Reaction coronas about olivines, due to its reaction with plagioclase have been described (See Plate 4F).

Plagioclase varies in grain size from approximately 1.5mm - 8mm over the whole intrusion, but within a single specimen it shows very little variation except where severe catclasis has granulited the rock producing smaller fragments. Undulose extinction and distorted twins are common. Many grains are strongly antiperthitic which possibly suggests subsolidus exsolution during cooling, or in response to deformation. Simple twins with superimposed multiple twinning was observed in many thin sections. Lath-shaped plagioclase grains are in many cases subophitically wrapped by both ortho and clinopyroxene. Intercumulus (interstitial) plagioclase often contains numerous

PLATE 4

A

333-64 Pigeonite. Exsolution of clino-pyroxene from ortho-pyroxene. Note subhedral plagioclase.

opx - orthopyroxene
pl - plagioclase X63x.n.

B

333-23 Dolerite. Exsolution of opaque (haematite or ilmenite) from clinopyroxenes.

cpx - clinopyroxenes
oq - opaque
X450 p.p.l.

C

333-35 Foliated meso ~~baggro.~~ gabbro Exsolution of clinopyroxene from orthopyroxene. Note also haematite(?) exsolution from cpx (bottom right)

pl - plagioclase
opx - orthopyroxene
cpx - clinopyroxene
X63 x.n.

D

333-60 Olivine meso ~~baggro.~~ gabbro Mantle of opx about olivine - also shows (less distinctly) reaction of plag. with olivine.

ol - olivine
pl - plagioclase
opx - orthopyroxene
X180 x.n.

E

333-72 mesol gabbro (with minor olivine). Note sub to anhedral grains giving rise to an allotriomorphic texture.

pl - plagioclase
opx - orthopyroxene
ol - olivine
oq - opaque
cpx - clinopyroxene X63 x.n.

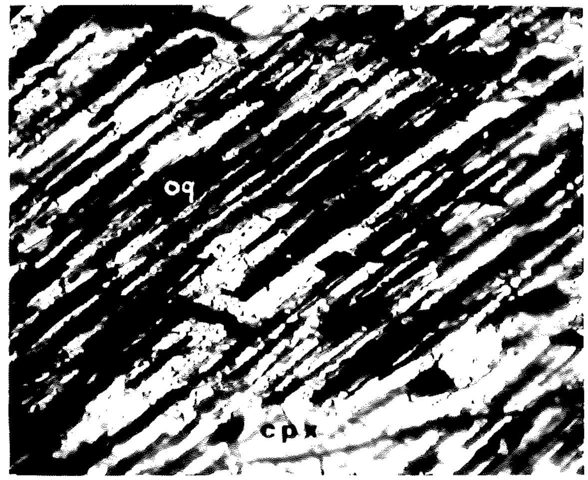
F

333-89 Olivine meso gabbro. Shows reaction rim (corona) between olivine grain and plagioclase.

pl - plagioclase
rr - reaction rim
ol - olivine
X180 x.n.

PLATE 4

A



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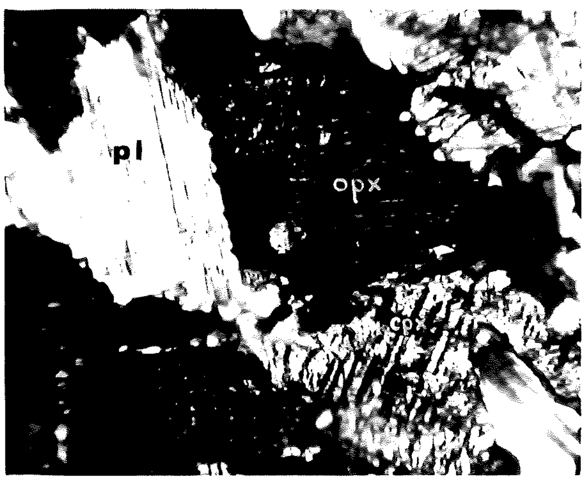
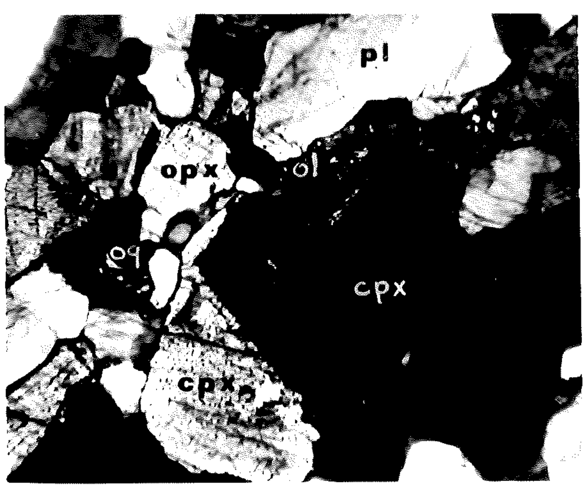


C

D



E

F

apatite inclusions of equidimensional habit, compared with the mafic granulites which are acicular. As stated above, the plagioclase percentage does not fall below 45%. X-ray diffraction analysis of 8 specimens (constituting a traverse across the eastern end of the body) gave plagioclase composition within the range 57.6 - 70.6 i.e. of labradorite composition. (See Figure 8).

Olivine is present in percentages generally less than 10 - 15% in many of the mesogabbros or norites of the Hinckley Range. Composition is toward the forsterite end of the scale. From optics, 2V of approximately 90° was measured. The olivine has a high content of magnesium relative to iron. It is readily recognised in thin section due to its characteristic response to deformation. Many specimens contain inclusions of opaque, possibly magnetite. Mantles of orthopyroxene (hypersthene) were commonly noted, as were reaction rims between olivine and plagioclase grains. This latter phenomenon manifests itself as a greenish-coloured symplectite of orthopyroxene, clinopyroxene, and spinel. (Green and Ringwood, 1969). Olivine occurs as both a cumulus and an intercumulus phase.

Orthopyroxene occurs in variable amounts in all the gabbroic rocks of the Giles Intrusives. It has characteristically marked pink-green pleochroism and is optically negative, i.e. is hypersthene. As with olivine, it was observed as both a cumulus and an intercumulus phase. In the latter form it commonly wraps laths of cumulus plagioclase. A curious form of exsolution (See Plates 4A and 4C) of clinopyroxene from hypersthene is developed in many of the deformed mesogabbro and norites. Exsolution of opaque (haematite and/or rutile) producing a schiller effect is common. Minor orthopyroxene forms as a reaction rim about olivine and also as an exsolution from clinopyroxene.

Clinopyroxene (as either augite or pigeonite) occurs in all of the gabbroic rocks, in variable amounts. Both cumulus and intercumulus pyroxene are represented, but no attempt has been made to classify rocks on this basis. Pigeonite was recognised by low 2V (sometimes almost uniaxial) and an extinction angle of approximately 45°. Many grains display exsolution lamellae of augite, parallel to (001) (Deer, et.al., 1967). Pigeonite is invariably inverted, thus causing difficulties in differentiating it from orthopyroxene, resulting from similarities in pleochroism. In thin section, augite was distinguished from pigeonite by the former's higher value of 2V, and almost complete lack of pleochroism. Augite commonly contains exsolution lamellae of orthopyroxene, parallel to (100). As well as the exsolution of both ortho- and clinopyroxene from both augite and pigeonite, lamellae of opaque (ilmenite and/or haematite) have commonly been exsolved. Where present, the opaque lamellae assume the form of parallelapipeds, with one axis very much longer than the other. Twinning within some grains can also be observed.

Opaques are represented by ilmenite, haemetite, and magnetite. The first two are usually present as exsolution from pyroxene, while magnetite is the most common opaque in the form of discrete grains. Small euhedral grains were rarely observed, but anhedral (in some cases almost amoeboid) grains are ubiquitous. The amoeboid shape may be a manifestation of the opaque's more ductile response to deformation.

Hornblende and biotite occur both as a primary phase and secondary alteration products. Hornblende often ophitically encloses opaque grains, and this is probably of a primary nature. However secondary alteration of pyroxene is common to many specimens. Biotite occurs interstitially as a primary phase, and like hornblende, as an alteration product of pyroxene.

Apatite is developed as aggregates of many small (amorphous) grains within intercumulus plagioclase. Its form is entirely different from that in the mafic granulites, which suggests (tentatively) that the mafic granulite "parent" cooled at a faster rate than the Giles Intrusives.

Myrmekite and zircon were found in very small quantities.

b) Discussion

The mineral assemblages observed, together with the composition of the plagioclase determined by X-ray diffraction suggest that the Hinckley Range gabbroic suite crystallised from a quartz thaleiite magma at less than 12K bars, if a temperature of approximately 1,100°C is assumed (Green and Ringwood, 1969). The dominance of orthopyroxene over olivine supports this contention. The nonoccurrence of rutile as a stable phase places an upper limit of 12K bars on the confining pressure (at 1,100°C). This agrees well with the limits set by the observed subsolidus reaction, which manifests itself as a greenish symplectic growth between olivine and plagioclase. The relatively high Al_2O_3 content of the orthopyroxene (indicated by marked pleochroism Howie, 1964) was used by Nesbitt, et.al. in postulating a high pressure of formation for the Mt. Davies and Gosse Pile intrusions. The pressure suggested corresponds to that of mantle or upper crustal environments.

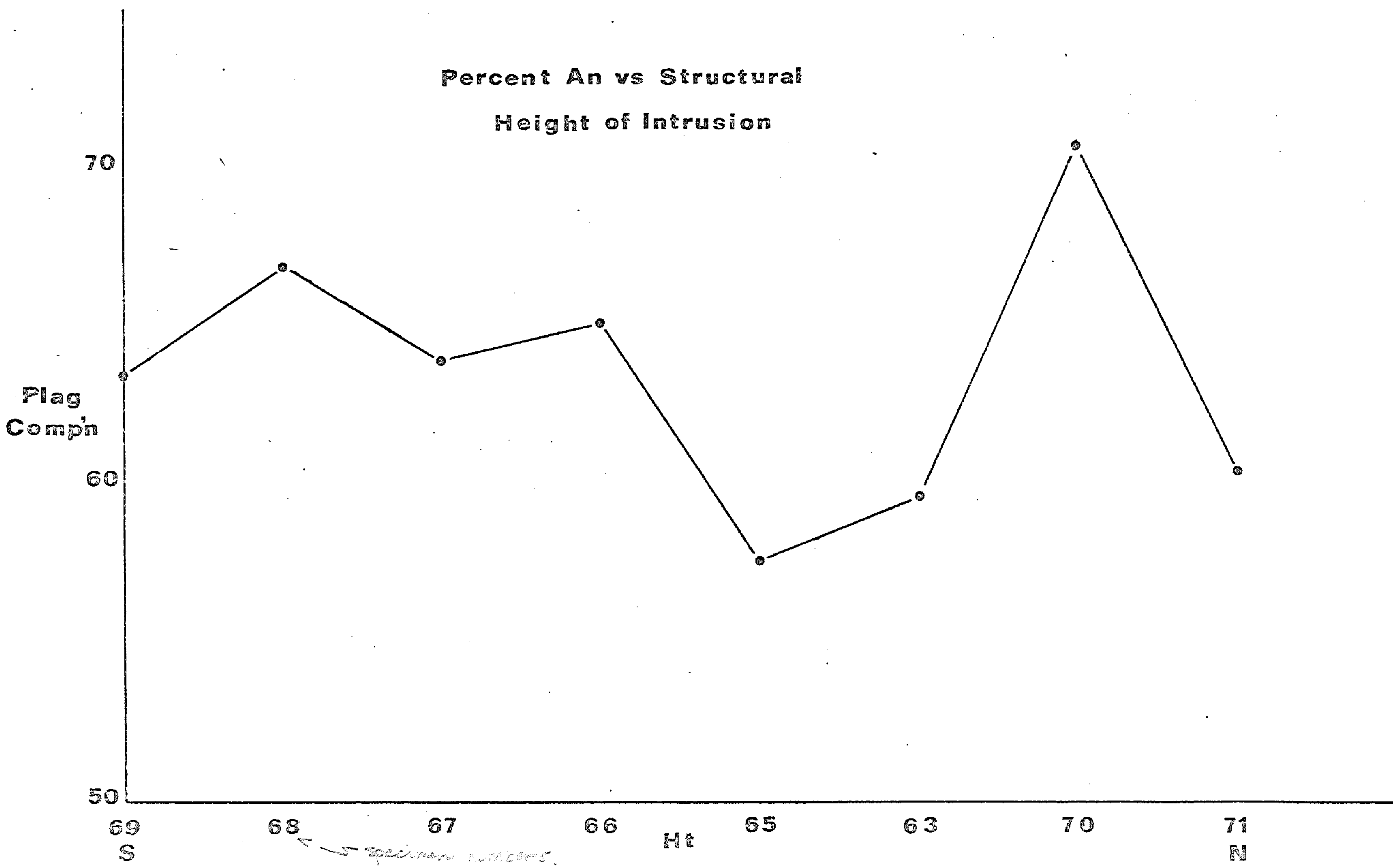

Percent An vs Structural
Height of Intrusion
Plag
Comp'n
70
60
50
69
S
68
67
66
Ht
65
63
70
71
N
← specimen numbers

Fig 8

The "anomolous" plagioclase compositions obtained by X-ray difraction can be explained in five ways:- two

1) the "intrusion" is in fact not one differentiated intrusion, but a series of same.

2) the relatively coarse sampling across the body did not allow subtle rhythmic variation to be recognised.

If the high An content of plagioclase from slide 333-70 is disregarded, a "broad decrease" in aronthite content from south the north can be inferred (See Figure 8). Sample 333-70 would therefore represent a second intrusion. However this explanation does not seem feasible in the light of work done on other Giles Intrusives. Hence the author favours the view that the method of sampling did not allow smaller variations to be detected.

MINOR INTRUSIONS

The minor intrusives can be divided into two groups:-

1) olivine meso gabbro plugs

2) dolerites - which can be subdivided into 3 types.

Gabbroic Plugs - mineralogically and texturally these rocks are similar to the lithologies present in the main gabbroic intrusive of the Hinckley Range. Outcrop of this type of intrusive is limited, being confined to four small hillocks in the extreme NW corner of the area. Minerals include cumulus, lath-like plagioclase subophitically enveloped by clinopyroxene (augite), and magnesian olivine. Orthopyroxene is rare. Minor phases are opaque, biotite with accessory symplectic intergrowth between plagioclase and olivine, apatite, and hornblende. Daniels (1967) has stated that in all cases these minor intrusives can be correlated with the major sheets.

Dolerites - the discordant intrusives can be subdivided into 3 categories on the basis of mineralogy and orientation. They correspond to the A, B and D subdivisions of Nesbitt, et. al. (1969). One significant change however is the placing of the type B dyke set rather than type A as the oldest set. Type B is the only set to have undergone any deformation and it is manifested as an obvious recrystallisation and crude orientation of biotite flakes. Little more than a brief mineralogical description plus a note on orientation can be included in this report. The nomenclature of Nesbitt, et. al is used below.

Type A. This set constitutes the prominent NW dykes which discordantly intrude the mafic granulites. Texture is subophitic to ophitic, with clinopyroxene (pigeonite) either partially or wholly enclosing plagioclase laths.

PLATE 5

A

33-18 Contact between fine grained dolerite dyke and "felsic granulite" Note flowage texture as manifested by streaked out plagioclase.

dol - dolerite
pl - plagioclase
cm - chilled margin

X63 X.n.

B

333-69 Meso gabbro. An example of extreme cataclasis-kinked exsolution lamellae:- cpx and crushed plagioclase grains.

oq - opaque
cpx - clinopyroxene
pl - plagioclase

X63 x.n.

C

333-49 Dolerite. Granular aggregates of pyroxene with biotite - plagioclase laths - exsolution of opaque from cpx.

bi - biotite
oq - opaque
pl - plagioclase
cpx - clinopyroxene

X108 x.n.

D

333-12 Dolerite (Type A) Major NW trending dyke. Laths of plagioclase subophitically enclosed by clinopyroxene.

pl - plagioclase
cpx - clinopyroxene

X63 x.n.

E

333-75 Dolerite (Type B). Similar to 333-49. Note simple twinning of plagioclase laths and granular aggregates of pyroxene

pl - plagioclase
cpx - clinopyroxene
bi - biotite.

X63 x.n.

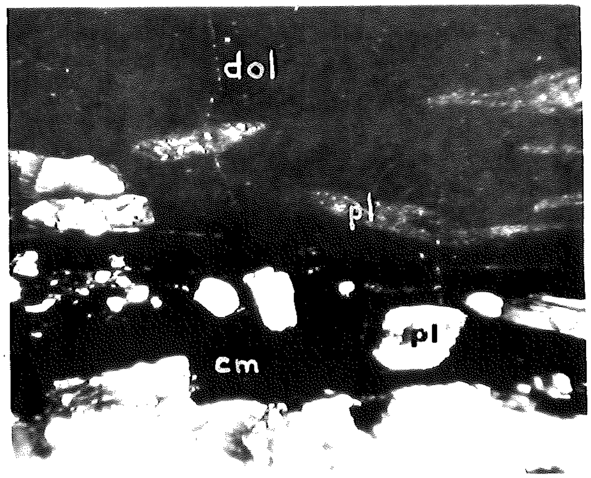
F

333-15 Dolerite (Type C or D). This dyke intersects the major dyke (see 333-12). Olivine, clinopyroxene and plagioclase are the chief constituents.

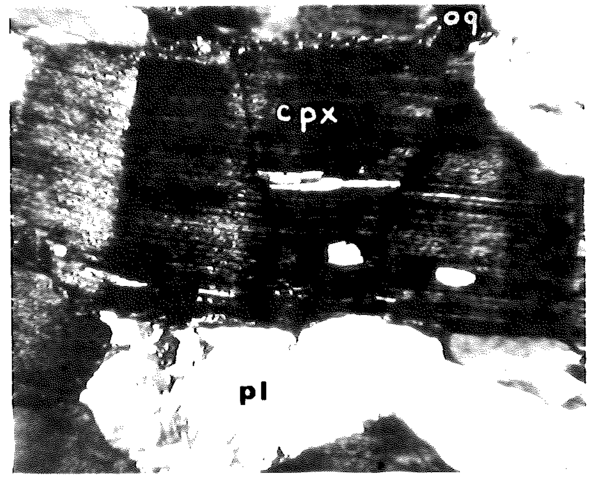
pl - plagioclase
oq - opaque
cpx - clinopyroxene
ol - olivine

X63 p.p.l.

PLATE 5



A



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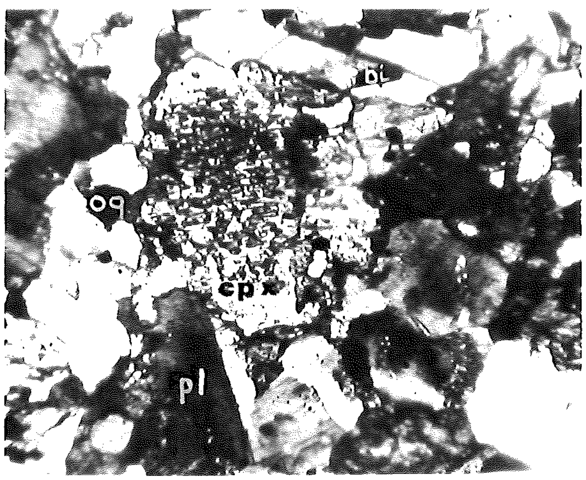

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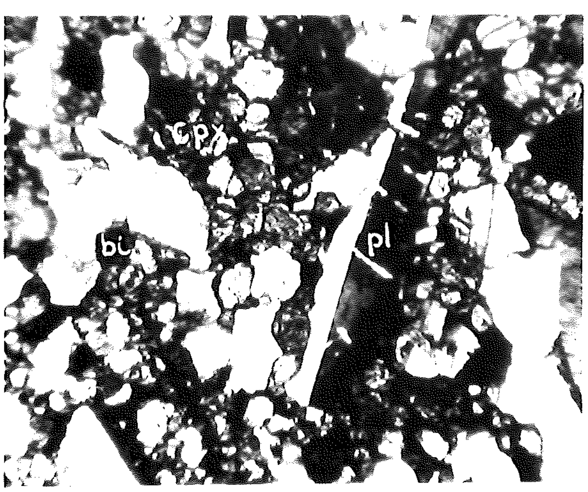
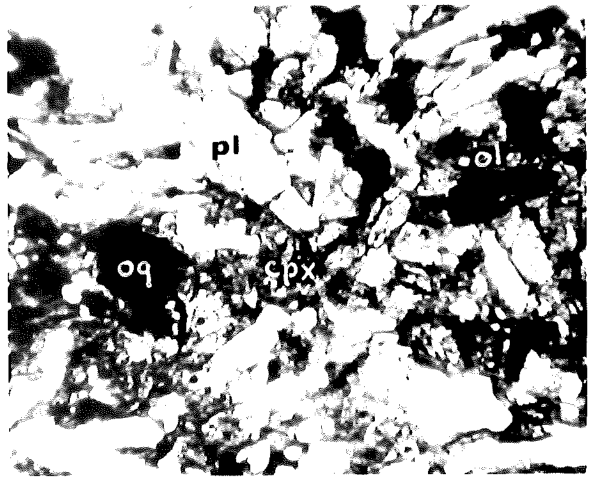


E



F

(See Plate 5D). Both the plagioclase and clinopyroxene are highly altered, the former appearing buff-coloured and turbid, whilst the pyroxene is bordered by a rim of amphibole (hornblende). Minor phases include opaque (magnetite) apatite in intergranular plagioclase, and biotite. The minerals show no preferred orientation, as distinct from the Type A dolerites of Nesbitt, et.al.

Type B. These dolerites are distinctive in the field as they occur in swarms of very narrow dykes (less than three feet), generally with a NE to ENE orientation. Deformation is manifested as preferred orientation of biotite, and obvious recrystallisation. The texture of these dolerites is distinctly different from Type A. Granular aggregates of pyroxene "subophitically envelop" plagioclase grains, which vary in habit from laths to essentially equidimensional (See Plate 5E). Both ortho- and clinopyroxene are present, the latter being distinguished from the former by abundant opaque exsolution, especially from the larger grains. Minor constituents include biotite (up to 3-4%), acicular apatite, magnetite, and ilmenite. Haemetite may possibly be an exsolution mineral from clinopyroxene.

Type D. This set is defined by the presence of zoned olivine megacrysts. Texturally the rock is ophitic to subophitic, with clinopyroxene enveloping plagioclase laths. No orthopyroxene is present. (See Plate 5F). Minor constituents are magnetite, ilmenite, biotite, hornblende, olivine-plagioclase symplectite and very minor acicular apatite. No deformation was observed, and orientation seems to be random.

In summary, the subdivision of Nesbitt, et. al. does not apply to the Hinckley Range dolerites. Type B obviously predates Type A, while Type D was observed to cross-cut a Type A dyke in the vicinity of sample point 333-15.

SEQUENCE OF EVENTS

The following sequence of events is modified after Goode (pers. comm, 1970) to fit the author's interpretation of the genesis of the Hinckley Range granulites, and gabbroic intrusives.[1]

Time ↑

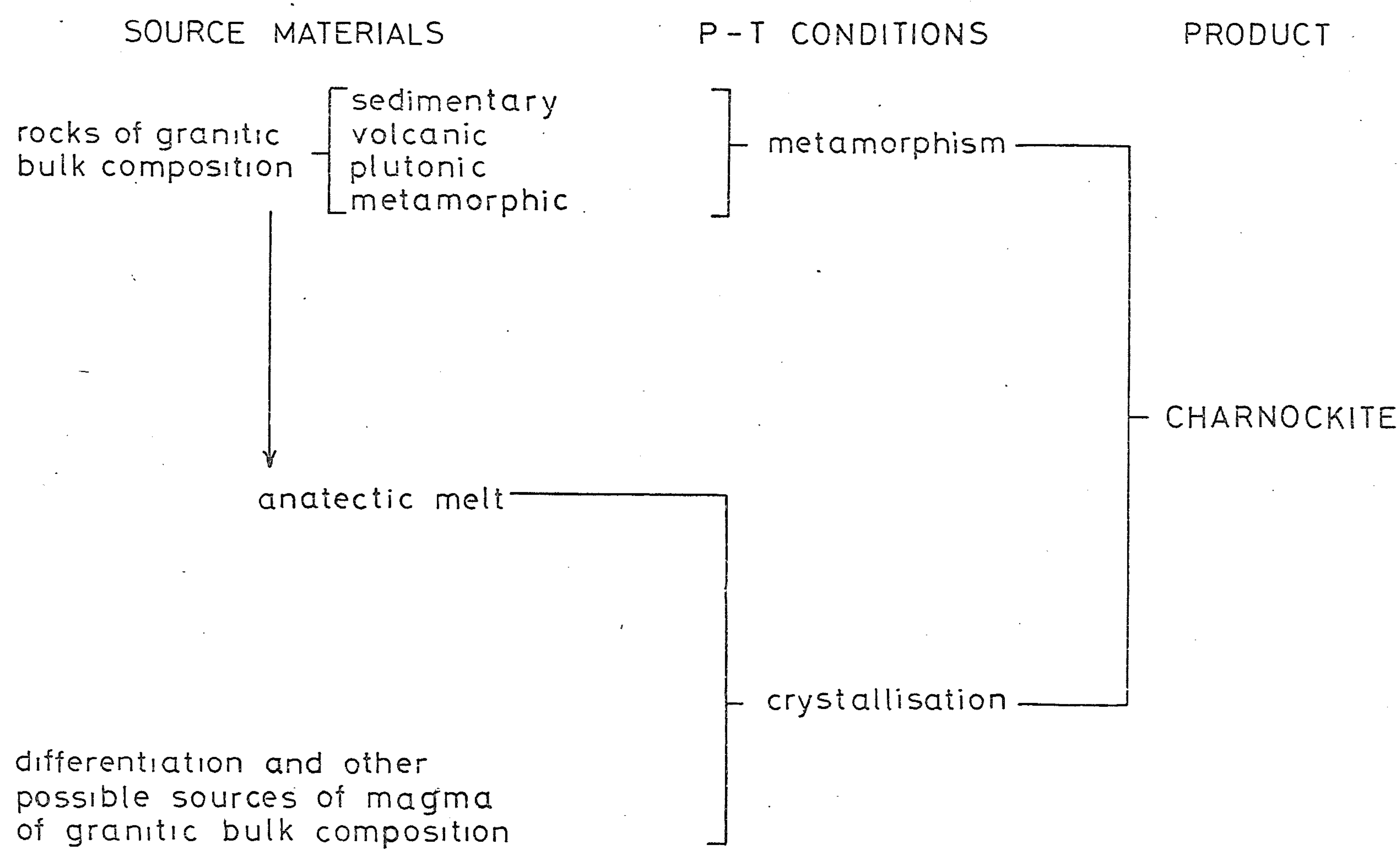
LOCAL SHEARING

HINCKLEY FAULT (mylonites and pseudotachylites)

"TYPE D" DYKES

F_3 FOLDING (braod warping)

[1] Goode does not agree with the pre-Giles sequence.



After Cooray (1969).

FIG 9

"TYPE A" DYKES

F_2 FOLDING (E-W folds)

"TYPE B" DYKES

GNEISSIC FOLIATION (S_1 surface developed)

GILES COMPLEX INTRUSIVES

"HYPERSTHENE ADAMELLITE INTRUSIVES" (palingenetic)

GRANULITE FACIES METAMORPHISM (F_1 fold style)

INTRUSION OF BASIC SILLS

DEPOSITION OF PROTEROZOIC SEDIMENTS

ORIGIN OF THE GRANULITES

It is the author's view that the interbanded felsic and mafic granulites represent original sediments and concordant basic sills, respectively. The basic sills (possibly of a dolerite composition) were intruded into partially granitised sediments which were originally grey wackes. Progressive metamorphism dehydrated the original sediments and recrystallisation produced the mineral assemblage now observed. The original sedimentary nature of the leucocratic rocks is indicated by rounded-zoned zircons, as well as field relations. The energy required for the dehydration process was a function of deep burial in a eugeosynclinal environment followed by granulite facies metamorphism, during which the F_1 fold style was developed within the mafic granulites.

The intrusion of the "hypersthene adamellites" was probably a palingenetic process initiated by the Giles Complex Intrusives at depth. The deeply buried (lower crust) eugeosynclinal sediments were remobilised due to the formation of a palingenitic melt which subsequently discordantly intruded the interbedded granulites. This hypothesis is supported by de Waard (1969) who postulates a convergence in the origin of charnockite. (See Fig. 9). Although not all the felsic intrusives of the Hinckleys can strictly be classed as charnockites, their charnockitic affinities seem obvious. A slightly higher PH_2O can be used to explain the non-stability of hypersthene in some intrusions. Thus two different types of felsic rocks were produced from the same source ie both the inter-banded and the intrusive leucocratic rocks were originally sedimentary.

The above hypothesis is preferred to the one suggesting that the "mafic grnulites" are contaminated Giles material. Although some small pods of Giles intrusive were recognised within the mafic granulite, the author does not feel that these represent "unrecrystallised" Giles Complex gabbro (norite), but rather they are small cupolas associated with a major intrusion. Similar pods of "unrecrystallised" material were described by Subramaniam (1959) in the mafic granulites of the type charnockitic province near Madras. Finally, the presence of F_1 intrafolials invalidates the "contamination hypothesis".

CONCLUSIONS AND RECOMMENDATIONS

The mafic granulites of the Hinckley Range were formerly basic sills intruded concordantly within eugeosynclinal sediments. Both have subsequently undergone granulite facies metamorphism. The felsic rocks of two types:-
1) a sedimentary type, metamorphosed to granulite facies, more or less in situ.
2) a remobilised palingenetic type of felsic rock which was intruded into the interbanded mafic and felsic granulites of type 1).

The above events were followed by intrusion of the Giles Complex gabbroic suite which in turn was followed by the development of gneissic foliation, etc. (See SEQUENCE OF EVENTS).

Finally the following recommendations are made in the hope that the validity (or otherwise) of the above hypothesis can be established.
1) A more detailed mapping programme needs to be initiated in order to subdivide the mafic granulite suite and classify the felsic rocks into types 1) or 2). Similarly the Giles Intrusives need to be mapped on a much smaller scale than was attempted. Three traverses with coarsely spaced sample points failed to bring out possible rhythmic variation.
2) Chemical analyses on whole rock samples as well as separated minerals and trace elements need to be carried out.
3) A much more intensive collection of structural data would help to elucidate the relationship between the mafic granulites and the "felsic rocks", and the former with the Giles Complex suite.

In conclusion, this report should only be considered a preliminary investigation in the problems of the area.

ACKNOWLEDGEMENTS

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APPENDIX I

PETROLOGY

A 307-2

TEXTURE: Hypidiomorphic granular - cumulus grains of subhedral to euhedral pyroxene (cpx and opx) in intercumulus plagioclase, biotite and opaque. Slightly cataclastic - indicated by undulose extinction and parting not along cleavage faces.

PETROLOGY: Orthopyroxene - 5 - 10% g.s. 1 - 1.5mm. Hypersthene Pink - green pleochroism, good cleavage - inclusions or exsolution of opaques - euhedral to anhedral - inclusions of higher birefringent material - cpx - augite? Euhedral to subhedral in form. Inclusions also of plag - anhedral. High 2V.

Clinopyroxene - 30 - 35% g.s. 3 - 4mm. Augite. Green - very weakly pleochroic - higher birefringence than the opx - exsolution lamellae of opx plus inclusions of opx? Inclusions of euhedral opaque ilmenite or magnetite - some orientated in the plane of cleavage, others not. Extinction angle 45°. Exsolved opx probably hypersthene. Some cpx occurs as granular aggregates, possibly due to cataclasis (also supported by distorted twins, lamellae and undulose extinction). Some iron staining.

Plagioclase - 60% g.s. 2 - 3mm. An 20 - An 30. Intercumulus - partially sericitised (cloudy appearance) twinning common and distorted - cleavage poor. Occurs infrequently as inclusions in pyroxene. Distortion of twin lamellae makes composition measurement difficult. - Carlsbad-albite and pericline twinning ubiquitous. Probably low anorthite content.

Biotite - 1% g.s. 1mm. Typical pleochroism - rusty orange to yellow anhedral - intercumulus interstitial - usually associated with opaque.

Opaque - 1 - 2% in total g.s. 1mm. In association with biotite as anhedral grains - probably magnetite - also as an exsolution (?) on inclusion in the pyroxenes - ilmenite.

Rutile (?) - Associated with opaque - uniaxial positive (?). Orange-brown in colour - anhedral grains.

COMMENTS: Plagioclase displays serated edges - possibly indicating some subsequent metamorphic event - small areas of myrmekite - quartz exsolution.

CLASSIFICATION: Meso gabbro.

A 307-3

TEXTURE: Hypidiomorphic granular with a distinct foliation exhibited by the pyroxenes with a mylonitic banding almost parallel to the foliation. Cataclastic texture superimposed on the above.

PETROLOGY: Olivine - 3 - 5% g.s. 3mm. High 2V and birefringence - high refractive index - severely broken up by cataclastic phenomena. Surrounded usually by hypersthene as a reaction rim (pink-green pleochroism) in which there are a few inclusions of cpx. Chlorite possibly as a secondary alteration product of the opx associated with opaque.

Cliropyroxene - 30% g.s. 1 - 2mm. probably Augite. 2V 45° Subhedral to anhedral grains - severely broken up - cleavage fair - distinct exsolution of opx probably hypersthene parallel to cleavage in form of lamellae - contains many euhedral to subhedral opaques together with biotite as inclusions. Alters to amphibole or chlorite at the edges.

Orthopyroxene - 10% g.s. 1 2 mm. Pink-green pleochraism straight extinction as reaction rim about the olivine and as discrete grains. Possibly exsolution of opx.

Plagioclase - 50 - 55% g.s. 4mm. Composition An45. Generally surrounding the "cumulus" pyroxenes and olivine - contains many inclusions. Lineation of the inclusions (many but not all) parallel to the foliation direction. Many of the twin lamellae are distorted due to cataclastic events. Pericline twinning most common.

Minor - Very fine biotite, chlorite with streaks of mylonite through the slide.

Opaques - As exsolution (?) or inclusions in pyroxene or associated with minor biotite. Opaques in the pyroxenes tend to be generally euhedral to subhedral.

CLASSIFICATION: Olivine meso gabbro (foliated mylonitised).

A 307-4

TEXTURE: Similar to A307-3. Hypidiomorphic - granular - cataclastic mylanitised.

PETROLOGY: Plagioclase - 50% g.s. 3 - 4 mm. Composition An45. Undulose extinction ubiquitous - contains many inclusions twinning poor and where present distorted due to the subsequent deformation. Twins are generally of the Carlsbad - albite type with some pericline twinning.

Olivine - 2 - 3% g.s. 3mm.
Severely deformed, containing inclusions of opaques - mylonitised, in many cases high interference colours, 2V, and R.1.

Clinopyroxene - 30 - 35% g.s. 2 - 3mm. Inclined extinction - fractured - exsolution of opx as lamellae - associated with opaques, usually enhedral. Opaques in some grains are confined only to the margins of the grain.

Orthopyroxene - 10% g.s. 1mm. Pink-green pleochroism hypersthene - usually as reaction rims about olivine and as exsolution lamellae in cpx.

Opaques - 1%. Very fine. As exsolution from pyroxene almost exclusively. Very minor amount associated with biotite.

Minor - 1% Very fine. Chlorite as alteration product from olivine, rutile(?) and biotite.

CLASSIFICATION: Olivine meso gabbro (foliated, mylonitised).

A 307-5

TEXTURE: Hypidiomorphic granular - completely lacking cataclastic texture and foliation.

PETROLOGY: Plagioclase - 60% g.s. 1.5mm. Composition An45. Very strong pericline twinning. Anhedral to subhedral - appear to be intercumulus to the olivine and pyroxenes.

Clinopyroxene - 25 - 30% g.s. 1.5mm. Inclined extinction - exsolution lamellae of opx - generally anhedral grains with inclusions or exsolutions of opaque. Probably Augite.

Orthopyroxene - 2 - 3%. Generally as reaction rims about olivine or exsolution from cpx. Where reaction rim pink-green pleochroism - hypersthene. Associated with opaques.

Olivine - 5%. Reaction rim of opx common, together with chlorite alteration product - highly fractured with veins of alteration. Also associated with opaques which are commonly oriented where lenticular.

Minor - Opaques as exsolutions from olivine and pyroxene - very little in the plagioclase. Together with chlorite as alteration of olivine, biotite and iron staining from breakdown of the olivine.

CLASSIFICATION: Olivine meso gabbro.

A 307-6

TEXTURE: Hypidiomorphic granular - no cataclastic phenomena or mylonisation.

PETROLOGY: Plagioclase - 65% g.s. 4mm. Composition An64. Pericline twinning is ubiquitous - in general undistorted - appears to be intercumulus to the pyroxene and olivine. Many inclusions, some oriented parallel to the twin lamellae. Undulose extinction.

Orthopyroxene - 2 - 3% g.s. 1mm. Pink-green pleochroism - usually as reaction rims about the olivine - contains abundant inclusions of opaque either exsolved or just included. No exsolution. Also as reaction rims about the cpx.

Clinopyroxene - 25 - 30% g.s. 3mm. Cumulus phase. Green-grey in colour, with no apparent pleochroism - abundant opaques generally euhedral with ubiquitous exsolution lamellae of opx. Often with reaction rims of opx. Exsolution lamellae often do not extend to the periphery of the grains.

Olivine - 2 -3%, g.s. 2 - 3mm. High relief, R.I., and interference colours - usually highly shattered with alteration products in the cracks - surrounded by opx generally and contains euhedral opaques.

Opaques - Generally euhedral inclusions, in opx, cpx, and olivine - very few in the plagioclase.

Minor - Urlonite as alteration of olivine - biotite and/or amphibole (?) associated with the opx and olivine.

CLASSIFICATION: Olivine meso gabbro.

A 307-7

<u>TEXTURE</u>: Hypidiomorphic granular - cumulus, olivine and pyroxene in intercumulus plagioclase.

<u>PETROLOGY</u>: <u>Plagioclase</u> - 65% g.s. 2mm. Composition An 64. Appears to be intercumulus - some undulose extinction although rare. Pericline albite twinning is uliquitous generally undistorted. Few inclusions and generally clear.

<u>Clinopyroxene</u> - 20 - 25% g.s. 4 5 mm. Augite. Cumulus to granular aggregates of discrete grains - many with exsolution lamellae of opx with euhedral grains of opaque, exsolved or included, quite often associated with opx.

<u>Orthopyroxene</u> - 5 - 7% g.s. 2mm. Pink green pleochroism - some with exsolution lamellae and exsolved or included opaques - occurs as reaction rims about olivines. Lower interference colours than cpx.

<u>Olivine</u> - 5% g.s. 2 - 3mm. Severely broken up - cracks filled with alteration product - surrounded by opx and chlorite with opaques included, predominantly about the margins. Magnesium - rich olivine.

<u>Opaques</u> - Euhedral shape 2%. As exsolution from ferro magnesium minerals with few in the plagioclase. Generally euhedral.

<u>Minor</u> - Chlorite as alteration product, iron staining, amphibole, biotite, possibly atotite, with inclusions of opaque.

<u>CLASSIFICATION</u>: Olivine meso gabbro.

A 307-8

<u>TEXTURE</u>: Hypidiomorphic granular - one part of the slide shows alteration of the minerals whilst the other exhibits very fresh rock.

PETROLOGY: Plagioclase - 50% g.s. 2mm. Composition An 52. Pericline and albite twinning very common - plagioclase appears to be intercumulus to the ferromagnesian - Subophitic - few inclusions - some undulose extinction but twins not distorted.

Orthopyroxene - 5%, g.s. 1mm. Hypersthene. Occurs as before as reaction rims about olivine or in association with cpx - no exsolution lamellae but opx - numerous euhedral grains of opaque are present. Pink-green pleochroism, however interference colours than cpx.

Clinopyroxene - 40 - 45% g.s. 2mm. High birefringence (relative to opx). Dominant exsolution lamellae of opx with many inclusions of opaques - generally euhedral, and oriented parallel to the exsolution lamellae - some evidence for reaction with the plagioclase. In some places quite severely altered by weathering.

Olivine - 5% g.s. - some grains up to 6mm, but generally smaller. High birefringence - relief. Severely parted with alteration products in the cracks - usually with mantle of opx and inclusions of opaque.

Opaques - As inclusions in ferromagnesians, with few in the plagioclase from euhedral to anhedral.

Minor - Amphibole, chlorite, iron staining, generally associated with the olivine - possible apatite in the plagioclase. In hand specimen - some evidence for minor mylonitisation. Foliation (?).

CLASSIFICATION: Olivine meso gabbro.

A 307-8B

<u>TEXTURE</u>: Beautiful example of cumulus, intercumulus textures. Essentially two textures in the slide - cumulus olivine in large concentration - continuous network of touching discrete olivine grains with minor opx and intercumulus plagioclase. Other texture - discrete cumulus grains of opx (hypersthene), cpx (augite), and olivine in intercumulus plagioclase.

<u>PETROLOGY</u>: <u>Orthopyroxene</u> - 20% g.s. 0.4mm. Hypersthene with few inclusions of opaques - subhedral to euhedral.

<u>Clinopyroxene</u> - 20%, g.s. 1mm. Augite. Subhedral to euhedral - good cleavage - poor pleochroism - exsolution lamellae - inclusions of opaques.

<u>Olivine</u> - 25%, g.s. 1mm. Forms as discrete cumulus grains in one section of the slide, and as a network of grains essentially free of pyroxene on the other. Intercumulus plagioclase occurs on both sides.

<u>Plagioclase</u> - 35% Composition An67. Intercumulus - well twinned - anhedral to subhedral - inclusions. Pericline and albite twins. Plagioclase - almost underformed, although some slight undulose extinction.

<u>Opaques</u> - 1%. Generally anhedral grains associated with the ferromagnesians - very few in the plagioclase.

<u>Amphibole</u> - Possibly litaniferous hornblende - mid brown to light brown pleochroism as alteration product (?) of olivine and/or pyroxene - possibly intercumulus.

<u>Minor</u> - Biotite, iddinysite(?), rutile(?).

<u>CLASSIFICATION</u>: Meso froctolite in contact with an olivine meso gabbro.

A 307-10

<u>TEXTURE</u>: Generally coarse-grained rock - cumulous ferr-magnesians in intercumulus plagioclase - hypidiomorphic granular-allotriamorphic.

PETROLOGY: **Plagioclase** - 60% g.s. 3mm. An54. Intercumulus grains - well twinned - little apparent deformation (few examples of undulose extinction).

Clinopyroxene - 15 - 20%, g.s. 5mm. Low 2V Biaxial positive. Augite and Pigeonite. Exsolution lamellae of opx - good cleavage - inclined extinction - exsolution of euhedral opaques - quite often in association with olivines. Subhedral to anhedral grains. Alteration to amphibole or intercumulus.

Orthopyroxene - 5%, g.s. 3mm. Hypersthene Pink-green pleochroism. Some exsolution and euhedral inclusions (?) of opaque - often as rims about the olivine - a cumulus phase.

Olivine - 10-15% g.s. 5mm. Highly fractured alteration along cracks - mantled by both cpx and opx. Inclusions of anhedral opaque. Reaction rims both great colourless.

Opaque - 1 - 2%. Generally as euhedral exsolution grains in the ferromagnesians. Intercumulus in the plagioclase.

Minor - Amphibole (hornblende), biotite (?), chlorite, iron staining and rims about the olivine.

CLASSIFICATION: Olivine meso gabbro.

A 307-15

TEXTURE: Coarse to very coarse grained - hypidiomorphic to allotriomorphic granular - seems to be some degree of foliation exhibited by the mafic minerals - somewhat cataclastic.

PETROLOGY: **Plagioclase** - 55 - 60% g.s. 8mm. Composition An31. Subhedral coarse grains with excellent twinning - albite and pericline - undulose extinction indicating some cataclastic activity - possibly a cumulus phase - zoning absent - very small inclusions, possibly of apatite - few opaques.

Olivine - 10-15% g.s. 2mm. High relief and interference colours - usually with a mantle of hypersthene and/or hornblende - highly fractured but fresh - some chlorite alteration product - few opaque inclusions. Some iron staining in association with some undulose extinction.

Hypersthene - 5 -10% g.s. 3mm. opx pink green pleochroism - usually as a reaction rim or mantle about the olivine - contains opaques and some examples of exsolution phenomena - cpx also included - generally anhedral.

Clinopyroxene - 10 -15% g.s. 3mm. with phenocrysts up to 4 - 5mm. Extinction Angle = 45° Augite. Numerous euhedral exsolutions or inclusions of opaques with exsolution lamellae of opx. Often in association with hornblende and olivine.

Opaques - 2-3%. Almost entirely as exsolutions or inclusions in ferromagnesians - from euhedral to anhedral.

Hornblende - Important as rim about ferromagnesians - brown - dark green - light green pleochroism - some opaques - anhedral with minor apatite in plagioclase - iron staining, chlorite (alteration of olivine) biotite, rutile(?).

CLASSIFICATION: Olivine meso gabbro.

A 307-16

TEXTURE: Allatriomorphic to hypidiomorphic granular - appears to be essentially unfoliated.

PETROLOGY: Plagioclase - 45 - 50%, g.s. 7mm, Composition An 31. Well twinned, subhedral very coarse grains, few inclusions of opaque with some apatite (?) - essentially an intercumulus phase - not as cataclastic as previous rocks - less undulose extinction.

Olivine - 10%, g.s. 5mm. Highly fractured, with rims of hypersthene on some grains, and/or hornblende - many inclusions of anhedral opaque.

Orthopyroxene - 5%, g.s. 3mm. Hypersthene. Pink - green pleochroism - usually as reaction rims about the olivine and cpx - contains some inclusions of opaque and exsolution lamellae of cpx.

Clinopyroxene - 30 - 45%, g.s. 4mm. Both Augite and Pigeonite are present. Augite $\gamma \wedge C = 45^{\circ}$, and Pigeonite with $2V = 0^{\circ}$. Both appear to have exsolution of opx and inclusions of anhedral to euhedral opaques. Cpx shows overlays of hypersthene. Relative proportion is difficult to assess.

Opaques - 1-2%. Anhedral to euhedral exsolutions from the cpx's - probably magnetite or ilmenite. Associated essentially with the ferromagnesians.

Minor - Biotite (with opaques), apatite generally with the plagioclase, hornblende about olivine and cpx, chlorite with olivine, and iron staining.

CLASSIFICATION: Olivine meso gabbro.

A 307-18

TEXTURE: Holocrystalline, hypidiomorphic granular to allatriomorphic with some degree of subaphitic texture.

PETROLOGY: Plagioclase - 55 - 60% g.s. 5mm. Composition An50. Well twinned - albite and pericline twins undulose extinction - slightly cataclastic - few inclusions of opaque and apatite.

Olivine - 5%, g.s. 2mm. Highly fractured with alteration products along cracks - usually with mantle of opx (hypersthene), also with rim of chlorite or hornblende - inclusion of opaques.

Clinopyroxene - 20 - 25% g.s. - Some ophitic grains 6mm. Both Augite ($\gamma \wedge c = 45^{\circ}$, biaxial positive) and Pigeonite (low 2V, biaxial positive) are present - they occur as subophitic grains about plagioclase (optically continuous), exsolution lamellae of opx and euhedral opaques. Anhedral opaques also associated with minor biotite. Some evidence for twinning and also good cleavage in some specimens.

Orthopyroxene - 5%, g.s. 2mm. Hypersthene. Generally as mantles about the olivine. Some opaque inclusions - essentially without exsolution or twinning.

Opaques - 1-2%. As euhedral exsolution from cpx or anhedral inclusions or intercumulus precipitation - sometimes with minor biotite but generally with ferromagnesians.

Minor - Biotite, chlorite, amphibole (?) apatite (?).

CLASSIFICATION: Olivine meso gabbro.

333-38

TEXTURE: Allotriomorphic, cataclastic texture - undulose extinction of the grains, particularly plagioclase - many of the pyroxenes seem to have been granulated by the deformation.

PETROLOGY:

Plagioclase - 60 - 65% g.s. 6mm. Composition An 39? Granular aggregation of grains - undulose extinction multiple albite, pericline-type twinning uluquitous - triple point junctions very common 120°. Many small parallel inclusions and some examples of exsolution of K feldspar. Many of the twins have been distorted due to metamorphism. Anhedral, with numerous small inclusions.

Hypersthene? 30%, g.s. 5mm. Pink - green pleochroism. Quite often as "granular aggregates" which are optically continuous - many inclusions of opaque, and inclusions of plagioclase as small anhedral grains. Highly fractured - associated with amphibole (hornblende). An exsolution (cpx) is apparent which forms every distinctive pattern - possibly due to deformation (?).

Clinopyroxene - 5% g.s. 0.5mm. Higher birefringence than the opx - generally associated with the hypersthene - exsolution lamellae (parallel to crystallographic directions) - twinning (?) $\gamma \wedge c = 45^{\circ}$. Some rutile exsolution (?) Pigeonite (?). Possibly some Augite Anhedral grains. The opx tends to poikilitically wrap the cpx as it does with the plagioclase grains, and possibly olivine.

Minor - Olivine, hornblende in association with opaques and opx, iron staining, uluquitous opaques usually associated with ferromagnesians.

COMMENT: General metamorphic (high grade), cataclastic texture.

CLASSIFICATION: Meso Norite to leuco norite.

333-52

TEXTURE: Fine to very fine grained granoblastic with some well defined layering due to concentration of opaques - xenoblastic.

PETROLOGY: Plagioclase - 35 - 40% g.s. 0.1mm. Composition An41. Undulose extinction - anhedral grains - many triple point junctions - somewhat sutured edges.

Orthopyroxene - 25% g.s. 0.1mm. Hypersthene. Pink - green pleochroism, associated with many opaques (magnetite (?)). Anhedral grains of approximately the same dimensions as the felsics.

Opaques - 35% Anhedral grains - as inclusions in the ferromagnesians or as discrete grains - form a well - developed layering which is broken in parts by small fractures.

CLASSIFICATION: Mafic granulite (opaque rich).

333-64

TEXTURE: Allotriamorphic - cataclastic texture - undulose extinction of many grains - grains highly fractured - some zoning of minerals also evident.

PETROLOGY: Plagioclase - 50 - 55% g.s. 4.5mm. Composition An57. Antiperthites. Anhedral grains - in some cases highly sutured edges - well-twinned (mainly pericline) - sometimes occur as granular aggregates (due to deformation) - many needle-like intrusions (apatite(?)) - many twins distorted. Some zoning apparent. Inclusions of smaller, anhedral grains of plagioclase. In some places a "finger print" like exsolution of K feld in the plagioclase. (Many small anhedral inclusions in the fingerprint type grains).

Orthopyroxene - 20 - 25% g.s. 3mm. Hypersthene. Pink - green pleochroism - anhedral grains - fractured - unusual exsolution of cpx - some grains enclosed by cpx (pigeonite(?)). Exsolution usually at an angle to the cleavage. Also grains of hypersthene enclosing anhedral grains of cpx. Euhedral exsolution of ilmenite or haemetite parallel to the cleavage - well developed.

Clinopyroxene - 10 - 15% g.s. 2.5mm $\gamma \wedge c$ 45° pseudouniaxial positive. - Pigeonite - euhedral exsolution of haemetite (ilmenite) generally parallel to the cleavage. In many cases includes smaller anhedral grains of hypersthene, or is included in hypersthene. (Contains anhedral opaques).

Opaques - 3 - 4%. Included with ferromagnesians or anhedral grains or euhedral exsolution of haemon ilmenite. Very fine grained.

Antiperthite - 5%. Finger-print type exsolution of K feld from plagioclase - many inclusions in these grains.

CLASSIFICATION: Pigeonite norite (hypersthene gabbro). Pigeonite meso norite.

333-46

TEXTURE Granublastic - xenoblastic equigranular polygonal - some porphyroblasts of feldspar are evident - crude foliation developed (preferred orientation of micas) - roughly parallelled by plagioclase laths. Slightly cataclastic (undulose extinction of plagioclase). Many triple point junctions.

PETROLOGY: **Plagioclase** - 50% g.s. 0.5mm, with porphyroblasts approximately equal to 2.5mm. Composition An36(?) Anhedral grains - many inclusions - well developed twinning (distorted in many grains) - exhibits some exsolution of K feldspar (antiperthite). Inclusions needle-like in form. (slight green tinge - apatite(?)). Some plagioclase well zoned. Sutured boundaries are common.

Orthopyroxene - 20 - 25%, g.s. 0.2mm. Hypersthene Pink - green pleochroism. Small lines of opaques mark old grain boundaries leading to solid-state growth of grains on metamorphism. Inclusions of opaques ubiquitous. Generally in association with the cpx and opaques. Inclusions of opx in cpx.

Clinopyroxene - 20% g.s. 0.3mm, 2V 45° Biaxial positive Augite. Anhedral grains and many inclusions - previous grain boundaries indicated by the above. No pleochroism associated with opaques (anhedral).

Biotite - 5% Good pleochroism - foliated in association with pyroxene and opaques.

Opaques - 3 - 5% Anhedral - associated with ferro-magnesians - probably magnetite. Minor acicular apatite.

CLASSIFICATION: Mafic granulite.

333-69

TEXTURE: Hypidiomorphic - holocrystalline - cataclastic - undulose extinction, also crenulations of the pyroxenes - foliated (elongation of pyroxene).

PETROLOGY: Plagioclase - 45 - 50%, g.s. 4mm. Composition An 30(?) Antiperthite. Highly deformed - fractured undulose extinction - some grains crenulated - many grains show exsolution of the K feldspar - many small inclusions. Carlsbad twins with albite and pericline twinning also. The antiperthite appears not to be crystallographically controlled. Again examples of the "finger-paint" type exsolution.

Clinopyroxene - 25 - 30% g.s. 2.5mm Pigeonite - Biaxial positive, low 2V - quite low birefringence - exsolution of ilmenite or haemetite generally at an angle to the cleavage - inclusions of anhedral opaques. Crenulations.

Orthopyroxene - 15 - 20% g.s. 4mm, hypersthene. Pink - green pleochroism - anhedral grains - many inclusions - exsolution lamellae of opaques $\approx 30^{o}$ to the cleavage. Inclusions of opaques also.

Opaques - 1 - 2% Associated with the ferromagnesians as exsolution features or as anhedral inclusions.

Minor - Antipethite, apatite (?), iron-staining, biotite, serisitisation (kaolinisation) of the plagioclase.

CLASSIFICATION: Hypersthene meso gabbro.

333-39

TEXTURE: Holocrystalline - allotriomorphic - slightly cataclastic - olivine highly fractured - undulose extinction.

PETROLOGY: Plagioclase - 55%, g.s. 2mm. Composition An41. Anhedral grains, undulose extinction. Some grains do not display twinning but are optically positive, therefore not K feld. Many inclusions - opaques and apatite(?). Fine scale antiperthite is however ubiquitous. Carlsbad - albite twinning is prevalent.

Orthopyroxene - 5 - 10%, g.s. 1.5mm. Hypersthene Anhedral grains - inclusions of opaques, pink - green pleochroism. Well cleaved - no observable exsolution. Also well fractured. Often in association with hornblende. Exsolution of opaques parallel to cleavage.

Olivine - 5 - 10%, g.s. 2mm. Generally in association with the other ferromagnesians. Often with hornblende (?) rims. Sub-poikilitically enveloped by pyroxene. Highly fractured with alteration along the cracks.

Clinopyroxene - 30%, g.s. 1mm. low 2V. Pigeonite. Generally higher birefringence than the opx Y∧C 60°. Well cleaved and exsolution developed - lamellae of the opx(?). Exsolution of haematite or ilmenite. Anhedral grains - no pleochroism. Some reaction rims with the plagioclase. Anhedral opaque inclusions. Often with rims of opx and in association with opaques and hornblende.

Minor - Opaques, hornblende, chlorite, biotite, and rutile(?).

CLASSIFICATION: Olivine meso gabbro.

333-48

TEXTURE: Subophitic - holocrystalline - pyroxene partially wrapping the plagioclase. Partially cataclastic - undulose extinction of the plagioclase.

PETROLOGY: Plagioclase - 50 - 55%, g.s. 3mm in length. Composition(?). Anhedral to subhedral grains which are elongate (broad needles) with the length approximately 5/6 times the breadth. Undulose extinction - partially kaolinised (sericitised). Many with anhedral inclusions of opaques - lines parallel to the cleavage. Grain boundaries separated by rows of opaques. Some with twins bent to knee shape. Between the plagioclase and pyroxene rims of chlorite are present. Possibly some exsolution of K feld.

Clinopyroxene - 40 - 45%, g.s. 1mm $\gamma \wedge c$ 47°. Pigeonite. Anhedral grains poikilitically enclosing plagioclase grains - fairly high birefringence - usually with a mantle of reaction rim material between it and the plagioclase - inclusions of opaque common, reasonable cleavage - little exsolution. Low 2V, biaxial positive. Grain boundaries separated by lines of small anhedral (commonly) opaques.

Opaques - 3 - 4%. Anhedral grains - interstitial - associated with ferromagnesians - ubiquitous through the rock.

Minor - Small amount of iron - staining. Reaction rim material as mantles about the cpx, apatite(?) as inclusions in the plagioclase.

CLASSIFICATION: Dolerite.

333-72

TEXTURE: Holocrystalline - allotriomorphic to hypidiomorphic granular. Cataclastic texture not developed - some slight undulose extinction.

PETROLOGY: Plagioclase - 50 - 55%, g.s. 1.5mm. Composition An55. Anhedral grains - weak undulose extinction. Well twinned albite pericline twins - very fresh grains. Quite well fractured - few inclusions (possibly apatite). Many triple point junctions (high grade metamorphism).

Clinopyroxene - 35 - 40%, g.s. 1.5mm. Pigeonite
Anhedral grains, elongate and parallel to the foliation - exsolution of opx parallel to cleavage. Biaxial positive - very low 2V. Also euhedral exsolution lamellae of ilmenite or haematite. Associated with opaques and olivine. Generally occur as grain aggregates.

Orthopyroxene - 10 - 15%, g.s. 1mm. Hypersthene. Anhedral grains in association with the cpx - inclusions of opaques. Generally totally enclosed by the cpx.

Olivine - 5%, g.s. 0.3mm. In association with the ferromagnesians. Enclosed by the pyroxenes - highly fractured - partially altered to iddingsite(?) inclusions of opaques.

Minor - Opaques (3 - 4%), biotite, iron-staining, apatite(?).

CLASSIFICATION: Foliated olivine meso gabbro.

333-49

TEXTURE: Granablastic - with elongation of the plagioclase which do not appear aligned - subophitic recrystallised dolerite - no apparent preferred orientation of mica, etc.

PETROLOGY: Plagioclase - 55%, g.s. 0.7mm. Antiperthite. Anhedral grains - generally well-twinned-elongate (rather lath-like) subophitically enclosed by granular aggregates of pyroxene. Many inclusions - opaques (fine anhedral). Severe undulose extinction - some exsolution of the K feld. Inclusions of zircon or apatite(?). Undulose extinction and small grain size make composition determination impossible.

Orthopyroxene - 5 - 10%, g.s. 0.25mm.
Hypersthene Pink-green pleochroism - many inclusions of anhedral opaques - generally occuring as granular aggregates about the plagioclase - also in association with biotite. Small grains of opaque between grain boundaries. Possibly zoned(?).

Clinopyroxene - 30 - 35% g.s. 0.4mm. Pigeonite.
Pale green anhedral grains - occur in granular aggregates - subophitically surrounding the plagioclase - many exsolution lamellae - needle like form - to square outline - forms a chequer board type pattern. (difficult to relate to cleavage).

Opaques - 3 - 4%. Anhedral associated with the ferromagnesians or as exsolution lamellae in cpx.

Biotite - 5%. Red-brown to pale yellow pleochroism - anhedral in shape, usually with opaques - inclusions of opaque.

Minor - Apatite(?) from plagioclase or zircon.

CLASSIFICATION: Dolerite (Type B).

333-50

TEXTURE: Granoblastic - cataclastic - inequigranular amoeboid to interlobate. Extreme undulose extinction - consisting mainly of K feld - quartz - hornblende with well sutured grain boundaries. Xenoblastic. Minor alterations and fingers of opaques along grain boundaries.

PETROLOGY: Quartz - 10 - 15%, g.s. 1.2mm. Anhedral grains - sutured edges - no alteration - inclusions - also a myrmekitic type inter-growth. Needle shaped to anhedral inclusion - apatite.

Orthoclase - 56 - 60%, g.s. 3mm. K feld - anhedral grains - slightly altered to kaolin especially along grain boundaries. Many exsolution textures - exsolustion of plagioclase to penthite occurs as blebs -

not crystallog - raphically controlled. Also along boundaries - tiny grains of opaque.

Plagioclase - 5 - 10%, g.s. 1mm. Multiple twinning - exsolution of K feld - anhedral grains - as discrete grains and as perthite from K feldspar. Inclusion of grains with multiple twinning within the K feldspar grains (inclusions in turn within the plagioclase).

Hornblende - 5 - 7% g.s. 1.0mm. Extremely good pleochroism - dark green - brown green - bright green. Anhedral grains - associated with opaques and biotite. Forms reaction fingers with the K feldspar - fern-like texture. Usually with iron-staining at the margins of the grains.

Minor - Opaques 2 - 3%, zircon, apatite(?), biotite 1%.

CLASSIFICATION: Granite greiss. (metamorphosed intrusive?).

333-60

TEXTURE: Holocrystalline - hypidiomorphic granular - some evidence of cataclastic texture (undulose extinction) - equigranular except for a few grains. Subophitic in part (olivine wrapping plagioclase). In turn opx wraps the olivine. Phenocrysts of plagioclase (apparently zoned).

PETROLOGY: Plagioclase 50%, g.s.:- phenocryst 4mm, other 1mm. Composition An41. Generally subhedral to anhedral - well twinned (albite) - phenocrysts show zoning. Twins deformed due to metamorphism. Slightly sericitised. Some grains have opaque inclusions together with opx (anhedral) Phenocrysts display antiperthite (K feldspar exsolved from the plagioclase. Along the plagioclase - plagioclase grain boundaries are small anhedral opaques - last intercumulus phase to crystallise.

Olivine - 5 - 10%, g.s. 2mm. Anhedral grains - subophitically wrapping the plagioclase - opx and cpx in turn partially wrap the olivine. Highly fractured - partially altered to iddingsite(?). Grain boundaries invariably curved. Boundaries with plagioclase usually sharp, with some opaque between. Association with olivine - fingers of opaque in the plagioclase ("myrmekitic").

Orthopyroxene - 10 - 15%, g.s. 0.4mm. Anhedral grains. Pink-green pleochroism. Generally as discrete grains in association with cpx - inclusions of opaques. Frequently occur as granular aggregates subophitically wrapping plagioclase. Also envelope olivine grains - form triple point junctions with the other pyroxene grains.

Clinopyroxene - 30 - 35% g.s. 2mm. Low 2V - Pigeonite. Anhedral grains - occur as granular aggregates - enclosing plagioclase and to some extent olivine. Frequent inclusions of opaque either anhedral or long prismatic grains. Well cleaved - some grains display exsolution of opx together with opaques.

Opaques - 5%. Anhedral grains - some "myrmekite like" intergrowths in plagioclase - generally associated with ferromagnesians.

Minor - Biotite, K feldspar, as antiperthite in plagioclase, iddingsite(?) amphibole.

CLASSIFICATION: Olivine meso gabbro.

333-56

TEXTURE: Holocrystalline-allatriamorphic - cataclastic (undulose extinction). Some phenacrysts of plagioclase. Plagioclase highly fractured with alteration(?) preferentially along these cracks.

PETROLOGY: Plagioclase - 55 - 60% g.s. 1.5mm, phenocrysts 4mm Composition An40. Anhedral grains - highly deformed (see texture) undulose extinction - twins distorted. Highly sericitised. Many grains have serated edges - many small inclusions of opaques(?) - defining old grain boundaries. Also patches of small anhedral opaques throughout the plagioclase - ubiquitous.

Orthopyroxene - 25 - 30%, g.s. 2mm. Hypersthene. Anhedral grains - some with serated edges - inclusions of opaque - pink-green pleochroism. Small thin lines of opaque throughout, and on the grain boundary - exsolution of cpx (perhaps haemetite). Some grains poikilitic about plagioclase. Commonly in granular aggregates.

Clinopyroxene - 15 - 20% g.s. 2.5mm. Anhedral grains - exsolution of opx and opaque (ilmenite, haemetite or magnetite) generally in association with the opx - opaque inclusions. Also fine lines of small anhedral opaques ubiquitous.

Opaque - 2 - 3%, g.s. 0.5mm. Generally anhedral grains associated with the ferromagnesians - few in the plagioclase.

Minor - Sericite as alteration of plagioclase, iron-staining, biotite, perhaps some minor K feldspar as antipettute (perthite) from the plagioclase.

CLASSIFICATION: Meso Norite.

333-18

TEXTURE: This section - contact between felsic granulite with cataclastic granablastic texture and a very fine grained dolerite (porphyritic), fine grained ophitic ground mass with phenocrysts of zoned plagioclase.

DOLERITE: Micro phenocrysts of plagioclase (zoned) in a "matrix" of plagioclase and pyroxene - pyroxene ophitically enveloping the small lathes of plagioclase - also generally anhedral opaques.

PETROLOGY: Plagioclase - (Phenocrysts) 30%, g.s. 3mm. Composition An49. The zoning, though very obvious, is only a very narrow band on the periphery of the grains.

Plagioclase - (Matrix) - 25 - 30%, g.s. 0.06mm. Very fine laths of plagioclase ophitically wrapped by pyroxene - composition impossible to determine. There is a rough parallelism of the phenocrysts indicating some sort of flowage parallel to the contact.

Pyroxene - 20 - 25%, that of fine plagioclase. Too fine for any optical properties - many inclusions of opaque within - as ophitic grains wrapping the plagioclase - probably cpx.

Opaques - 5 - 10%. As anhedral grains within the pyroxene finer than both the plagioclase and pyroxene.

COMMENTS: Contact with the granulite is glassy, with quite a concentration of fine opaques in a greenish coloured matrix - examples of magmatic assimilation of the granulite. Some small cavities with opaque in the core and with "corona" of brownish amphibole - some sort of structure perpendicular to the contact of the opaque and the surrounding dolorite. Augen-shaped structures of partially resorbed grains parallel to the flowage.

FELSIC GRANULITE: Cataclastic, granablastic texture of equi-granular grains of plagioclase, quartz, pyroxene and opaque.

PETROLOGY: Quartz - 25 - 30%, g.s. 1mm. Undulose extinction - well fractured - serated edges with other grains - also occurs as myrmekite.

Plagioclase - 55 - 60% g.s. 2.5mm. Antiperthite. Some deformation twinning together with multiple twinning exsolution of the K feldspar. Highly fractured - undulose extinction - some inclusions of opaques and quartz - iron staining in the fractures.

Pyroxene - 10 - 15%, g.s. 0.3mm $\gamma \wedge c$ 45°. Almost entirely cpx - much alteration to hydrous iron oxides - associated with many anhedral opaques - anhedral grains.

Minor - Hypersthene, opaque 2 - 3%, iron staining, myrmekite, antiperthite.

CLASSIFICATION: Felsic granulite. Little reaction between the felsic granulite and the intruded dolorite - chilled margin very slight 3mm.

333-94

TEXTURE: Granoblastic cataclastic texture. Many of the plagioclase grains however are roughly lath-like with no degree of preferred orientation - possibly remnant dolorite texture - granular aggregates of pyroxene about the plagioclase.

PETROLOGY: Plagioclase - 55% g.s. some porphroblasts 3mm, generally 1mm. An49. Antiperthite. Generally elongate grains - multiple twinning ubiquitous - exsolution of the K feldspar - generally anhedral grains - inclusions of pyroxene and opaque. Serated edges - dendritic type opaques quite common.

Clinopyroxene - 20%, g.s. 0.25 - 1.0mm. Augite. ($\gamma \wedge c$ 45°). Pale green - poor pleochroism - many anhedral inclusions of opaque - some exsolution of opaque. Occur as granular aggregates.

Orthopyroxene - 20 - 25%, g.s. 0.3mm. Pink-green pleochroism - many inclusions of opaques - granular aggregates. Anhedral grains generally are smaller g.s. than the cpx. Many of both the pyroxene types show fine lines of opaque along the grain boundary with the plagioclase, etc.

Opaque - 5 - 10%. Generally anhedral grains associated with the ferromagnesians - some dendritic opaque in the plagioclase.

Minor - Biotite - antiperthitic from the plagioclase - possibly some K feldspar as a kind of devitrified mesostasis(?).

CLASSIFICATION: Mafic granulite.

333-90

TEXTURE: Allotriomorphic to hypidiomorphic granular - slightly cataclastic - some of the opx subophitically wraps the plagioclase.

PETROLOGY: Plagioclase - 50 - 55% g.s. 6mm, generally 2 - 3mm. An57. Anhedral to subhedral grains - twinning is ubiquitous - many triple point junctions - some patches of sericite associated - some inclusions of very fine opaques. Where in contact with olivine - small scale structure - reaction rim possibly of opx - structure perpendicular to boundary.

__Olivine__ - 20 - 25% g.s. 3mm. Highly fractured grains - fractures usually infilled with possibly an amphibole - above contact effect with the plagioclase grains some grains wrapped with opx and cpx - inclusions of anhedral opaques - usually embayed - magnetic resorption.

__Clinopyroxene__ - 20 - 25%, g.s. 6mm. Augite. Anhedral grains - some ophitically wrap the plagioclase - associated with opaque or as inclusions - also some small olivines enclosed - exsolution lamellae - castellate structure - opx as small intergrowth, into plagioclase - some of opaques lath-shaped and parallel to cleavage - exsolution phenomenon. Some grains enclosed by opx and in apparent optical continuity with it.

__Orthopyroxene__ - 5 - 10%, g.s. 3mm. Subhedral to euhedral grains - some sort of exsolution phenomenon - inclusions of olivine and laths of plagioclase, also anhedral opaques - as well as the above castellate texture and rims about olivine.

__Minor__ - Biotite, opaque 2 - 3%, dendritic type interstitial grains fingering into the surrounding grains - some exsolution of the K feldspar - antiperthite. Sericite as alteration of the plagioclase. Amphibole(?) - very fine grains as rims about olivine, and iron staining.

__CLASSIFICATION__: Olivine meso gabbro.

APPENDIX II

GEOCHEMISTRY

APPENDIX II

GEOCHEMISTRY

Selection of Samples

Eight samples, viz. 333-63, 333-65, 333-66, 333-67, 333-68, 333-69, 333-70 and 333-71 were selected for whole rock tract element analysis, using the atomic absorption technique. These samples constituted a N-S traverse across the eastern end of the gabbroic intrusion.

333-63, -65, -67 and -71 are classified as meso-gabbros.

333-66 and -70 are classified as olivine meso-gabbros.

333-68 is classified as a mylanitised meso-gabbro.

333-69 is classified as an hypersthene meso-gabbro.

Preparation

This involved removal of weathered surfaces, crushing firstly in a fly press to fragments less than 1 cm. in diameter, then in a 200 ml. chrome steel Seibtechnik Mill. It took approximately 3 minutes to crush the samples to a size suitable for digestion. The 0.5 gm of sample required for analysis was taken from a 1/16 split of the crushed rock. In order to obtain a representative sample, between 350 gm and 650 gm of rock were crushed, thereby minimising sampling error. Aqua regia was used for digestion. Following dissolution of the sample, analysis was undertaken using the Techron Atomic Absorption Spectrophotometer. The results obtained are tabulated below.

	Sample No.	Co ppm	Cu ppm	Cr ppm	Mn ppm	Ni ppm
N	71	4	31	52	-	20
	70	28	26	100	292	136
	63	4	8	40	12	20
	65	6	23	44	24	28
	66	20	10	18	200	84
	67	4	44	24	-	16
	68	4	3	46	10	28
S	69	4	24	32	4	28

Discussion

Unfortunately these results are meaningless with regard to giving an indication of the facing of the body because of the following factors:

1) aqua regia failed to completely reach the sample, i.e. HF digestion would have been preferable if time had allowed.
2) differences in modal plagioclase between samples would have given anomalous values for the 5 trace elements analysed. Consequently it would have been desirable to separate out one of the ferromagnesian components and undertake the analysis on it, rather than the bulk rock trace element analysis attempted above. An analysis of one of the three ferro-magnesians viz. clinopyroxene, orthapyroxene or olivine would thus give the differentiation trend, if any.

The expected concentration in parts per million of the five trace elements in mafic rocks is given below:

Co	45 ppm	
Cu	140 ppm	
Cr	300 ppm	
Mn	2200 ppm	
Ni	160 ppm	Hawkes & Webb (1962).

Thus it can be seen that the results tabulated above are of the order of 1/10 the expected trace element values from mafic rocks.

It is significant to note that although in absolute terms the analyses are meaningless, the two samples containing olivine, viz. 333-66 and 333-70 display high concentrations of all the trace elements (except Cu) relative to the other samples. For this phenomenon, three explanations are proposed:

1) coincidence
2) olivine is more readily digested by the aqua regia solution than are the pyroxenes, hence giving "anomalous" values.
3) olivine "maps up" all of the trace elements (with the exception of Cu) in preference to the pyroxenes, i.e. the olivine lattice is more readily able to tolerate "impurities" than are the lattices of the various pyroxene minerals.

Thus the following recommendations are made for the trace element analysis of gabbroic-type rocks:

1) the sample collected should be greater than 600 gm in order to reduce sampling error.
2) one ferromagnesian component, especially olivine, should be separated from the crushed rock sample. This negates any correction for differences in modal concentration of minerals in the various samples.
3) the sample should be digested by HF and not aqua regia as the latter leads to incomplete digestion.

<u>Reference</u>

Hawkes, H.E. and Webb, J.S. (1962) Geochemistry in Mineral Exploration. Harper and Rowe.

APPENDIX III

X-RAY DIFFRACTION

APPENDIX III

X-RAY DIFFRACTION

Aim

X.R.D. was attempted because of the failure of the geo-chemistry to give reproducible results. It was hoped that this would substantiate limited field evidence that the gabbro body faced north, by showing an increase in albite content of the plagioclase from the proposed base of the intrusion (south), to the proposed top (north). However this simple trend did not eventuate.

Procedure

The same samples are used for the abortive geo-chemical analysis were utilised in the X.R.D. of the separated plagioclases.

After sieving, the fraction between the 105 to 120 mesh sizes was firstly washed (to assist separation) and then separated, using a Frans magnetic separator. The separation was aided by magnetite inclusions in the ferromagnesians. Almost 100% purity of sample was obtained. The pure sample was then analysed by X.R.D. using the method described by Kleeman and Nesbitt (1967).

Theory on which Method is Based

The method utilises measurement of the angle Γ, defined as $2\Theta(131) + 2\Theta(220) - 4\Theta(1\bar{3}1)$ and is dependent on the reciprocal angle γ^* which in turn is sensitive to composition changes. γ^* is also related to the structural state of the plagioclase, and as only relative compositions were required it was assumed that all of the plagioclase crystals from the various samples were in the same structural state. Thus the plagioclase compositions given below are not absolutely accurate, but relative to each other would show a compositional trend, if any.

The two equations relating Γ to the An % are given below. They refer to unheated plagioclase crystals - equation 1) for the An composition 63 - 75, and equation 2) for An 76 - 87.

1) An % = 31.6 + 37.15 Γ

2) An % = 7.7 + 57.39 Γ

It was found however that only equation 1) was required, as the plagioclase crystals analysed fell in the range An 57.6 to An 70.6.

<u>Results</u>

Sample 333-63.

Measured Γ	Av. Γ	An %
0.745°		
0.735°	0.754°	59.6
0.755°		
0.780°		

Sample 333-65.

Measured Γ	Av. Γ	An %
0.666		
0.730	0.699	57.6
0.695		
0.705		

Sample 333-66.

Measured Γ	Av. Γ	An %
0.910		
0.900	0.901	65.1
0.910		
0.885		

Sample 333-67.

Measured Γ	Av. Γ	An %
0.845		
0.870	0.868	63.9
0.885		
0.870		

Sample 333-68.

Measured Γ	Av. Γ	An %
0.920		
0.975	0.948	66.8
0.955		
0.940		

Sample 333-69.

Measured Γ	Av. Γ	An %
0.835		
0.925*	0.860	63.5
0.885		
0.860		

* This value was neglected in the determination of average Γ as it falls well outside the limits of error for the method.

Sample 333-70.

Measured Γ	Av. Γ	An %
1.065		
1.040	1.050	70.6
1.030		
1.065		

Sample 333-71.

Measured Γ	Av. Γ	An %
0.730		
0.805		
0.775	0.776	60.4
0.800		
0.735		
0.810		

<u>Reference</u>

Kleeman, J.D. and Nesbitt, R.W. (1967) X-Ray Measurements of some Plagioclases from the Mt. Davies Intrusion, South Australia. J. Geol. Soc. Aust. 14 (1) pp39 - 42.

GEOLOGY OF HINCKLEY RANGES,
GILES COMPLEX,
WINGELLINA, WA.
REFERENCE
SHEAR
FAULT
LITHOLOGICAL BOUNDARY
INFERRED LITHOLOGICAL BOUNDARY
FOLIATION
VERTICAL FOLIATION
DIP (PRIMARY LAYERING)
CLEAVAGE
VERTICAL CLEAVAGE
PHOTO CONTROL POINTS
·25 SAMPLE LOCATION POINTS (ACCESSION NO. 333/)
·307/1 etc TRAVERSE BY RWN & JLT.
ROAD
ogb OLIVINE GABBRO
gb GABBRO
no NORITE
fg FELSIC GRANULITE
mg MAFIC GRANULITE
ag ACID GNEISS
my MYLONITE
dol DOLERITE DYKE
ono OLIVINE NORITE
GUNBARREL HWY
INTER LAYERED MG & FG
LOCALITY MAP
NT
QLD
WA
SA
NSW
VIC
TAS
SCALE
MILES
KMS.
128°45'
129°00'
26°05'
P.C.SMITH HONS. 1970.