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Petrology, Structure and Geochronology of some High Grade Metamorphic Rocks at Fishery Bay and Cape Carnot, Southern Eyre Peninsula.

by

C.M.Fanning, B.Sc. 1975

PETROLOGY, STRUCTURE AND GEOCHRONOLOGY OF SOME HIGH GRADE METAMORPHIC ROCKS AT FISHERY BAY AND CAPE CARNOT, SOUTHERN EYRE PENINSULA

by

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Thesis submitted in partial fulfillment of the requirements for the Degree of Bachelor of Science with Honours in Geology, at the University of Adelaide.

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ABSTRACT

Two coastal sections were mapped in detail at Fishery Bay and Cape Carnot, southern Eyre Peninsula, in an attempt to delineate characteristicts of the Hutchison Group (Johns 1960).

Structurally, the rocks in both areas have undergone three phases of deformation, resulting in a folded layering, which has also been crenulated. The lithologies are believed to represent a series of meta-sediments which have been intruded by basaltic dykes (quartz tholeiites in composition). At Cape Carnot an intrusion of an anatectic granite probably took place prior to the basaltic intrusions. A younger intrusion of pegmatites has subsequently occured, but prior to this intrusion the sequence had been metamorphosed to the pyroxene granulite sub facies (Turner 1968). It is proposed that the intrusion of pegmatites was accompanied by retrogression to the hornblende-pyroxene sub facies.

A comparison of the mineralogy observed with a compiled pressure-temperature plot of experimentally determined curves, placed the temperature of the prograde granulite facies metamorphism at 800 to 1000^{o}C and the pressure at 8 to 10 Kb.

A detailed Rb-Sr whole rock geochronological study of the augen gneiss, layered gneiss and leuco-gneiss at Cape Carnot failed to produce a satisfactory isochron. However the age of these gneisses does appear to lie in the range 2100 to 2850 M.a. and several alternative explanations of the data have been proposed.

1. INTRODUCTION

1.1. Previous Studies

In the following discussion on the previous geological and geochemical studies of southern Eyre Peninsula, it is necessary for the purpose of this thesis to restrict discussion to essentially the Precambrian basement.

The first cursory remarks on the geological features of the Precambrian complex of southern Eyre Peninsula were reported by Mawson (1907). The Precambrian complex was first subdivided by Tilley (1920, 1921 a,b,c,) into four divisions or series, The Hutchison Series, The Flinders Series, The Warrow Series and The Dutton Series.

The Hutchison Series (Tilley) consists of dolomites and calc-magnesian silicates, paragneisses and graphitic rock; and was considered to be predominantly of sedimentary origin.

The Flinders Series (Tilley) consists of a complex of igneous rocks: granites and gneisses with associated basic rocks, amphibolites, hornblende schists and pyroxene granulites. Its relationship to The Hutchison Series was regarded by Tilley (1921a) as being always of an intrusive kind. The Flinders Series as shown in figure 1 of Tilley (1921a) extends from Redbanks in the west through to the western end of Sleaford Bay, then from the eastern end of Sleaford Bay east to Cape Catastrophe and north through Pt. Lincoln (Locality Map, figure 1).

The Warrow Series (Tilley 1921a) consists of a metamorphosed sequence of sediments, distinct from the Hutchison Series due to a great thickness of massive quartzite. It was metamorphosed by a later intrusion of granites, the Dutton Series (Tilley 1921a).

Glaessner and Parkin (1957)* and Johns (1961) redefined the Flinders and Hutchison Series of Tilley (1920, 1921 a,b,c,) as the Flinders Group, comprising of the oldest gneissic rocks of the region, and the Hutchison

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* Jour. Geol. Soc. Aust., Vol. 5, Pt. 2, for the year 1957 contained The Geology of S.A., prepared by members of the S.A. division and edited by Glaessner and Parkin. Chapt. iv covered Eyre Peninsula, and the original draft was prepared by Johns (Geol. Survey of S.A.).

Group, which embraced the younger schistose rocks. They interpreted the Flinders Group as being an older basement to the younger Hutchison sediments. The Dutton and Warrow Series of Tilley were abandoned. The Flinders and Hutchison Group were interpreted as Archaean.

In figure 16 of Glaessner and Parkin (1957)** and figure 42 of Johns (1961)** it can be seen that the section from Redbanks to the western end of Sleaford Bay, including Cape Carnot is interpreted as belonging to the Hutchison Group (c.f. Tilley).

Frears (1972 unpub. Hons. thesis) conducted a study of the gneisses and associated amphibolites from the western end of Sleaford Bay south to Fishery Bay in an attempt to determine the possibility of a boundary between the two metamorphic rock series. He found no changes in rock type or metamorphic grade significant enough to be a metamorphic boundary. On the basis of a study of amphibolites, Frears tentatively placed the pressure and temperature conditions of metamorphism at 620 deg. to 940 deg. C. and 3 to 5.5Kb pressure.

Bradley (1972 unpub.Phd.thesis A.N.U.) surmised, after a detailed geochemical survey, that the acid and basic rocks of the area were subjected to temperatures of 800 to 950 deg.C. and pressure of 7 to 9Kb during granulite facies metamorphism. This metamorphism was interpreted as having taken place at relatively deep crustal levels (20-26Km) and with moderately high geo-thermal gradients (35-45deg./Km). Bradley (1972) noted a depletion of K,Rb,Cs,Sr,Th,U, and Li, with high K/Rb ratios in many of the acid gneisses and a corresponding enrichment of K.Rb,Cs,Ba,Sr,Pb,Th,Li and light rare earth elements in the anatectic pegmatites. A proposed anatectic fractionation model of Bradley's (1972) predicted the observed depletion in most of the elements in the acid gneiss, an unexplained exception being the depletion of Sr.

Bradley (1972) also noted a dehydration fractionation of the basic rocks resulting in a depletion of K,Rb,Ba and increased K/Rb ratios, with rehydration resulting in the reverse effect.

** In both cases a tectonic map of southern Eyre Peninsula compiled by Johns (Geol. Survey of S.A.).

1.2. Present Study

As can be appreciated from the above discussion of previous literature, there exists some conflict as to the status of the Precambrian in southern Eyre Peninsula.

Two students (M. Flook and the author) therefore undertook the detailed mapping structural analysis and petrological examination of several small areas, followed by Rb/Sr geochronology. Co-worker M. Flook was assigned to the Flinders Group and investigated sections at Kirton Point and Cape Donnington. (fig. 1)

The author was assigned to the Hutchison Group and investigated sections at Fishery Bay and Cape Carnot (fig. 1) approximately 40 to 50 km. south of Port Lincoln respectively. The outcrop of the Hutchison Group in these areas is essentially restricted to the coastal platforms, with a few isolated outcrops inland; the sections mapped were along the coastal platforms.

At Fishery Bay (fig. 1) an area roughly 140 metres long by 20 metres wide at its maximum, was mapped on a scale of 1:200. At Cape Carnot, extensive outcrop occurs on a small peninsula separated from the mainland by a crevasse. A rectangular area 90 metres by 40 metres was mapped on a scale of 1:100 (fig. 2).

Due to the detailed mapping scales air photographs were ineffective, and the maps were made by means of a tape and compass survey. Reference stations at prominent points were initially sited, then plotted on centimetre square graph paper.

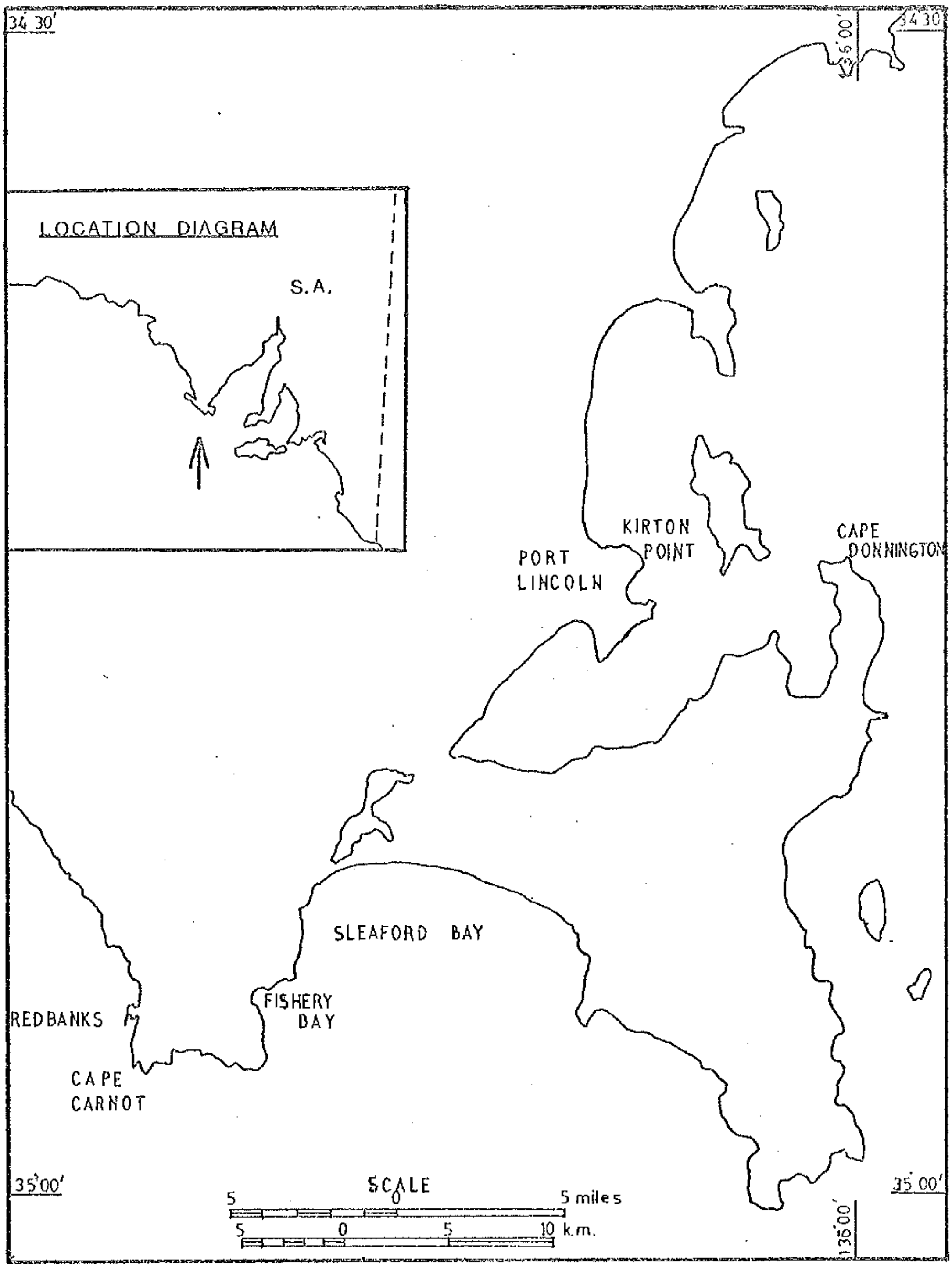

Fig. 1 LOCATION MAP : SOUTHERN EYRE PENNINSULA

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2. STRUCTURE

2.1 Folding

2.1.1 Fishery Bay

The most dominant structural feature observed at Fishery Bay is a layering S_0, striking approximately north-south and generally dipping steeply either to the west or east. This S_0 has been interpreted as representing the original sedimentary layering (Tilley 1921 a,b,c; Johns 1960; Frears 1969), however there is the possibility that it may be a metamorphic layering (i.e. S_1) since lithologies change along strike as often as across strike. Also the layering is essentially due to mineral segregations resulting in the development of biotite and garnet rich layers, as well as quartz and potash feldspar rich layers. Therefore S_0 may in fact have been transposed during phase F_1 to give a layering S_1.

This S_1 has been folded during folding phase F2 (F2 only if F_1 is true) into a series of tight anticlines and synclines (Plate I, A and B) the limbs of which are essentially parallel. In the hinge zones (e.g. sample F55 taken from the hinge zone of fold shown in Plate I B) an axial plane schistosity S_2, manifested by the parallelism of biotite, is developed. Within the limbs this S_2 can be seen to be sub-parallel to the layering S_1.

Plate I B indicates that the basics were intruded prior to the F_2 phase as the layering in the acid gneisses is folded independently of the more competent basic granulites. Note also that the basic granulites were observed to have been involved in an F_2 fold.

The equal area plot of poles to layering S_1, fig. 3(a), indicates that overall the F_2 fold axis is horizontal, trending towards 008^0 (or 188^0). A plot of six individual fold axes measured, fig. 3 (b), indicates that in detail individual fold axes have shallow plunges towards 010^0 or 190^0, and in one instance 170^0. This slight variation in plunge of the fold axis can be attributed to a slightly heterogeneous deformation.

The last phase of folding (F3) recorded at Fishery Bay is associated with the development of the pegmatitic veins. These veins have two distinct strike orientations, namely (i) striking at 110^0 to 120^0, across the S_1 layering and (ii) parallel to the S_1 layering. When the veins are cross cutting, the S_1 layering is rotated dextrally with respect to the veining direction (Plate II A, although taken at Cape Carnot the angular relationships are similar). This rotation can be interpreted as a crenulation of S_1 during the F_3 phase, with the development of pegmatitic veins axial plane to F_3. There may be some shearing associated with this folding as thinning of the layering occurs in the hinge zones.

2.1.2. Cape Carnot

In the main, structural measurements of dips or plunges were restricted due to the nearly planar surface of the outcrop. In terms of structural analysis one can, however, qualitatively recognize a similar deformational history to that proposed for Fishery Bay.

The dominant feature is a layering of the acid gneisses, perhaps equivalent to S_1. This layering has been folded and can be seen to follow conformably the outline of the basic granulites, (Plate I C), similar to the expression of F_2 at Fishery Bay. At Cape Carnot the acid gneisses appear to have been more plastic and to have deformed as incompetent "flow" folds, compared with the basic granulites which have remained essentially solid and competent.

The last phase of folding F_3 is characteristically well developed at Cape Carnot (see Plate II A). There is a dextral rotation of the layering, apparently representing crenulation of S_1 during F_3, and the development of pegmatitic veins axial plane to F_3.

Shearing was also observed, occuring essentially along the axial plane of F_3 and displacement of layers can be seen (see Plate II B).

At Cape Carnot there are more pegmatitic veins developed parallel to the layering than observed at Fishery Bay. This can be attributed to shearing occuring parallel to the layering S_1 during the F_3 phase. These shear planes then acted as locii for the development of the coarse augens of potash feldspar (see Plate III A).

2.2. Faulting.

No faulting was observed at Fishery Bay.

At Cape Carnot two faults were observed

(a) A minor left lateral displacement of 0.5 m. occured parallel to the proposed axial surface of the F_3 phase (Plate II B).

(b) A larger feature, also with left lateral displacement, trending east-west across the neck of the small peninsula (see fig. 2).

Both these faults have the same sense of movement and essentially the same strike direction. They may be contemporaneous.

2.3 Summary

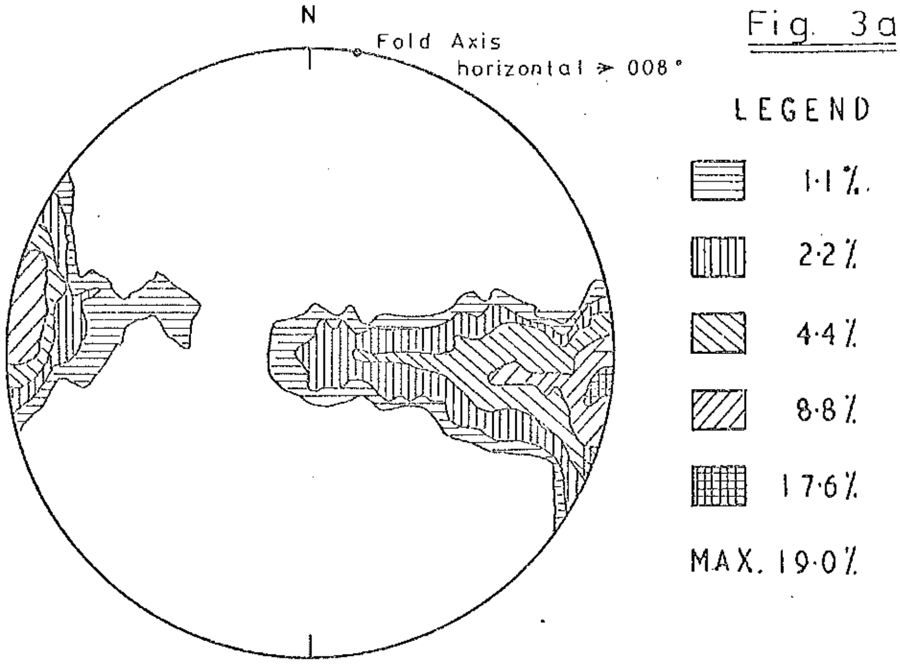
The structure of both areas can be summarised as follows:

Deformation	Surface	Geological Expression
F_1	S_o) S_1)	Combined as S_{o-1} layering
F_2	S_2	Parallelism of biotite in hinge zones of F_2 folds
F_3	S_3	Dextral folding and emplacement of pegmatites in axial plane of F_3 folds. Shearing with production of augen at Cape Carnot.

EQUAL AREA PLOTS

FISHERY BAY

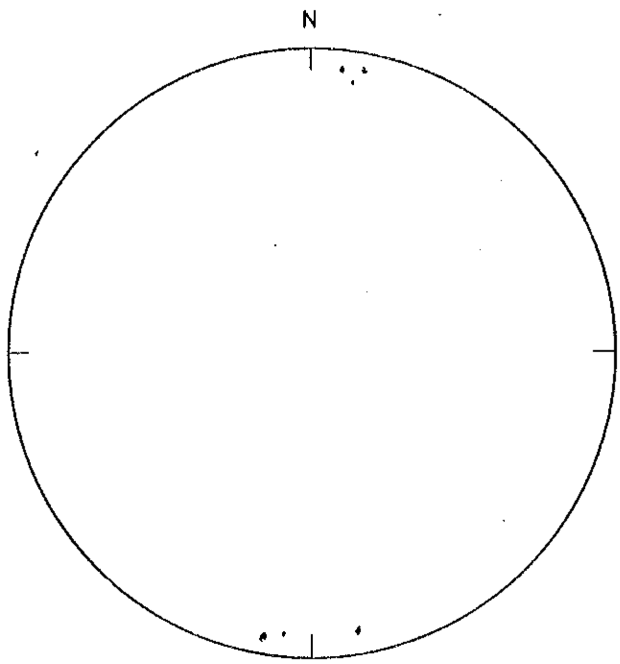
Fig. 3a.



POLES TO LAYERING (S_1

(79 MEASUREMENTS)

Fig. 3b.



FOLD AXES (F_2)

(6 MEASUREMENTS)

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3. PETROLOGY

3.1. Terminology

The term "granulite" has been under much discussion of recent (Behr et. al. 1971).

> The definition used in this thesis is that of White (1971): "Granulite is a regionally metamorphosed rock composed of a granular aggregate of minerals that have certain chemical and structural characteristics. The minerals are chiefly feldspar ± quartz ± pyroxene ± garnet. Ferromagnesian minerals are predominantly anhydrous".

The presence of orthopyroxene in the basic rocks is assumed diagnostic of the granulite facies.

Textural terms are according to Moore (1970). The term paragneiss is used for a rock of granulitic composition whose origin is thought to be sedimentary.

3.2. Fishery Bay

Fifty nine samples collected at Fishery Bay were examined in thin section.

The dominant lithology is a garnet gneiss with layered garnet gneiss, leuco-gneiss and biotite garnet gneiss variants.

Intrusive basic dykes occur essentially concordant with the garnet gneiss, generally boudinaged along the strike of the layering. Cross cutting pegmatites are a late stage development.

Thin section descriptions of type lithologies are given in Appendix A, sample locations are recorded on map 1, and modal analyses of all thin sections in Appendix B.

3.2.1. Garnet Gneiss

In hand specimen there appears to be three sub-types of garnet gneiss.

(a) A layered garnet gneiss consisting of intercalated leuco layers of quartz feldspar and garnet, and mafelsic layers of quartz, biotite and garnet.

(b) A leuco-gneiss variety consisting of a fairly homogeneous mixture of quartz and feldspar, with porphyroblasts of garnet and subordinate amounts of biotite.

(c) A biotite garnet gneiss which occurs as isolated pods.

The distribution of these three lithologies is generally random. They do not form continuous zones parallel to the layering, implying that the layering is parallel to a surface on which the original bedding was transposed (c.f. Tilley 1921 b, Johns 1960).

(a) Layered Garnet Gneiss

The texture of the layered garnet gneiss, in thin section, is essentially seriate, interlobate to amoeboid (Moore, 1970), but is inequigranular, interlobate to amoeboid in some instances.

The layering can be coarse or fine, ranging from 7 to 10 mm. (generally quartzo-feldspathic layers) down to 2 to 3 mm. (generally biotite rich layers) in thickness.

The main mineralogy consists of potash feldspar, plagioclase, quartz, garnet, biotite, and minor zircon, with varying amounts of sillimanite, spinel, opaque, sericite, chlorite, rutile and apatite.

Potash feldspar is usually finely perthitic, with some microcline cross hatching present. Myrmekite is a common feature occuring at grain boundaries between plagioclase - potash feldspar and potash feldspar - potash feldspar.

Plagioclase composition ranges from Ab_{74} to Ab_{62}, i.e. oligoclase to andesine. Grains are either twinned, albite and pericline lamellation generally, although some carlsbad was recorded, or untwinned and in some cases the lamellae are kinked.

Quartz is typically present as elongated grains orientated parallel to the layering. Garnet occurs as rounded, isotropic, nearly colourless porphyroblasts which have a marked cracking pattern resulting in segmentation of the coarser grains.

Biotite occurs as elongate flakes usually showing parallel orientation. The biotite is strongly pleochroic, dark reddish brown to pale fawn the usual colour scheme.

Zircon occurs as round colourless grains of high relief and high maximum birefringence.

Sillimanite where present occurs either in the form of rhombic sections with well developed diagonal cleavage (010) or as slender elongate prisms with the prismatic axis parallel to the foliation. Usually the elongated prisms are arranged in stringers and bands associated with biotite.

Sample F_8 is a typical layered garnet gneiss (described in Appendix A.)

(b) Leuco-gneiss

The leuco-gneiss and the layered garnet gneiss are differentiated by a distinct lack of biotite in the leuco-gneiss and a corresponding lack of a distinct layering. The Leuco-gneiss does possess some layering, however, as shown by the parallel orientation of elongate quartz and feldspar grains in thin section.

The mineralogy of the leuco-gneiss is essentially the same as that described for the layered garnet gneiss.

Sample F_{20} is a typical leuco-gneiss (described in Appendix A).

(c) Biotite Garnet Gneiss

The biotite garnet gneisses are characterised by high volume percentages of biotite (10-20%) and garnet (up to 25%). They occur as isolated pods in the layered garnet gneiss and leuco-gneiss.

The mineralogy is essentially the same as that described for the layered garnet gneiss.

Sample F39 is a typical biotite garnet gneiss (described in Appendix A).

3.2.2. Basic Granulites

Basic granulites are intrusive (originally) into the garnet gneisses, occuring as elongate pods or layers cross cutting at a low angle the layering of the garnet gneisses.

The mineralogy consists essentially of orthopyroxene, clinopyroxene, and plagioclase with lesser amounts of quartz and opaques. Present also, in minor variable amounts, are biotite, hornblende, potash feldspar, zircon and sericite. Parallel elongation of the ferro-magnesian minerals gives the basic granulites a foliation.

The plagioclase composition ranges An_{58} to An_{64}, i.e. labradorite. Pericline and albite twinning is present. Orthopyroxene was observed to be the dominant pyroxene in most thin sections. The orthopyroxe is of the hypersthene variety whereas the clinopyroxene is probably diopside.

Samples F_{36} and F_{56} were located in an area that has extensive pegmatitic veining. In this case the veining appears to have a retrogressive effect on the basic granulites as indicated by the replacement of orthopyroxene by green hornblende.

Sample F_{30} is a typical basic granulite (described in Appendix A).

3.2.3. Pegmatites

Pegmatites occur as veins either cross cutting the S_1 layering (axial plane to the F_3 folding), or are parallel to the S_1 layering.

They are clearly distinguished by their relatively coarse grain size and distinct lack of a foliation.

In thin section the texture of the pegmatites is inequigranular, interlobate to amoeboid (Moore 1970).

The mineralogy is essentially quartz and potash feldspar, with plagioclase and sericite. Quartz exhibits undulose to slightly undulose extinction. Potash felspar is commonly finely perthitic with a fair proportion of the grains possessing microcline cross hatched twinning. Myrmekite is present. The plagioclase composition is that of andesine. Sericite is a later development commonly replacing plagioclase and potash feldspar.

Minerals present in varying minor amounts include biotite, opaques, zircon, chlorite, garnet, and sillimanite.

3.3. Cape Carnot

The area mapped in detail at Cape Carnot is part of a more extensive layered series (see fig. 2). On the nearby coastal exposures the layered series (note the distinction from the layered gneiss) was seen to consist of a mixture of felsic and mafic layers, the felsic layers tending to dominate and the mafic layers appearing as pods essentially concordant with the layering.

The layered series is restricted to the eastern and western ends of the peninsula, the main part of the peninsula consisting of two massive layers of augen gneiss and layered gneiss (note the distinction from the layered series). Basic rocks are intrusive into these two lithologies, and subsequent deformation has resulted in accommodation of the layering around them. In several instances the basic rocks are boudinaged along strike.

The textures of the augen gneiss and layered gneiss, together with the "flow" structure (mentioned in 2.1.2. above) indicate a certain degree of melting occured during metamorphism.

The presence of zones of coarse feldspar megacrysts parallel to the layering, the cross cutting pegmatitic veins and some finer aplitic developments are a late stage development.

Sample locations are recorded on map 2, thin section description of type lithologies are given in Appendix A, and modal analyses of all thin sections in Appendix B.

3.3.1. Augen Gneiss

The augen gneiss was seen to consist of two types, either with the felspar augens orientated parallel to the foliation, or with them in random orientation (Plate III B and III C).

Texturally, in thin section the augen gneiss is inequigranular amoeboid to interlobate (Moore 1970).

Mineralogically it is composed of potash feldspar, quartz and plagioclase, with lesser amounts of biotite and garnet. Accessory minerals are opaques, zircon, sericite and chlorite, with traces of sillimanite.

The potash feldspar is finely perthitic, myrmekitic and shows microcline cross hatched twinning in a lot of grains. Coarse augens range up to 2 cm. in length. The plagioclase composition ranges from Ab_{73} to Ab_{66} i.e. oligoclase to andesine. It sometimes shows antiperthite exsolution. The biotite has a typical deep reddish brown to pale fawn pleochroism and, where sillimanite is present, they appear to have a close relationship (see Plate IV A).

Round zircons were seen in all thin sections. Sericite was seen to be replacing biotite.

Sample C256 is used as a typical example of the augen gneiss. A detailed thin section description is given in Appendix A.

3.3.2. Layered Gneiss

The layered gneiss is distinguished from the augen gneiss by the presence of a distinct mineralogical layering. The layering can be seen, in thin section, to be due to parallel alignment of elongate quartz and feldspar grains, and the concentration of biotite in certain zones.

In thin section the texture of the layered gneiss is seriate, amoeboid to interlobate.

Mineralogically it consists of potash feldspar, quartz and plagioclase, with lesser amounts of biotite and garnet. Minerals present in accessory amounts are zircon, opaques, sericite, chlorite, and traces of sillimanite and spinel. The features of these minerals are the same as those described for the augen gneiss. A notable exception is the presence of spinel in specimen C121, where it was seen to be involved in a metamorphic reaction with sillimanite, garnet and biotite (Plate IV B)

i.e. Biotite + quartz = orthoclase + garnet + spinel + H_2O.

and/or Biotite = orthoclase + spinel + sillimanite + H_2O.

Sample C263 is a typical example of the layered gneiss (described in Appendix A).

3.3.3. Biotite Garnet Gneiss

This lithology is present as small pods in the augen and layered gneiss. It is distinctive due to a high concentration of biotite and garnet, and may represent relict pods of pelitic sediment.

Sample C208 is a typical example of the biotite garnet gneiss (described in Appendix A).

3.3.4. Basic Granulites

The originally intrusive nature of the basic granulites has been mentioned.

A foliation is manifested in these granulites by the parallel orientation of elongate ferromagnesian grains as seen in thin section. Texturally they are equigranular to inequigranular, amoeboid to interlobate.

All of the basic granulites examined in thin section contain plagioclase, orthopyroxene, clinopyroxene and opaques. Variations are provided by the presence in some cases of hornblende, biotite, or both hornblende and biotite.

Quartz was commonly present in minor amounts; traces of potash feldspar, zircon and spinel were also seen. The plagioclase composition ranges from An_{58} to An_{68} i.e. labradorite. Pericline and albite twinning was observed, as well as some zonation, presumably compositional. Orthopyroxene was observed to be present in greater than or equal amounts to clinopyroxene. The orthopyroxene is of the hypersthene variety whereas the clinopyroxene is probably diopside.

Replacement of orthopyroxene by dark green to pale green, pleochroic hornblende is a common feature. In some instances the hornblende may be primary as indicated by its stable well defined grain boundaries, but usually it forms due to retrogression of the basic granulites.

Similarly some of the biotite present was seen to be replacing the pyroxenes. However, most of the biotite has a reddish-brown to pale fawn pleochroism, suggesting that it crystallized in the granulite facies.

A much later stage of alteration is indicated by the replacement of plagioclase by sericite, and biotite by chlorite.

Sample C142 is a typical example of the basic granulites (described in Appendix A).

3.3.5. "Mixed" Gneisses

The term "mixed" gneisses applies to a sequence within the layered series (note the distinction from the layered gneiss - fig. 2) that was mapped in detailed scale on the eastern end of the peninsula. These "mixed" gneisses consist of essentially layered gneisses and basic granulites intimately inter-layered to the extent that the lithologies change randomly over a distance of a few centimetres across strike (e.g. samples C180 and C181 are adjacent samples yet C180 has 40 volume % opx. whereas C181 has only 2 volume % opx.)

Compositions range from orthopyroxene rich basic granulites through to orthopyroxene bearing layered gneisses. These "mixed" gneisses may represent partial melting of a sequence of acid gneisses and basic granulites.

Samples C180 and C181 are typical examples of the range in lithologies grouped as "mixed" gneisses (described in Appendix A).

3.3.6. Leuco-gneiss

Within the layered series there are developed thin layers of essentially potash feldspar, quartz and plagioclase. Biotite and garnet are present in very minor amounts. One can envisage these layers as being either acid concentrates of a partial melting phase, or a relict thin sedimentary layer.

Mineralogically these leuco-gneiss layers on the peninsula have similar compositions to those sampled for the geochronology (see location on fig. 2).

Sample C192 is a typical example of the leuco-gneiss (described in Appendix A).

3.3.7. Sillimanite Cordierite Gneiss

Sample C209 (described in Appendix A) is unique in that it contains approximately 20 volume percent sillimanite and also 2 to 3 volume percent cordierite.

The cordierite is distinctive in that it possesses pleochroic haloes around zircon inclusions (Plate IV C). It also shows multiple lamellar twinning.

Also present in thin section is potash feldspar, sillimanite, quartz, plagioclase and sericite, with lesser amounts of biotite, spinel, opaques, zircon and chlorite.

This lithology has significant pressure and temperature implications (see conditions of metamorphism).

3.3.8. Pegmatitic Zones and Veins

Pegmatitic zones are developed approximately parallel to the layering. They consist of extremely coarse potash feldspar augens, up to 20 cm. in length. The contacts between these zones and the surrounding gneisses are diffuse implying that these zones were formed from the gneisses. In the section on structure it was suggested that shears parallel to the layering may have acted as locii for the development of these coarse feldspar augens. Pegmatitic veins cross cut the layering, trending approximately 300 to 310^{o}, and possibly along the axial plane of the F_3 phase of folding. The contacts with the gneisses are more clear cut than the zones, but the mineralogy is the same.

The pegmatites also intrude the basic granulites. No distinct pattern was observed, their distribution being random. In the hand specimen the pegmatites from a basic granulite have a green colouration, however in thin section there appears little difference between crosscutting pegmatites in the acid gneisses or basic granulites.

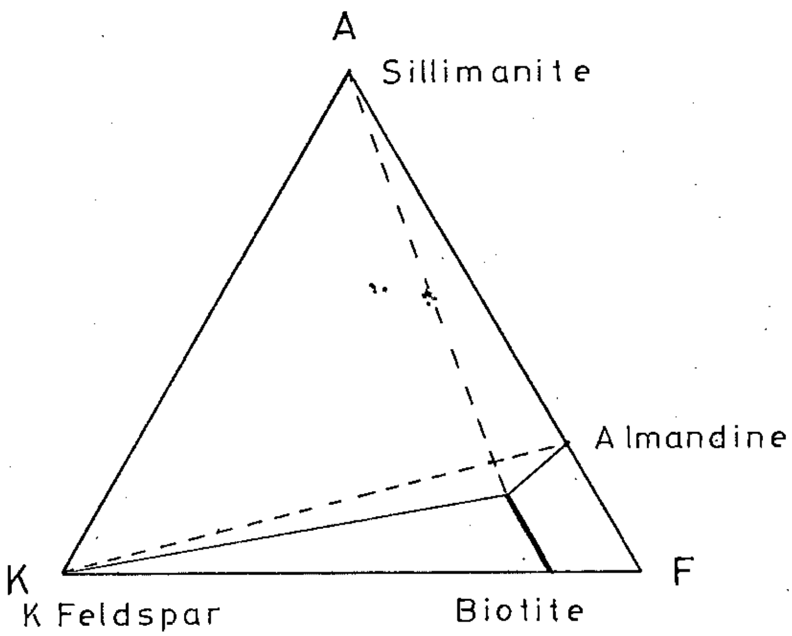
The pegmatites do not posses a foliation and thus little structural deformation has taken place since their development.

Sample C158 is an example of a pegmatite zone (described in Appendix A.)

3.3.9. Aplitic Veins

Finer veins of quartz and feldspar also cross cut the layering.

Sample C150 (described in Appendix A) consists of an aplitic vein with a rimming of biotite. This is a common feature of the aplitic veins, and it appears that this may represent granitization of restricted zones of the gneisses, resulting in expulsion of the mafic minerals (causing a rim of biotite). A reconstitution of the felsic minerals into an even grained more homogeneous segregation also resulted.



AKF plot : geochemically analysed acid gneiss samples

$A = Al_2O_3 + Fe_2O_3 + Na_2O + CaO$

$K = K_2O$

$F = FeO + MgO$

3.4. Origin of the Gneisses

It has been proposed by various authors that the garnet gneisses in the Cape Carnot - Fishery Bay - Sleaford Bay region have a sedimentary origin (Tilley 1921 b, Johns 1960, Bradley 1972). The presence of round zircons has been taken by some to be indicative of sedimentary origin (Murthy and Siddique 1964, Saxena 1966). If the gneisses did have a sedimentary origin, all traces of original clastic structures have been destroyed by complete recrystallisation.

The geochemical composition corresponds to that of silty shales, possibly, ranging into more quartzose types. An AKF plot (shown opposite) of the geochemically analysed samples indicates a relatively alumina rich composition. The abundance of potash feldspar reflects relatively high potassium, suggesting constituents such as sericite, biotite or illite in the original shales. The crystallisation of the potash feldspar involves the release of excess alumina, hence the appearance of garnet and more rarely sillimanite and spinel.

For example:

$$2H_2KAl_3(SiO_4)_3Mg_2Fe_4(SiO_4)_3 + 3SiO_2 = 2KAlSi_3O_8 + 2Fe_2MgAl_2(SiO_4)_3 + H_2O$$

i.e. biotite + quartz = orthoclase + garnet

At Cape Carnot the presence of the relict igneous texture shown by the random orientation of feldspar augens in the augen gneiss, implies that at some stage it has been molten. Thus this gneiss may have resulted from the concordant intrusion of a granitic magma into the layered sequence prior to, or contemporaneous with metamorphism. The presence of pelitic pods with sillimanite, and round zircons may have resulted from the incorporation of some of the sediments during intrusion. The augen gneiss may have formed due to anatexis of the sediments in situ, during high grade metamorphism.

4. GEOCHEMISTRY

4.1. Samples and Analyses

Nine samples in all were selected for geochemical analysis. These consisted of three garnet gneisses from Fishery Bay (samples F8, F25, and F52), two augen gneisses (samples C256 and C261) and a layered gneiss (sample C263) from Cape Carnot, a basic granulite from each area (samples F30 and C142), and a pegmatite (sample F34) from Fishery Bay.

Whole rock analyses were made using a Siemens S.R.S. following the procedures of Norrish and Chappell (1967). The trace elements Rb, Sr, Y and Th were determined on the same apparatus. Ba and Mn were determined on a Phillips PW 1540 X-ray Fluorescence spectrometer. Na and K were determined by flame photometry. A more detailed outline of the procedures is given in Appendix C.

Table I sets out the results of the geochemical analyses as well as some calculated element ratios.

4.2. Discussion of Results

Calculation of C.I.P.W. normatives (Table II) for the basic granulites indicates that these rocks are quartz normative.

The gneissic rocks are corundum normative, reflecting the relatively high amount of alumina present - evidence for their origin as shales.

The gneisses all have greater than 65% SiO_2, and therefore can be termed acidic.

4.2.1. Acid gneisses and the Pegmatite

The K/Rb ratios for the acid gneisses range from 348 to 412 at Fishery Bay, and at Cape Carnot 346 to 366. The K/Rb ratio for the single pegmatite is significantly lower at 279. The high K/Rb ratios, relative to the crustal average of 230 (Heier 1973), may be attributed to a depletion of Rb relative to K taking place during high grade metamorphism.

On a plot of K/Rb versus K (fig. 4) there is considerable scatter. However, the fact that the acid gneisses from both areas plot above or just below the upper K/Rb limit for amphibolite facies and low pressure granulite facies indicates that these acid gneisses were probably subjected to medium to low pressure granulite facies metamorphism.

4.2.2. Basic Granulites

The $(Na_2O + K_2O)\%$ versus $SiO_2\%$ has been plotted for the two basic granulites on fig. 5. Clearly these rocks plot in the tholeiitic field, and combined with the fact that quartz is normative in these rocks, one can tentatively propose that they are metamorphosed equivalents of quartz tholeiites.

TABLE I

WHOLE ROCK ANALYSIS (in %)

	F8	F25	F52	C256	C261	C263	F30	C142	F34
SiO_2	68.10	70.66	70.41	70.08	69.23	68.27	47.54	50.69	72.72
Al_2O_3	15.61	14.04	13.52	14.97	14.61	14.89	13.03	14.57	14.88
Fe_2O_3	4.35	5.84	5.53	3.59	3.77	4.88	17.77	12.94	1.48
MnO	0.06	0.07	0.08	0.04	0.04	0.07	0.26	0.21	0.01
MgO	2.00	2.74	2.80	2.08	2.10	1.86	6.83	7.77	0.92
CaO	1.23	1.41	1.58	1.32	1.24	1.61	10.04	11.76	1.29
Na_2O	2.91	2.43	2.40	2.79	2.71	2.78	1.64	0.94	3.27
K_2O	5.81	2.94	2.91	5.50	5.59	4.96	0.25	0.65	5.38
TiO_2	0.36	0.56	0.51	0.64	0.63	0.71	2.67	0.84	0.30
P_2O_5	0.08	0.06	0.03	0.09	0.09	0.07	1.09	0.06	0.11
Loss	0.07	-0.14	0.09	0.15	0.25	0.23	-0.54	-0.01	0.53
Total	100.58	100.61	99.86	101.25	100.30	100.33	100.58	100.42	100.89

TRACE ELEMENT ANALYSIS (in p.p.m.)

	F8	F25	F52	C256	C261	C263	F30	C142	F34
Sr	195	176	94	143	136	138	62	82	3788
Rb	117	70	66	132	130	122	4	19	160
Y	21	39	36	16	14	26	61	26	12
Th	14	5	5	52	54	50	1	1	201
Ba	701	623	696	664	710	657	317	203	1491

SELECTED ELEMENTAL RATIOS

	F8	F25	F52	C256	C261	C263	F30	C142	F34
Rb/Sr	0.60	0.40	0.70	0.92	0.95	0.88	0.06	0.24	0.42
K/Rb	412	348	366	346	357	337	519	284	279
K/Ba	69	39	35	69	65	63	77	27	30

C.I.P.W. NORMATIVE ANALYSIS TABLE II.

	F8	F25	F52	C256	C261	C263	F30	C142	F34
Qtz.	21.78	36.01	35.64	25.94	25.23	25.32	4.38	4.32	28.82
C.	2.50	4.45	3.63	2.24	2.10	2.18	-	-	1.59
Or.	34.34	17.38	17.19	32.47	33.05	29.30	1.47	3.82	31.77
Ab.	24.62	20.56	20.31	23.61	22.93	23.52	13.88	7.95	27.67
An.	5.55	6.59	7.62	5.98	5.57	7.56	27.45	33.63	5.71
Di. Wo.	-	-	-	-	-	-	6.34	10.17	-
En.	-	-	-	-	-	-	3.18	5.47	-
Fs.	-	-	-	-	-	-	3.02	4.37	-
Hy. En.	4.98	6.82	6.97	5.17	5.23	4.64	13.82	13.89	2.29
Fs.	3.89	5.10	4.86	2.65	2.85	3.88	13.13	11.12	1.03
Mt.	1.58	2.12	2.00	1.30	1.36	1.77	5.15	3.76	0.54
Il.	0.69	1.07	0.98	1.22	1.19	1.35	5.07	1.60	0.58
Ap.	0.19	0.14	0.08	0.21	00.21	0.16	2.54	0.13	0.25
Total	100.13	100.24	99.28	100.79	99.73	99.67	99.44	99.70	100.23

Explanation:
Qtz. = quartz   Di. = diopside   Mt. = magnetite
C. = corundum   Wo. = wollastonite   Il. = ilmenite
Or. = orthoclase   En. = enstatite   Ap. = apatite
Ab. = albite   Fs. = ferrosilite
An. = anorthite   Hy. = hypersthene

Note for CIPW Norms.

Acid Rocks ¼ Fe_2O_3 (as total Fe) Fe_2O_3; remaining (Fe_2O_3) 0.9 FeO
Basic Rocks 1/5 " " " " " " " " "

Explanation of Fig. 4 and Fig. 5 shown on page facing

Fig. 4 : Upper K/Rb Limits for High Pressure Granulites, -Amphibolites and Low Pressure Granulites.

Points plotted consist of the six acid gneisses analysed. High pressure granulite limits include medium to high pressure granulites from: Australia (Musgrave and Fraser Ranges; Lambert, 1967), Norway (Lofoten-Vesteraalen; Heier et al. ,1969, Heier and Compston, 1969, Green et al. 1969).

The amphibolite and low pressure granulite limits include all the amphibolites from the medium-high granulite sources and rocks from the low pressure granulite terrains as follows: Australia (Kimberly Block, Cape Naturaliste and the South-West Shield; Lambert, 1967), North America (Adirondacks; Whitney, 1969).

Fig. 5 : Macdonald - Katsura Silica - Alkalis Plot for the Basic Rocks.

The modified Macdonald - Katsura line is from Irvine and Baranger (1971), and the original line from Macdonald and Katsura (1964).

Explanation of Fig. 4 and 5 on page facing.

Fig. 4

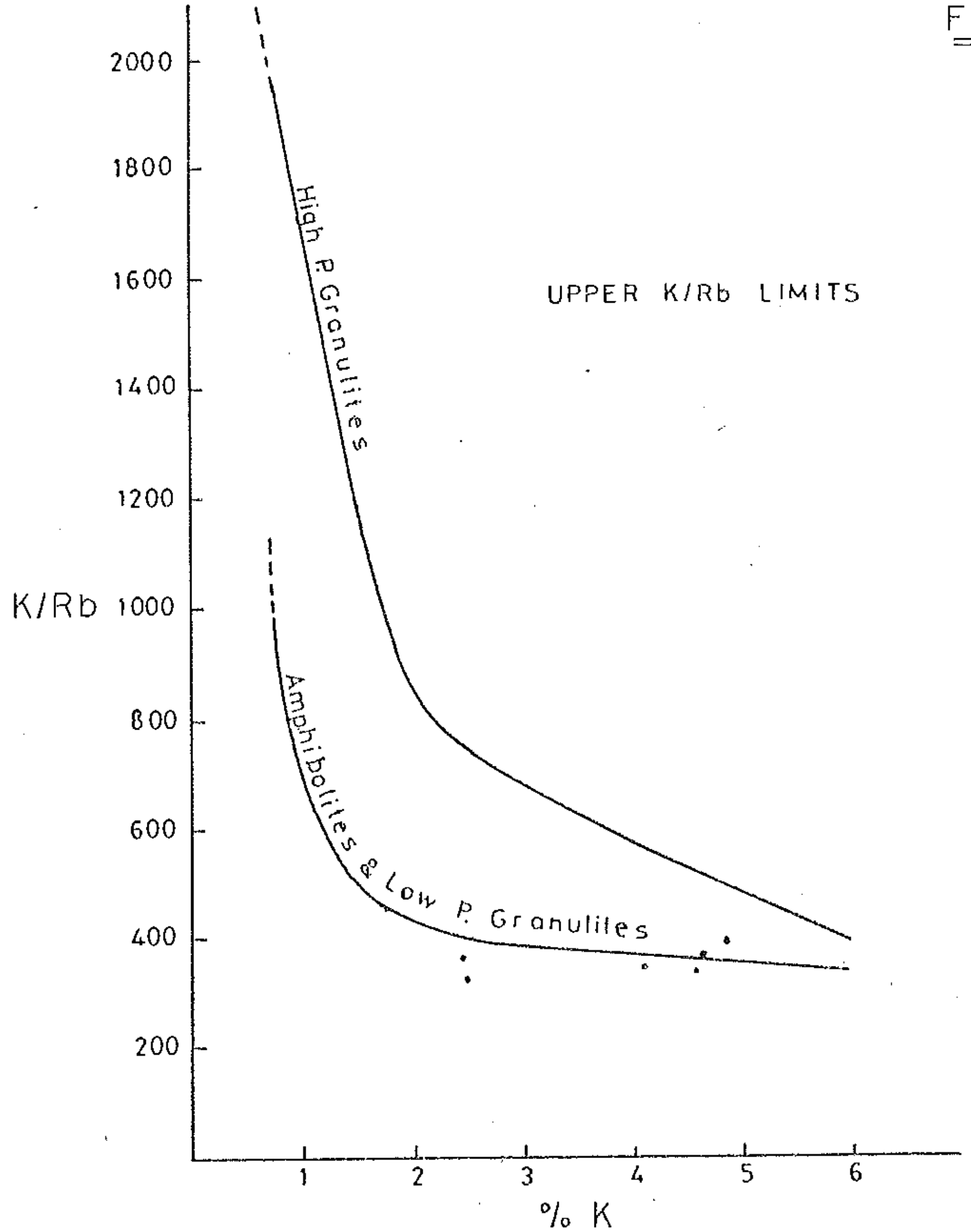
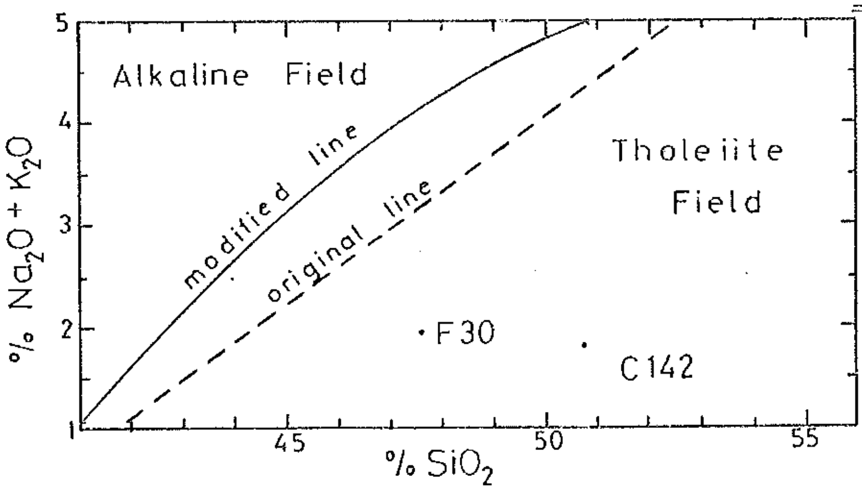


Fig. 5



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5. CONDITIONS OF METAMORPHISM.

Since this investigation involved essentially a petrological description of the various lithologies, with only nine whole rock geochemical measurements the determination of the conditions of metamorphism rests primarily on observed mineral assemblages in thin section and the comparison with experimentally determined stability curves for pressure and temperature.

Figure 6 is a compilation of relevant mineral stability curves determined experimentally and reported in the literature. It should be noted that this plot is of pressure (P) and temperature (T). In natural rock systems P H_2O, P CO_2, Po_2 and the chemical composition of phases also influence the phase equilibrium boundaries.

The dominant mineral assemblage observed in the basic granulites is essentially anhydrous, consisting of plag. + opx + cpx + qtz. This lithology thus lies in the intermediate pressure granulite field of Green and Ringwood (1967) - see fig. 6. No garnet was observed in the basic granulites, therefore the conditions lie below those for high pressure granulites (fig. 6).

Two of the basic granulites (samples F30 and C142) have a composition corresponding to that of a quartz tholeiite. Field relations indicate that although the acid gneisses may have undergone partial melting (e.g. the augen gneiss at Cape Carnot), the basic granulites have remained in the solid state. Hence the upper limit of temperature (see fig. 6) lies to the left of the curve for the beginning of melting of anhydrous quartz tholeiite (Green and Ringwood 1967).

In the acid gneisses the presence of sillimanite, plus potash feldspar which is commonly perthitic, place the conditions of metamorphism below the Kyanite - Sillimanite reaction line and to the right of the perthite line (fig.6).

In all but one case (sample C209) garnet was found to exist in preference to cordierite, placing the pressure above that for the upper limit of stability of cordierite, which has been established by Hensen (1971). Sample C209 consists of a sillimanite - cordierite assemblage. Its presence may indicate that although generally the pressure is greater than that allowing cordierite to be stable, it is likely that the operating pressure lies close to that of the upper limit of stability of cordierite.

In general, it can be inferred that the pressure - temperature conditions for the prograde metamorphism of the rocks concerned are, T approximately 800^{o} to 1000^{o} C and P approximately 8 to 10 Kb.

Note: This postulation is dependent on the position of the garnet / cordierite boundary, which is very dependent on the Fe/Mg composition of the garnet and cordierite. This composition is partly also, a reflection of the bulk rock composition.

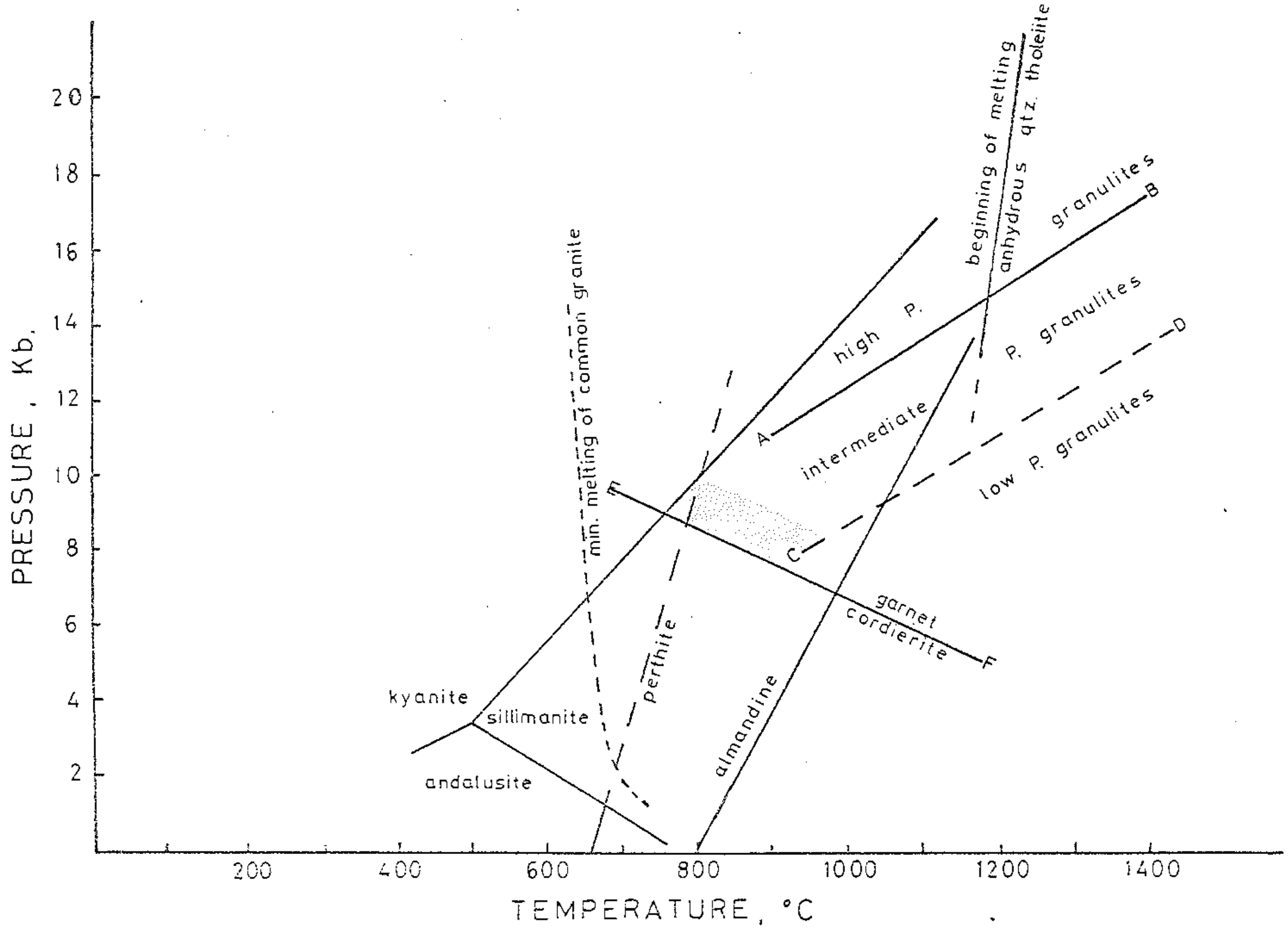
The mineral assemblages of the basic granulites correspond to the pyroxene sub facies of the granulite facies as defined by Eskola (1939), or the orthopyroxene - plagioclase sub facies of De Waard (1965).

Retrograde metamorphism is indicated by the replacement of orthopyroxene and clinopyroxene by hornblende (and biotite ?) in the basic granulites, potash feldspar by sericite and biotite by chlorite in the acid gneisses. There is also the possibility of biotite replacing sillimanite in some of the acid gneisses (e.g. sample C121).

This retrogression can be attributed to an influx of water into the essentially anhydrous granulite facies rocks. This could have taken place at the time of the introduction of the pegmatites.

The effect of this retrogression was to form assemblages corresponding to the hornblende - orthopyroxene - plagioclase sub facies of De Waard (1967).

Fig. 6: P-T diagram compiled from Green & Ringwood (1967), Hensen & Green (1971), Hyndman (1972)



Boundaries A-B & C-D (Green & Ringwood, 1967) are for quartz tholeiite compositions

Boundary E-F (Hensen & Green, 1971) is for synthetic compositions with 100 Mg / Mg + Fe = 70

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6. GEOCHRONOLOGY

6.1. Introduction

6.1. Previous Geochronological Studies of Eyre Peninsula

In an attempt to put radiometric estimates of the duration of sedimation in the Adelaide Geosyncline, Compston et al. (1966) reported dates on several of the proposed underlying basement rocks of Eyre Peninsula. The following ages come from this paper unless where otherwise acknowledged.

Total rock and feldspar data for the Moonabie Porphyry was indeterminate, but the Charleston Granite (intrusive into the Moonabie Porphyry) was dated at 1590 $\pm$ 30 M.a. (total rock and apatite). Another intrusive dated was the Burkitt Granite, at 1550 $\pm$ 70 M.a. (Rb-Sr) and 1640 $\pm$ 30 M.a. (K-Ar in hornblende). An overlying sediment, the Corrunna Conglomerate gave an age of 1535 M.a. (total rock and separated illite) and the penecontemporaneous Gawler Range Volcanics 1535 $\pm$ 25 M.a. (isochron). Still younger, they reported the Roopeena Volcanic at 1345 $\pm$ 30 M.a. (isochron) and the Cultana Granite at approximately 1320 M.a. (single highly radiogenic total rock sample).

The most relevant data for this study is the age of 1780 $\pm$ 120 M.a. reported by Compston and Arriens (1968) for gneissic granulites of the southern tip of Eyre Peninsula. Unfortunately nowhere in the literature is there recorded a table of isotopic values, an isochron plot or a proposed initial $^{87}Sr/^{86}Sr$ ratio for this age determination. However it can be seen in Compston and Arriens (1968) that sampling was on a regional scale and no unit was systematically studied in detail.

The oldest age suggested for the Gawler Platform is proposed by Compston et al. (1966) for measurements on the Glenloth Granite. A single total rock and feldspar join suggests an age of 1930 $\pm$ 200 M.a.

6.1.2. Present Study

Cape Carnot was selected as the most suitable area for this investigation since it provides a larger area of more uniform rock type, in comparison with the Fishery Bay area, where one finds a far less extensive or massive section.

6.2. Dating Methods

6.2.1. Sampling

(a) Augen Gneiss and Layered Gneiss

Samples C250 and C251 were taken as 2" diameter drill cores, using a hand held, two stroke powered, rotary drill. This machine proved too hard to handle due to extreme vibrations, and the remaining 12 samples were collected by means of hammers. As a result these samples were restricted to areas where "edges" had developed on the normally rounded or flat surface of Cape Carnot, rather than from locations that could be nominated to the nearest inch.

Sample locations are given on Map 2, and petrological descriptions of selected samples in Appendix A.

(b) Leuco Gneiss

The seven leuco gneiss samples (JC1 to JC8) were collected within a strike length of ten metres, on the mainland side of the crevasse separating the small peninsula from the mainland. Sample locations are given in figure 2 and petrological descriptions of all samples in Appendix A.

6.2.2. Sample Preparation

Each sample was examined in the laboratory for visible weathering effects and all doubtfull areas were removed.

Whole rocks were initially crushed in Sturtevant jaw crusher, all size fractions were retained. A chrome steel Sieb mill was then used for finer grinding of the "whole rocks". Initially a large representative portion was ground briefly to thoroughly mix all size fractions and grind them to roughly 100 mesh. "Grab" portions were then removed from the Sieb mill, leaving approximately 150 gm. of sample. This was then thoroughly ground to less than 200 mesh.

6.3. Results of Dating Measurements

The results of the mass spectrometer and X-ray fluorescence measurements are summarised in table III. Table IV sets out the regression of various groupings between labelled groups I-XI. (Composition of the groups is given in Appendix E). The analyses are plotted on an isochron plot, fig. 7. It is obvious that a single isochron relationship has not been obtained, and the

TABLE III : Results of X-ray Fluorescence and Mass Spectrometer measurements.

Cape Carnot : Augen and Layered Gneisses

Sample	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Comments
C250	114	I49	2.243	0.7860	Longer piece of core
C25I	138	I33	3.017	0.8096	Shorter piece of core
C252	131	252	1.513	0.7578	
C253	122	I28	2.781	0.8032	
C254	123	I23	2.921	0.8079	
C255	148	I3I	3.284	0.8220	
C256	126	I40	2.635	0.7998	
C257	130	I28	2.972	0.8I02	Located off mapped area
C259	I23	I33	2.694	0.8024	
C260	122	I45	2.441	0.793I	
C26I	124	I3I	2.768	0.8030	
C262	144	I34	2.484	0.7958	Layered gneiss
C263	118	I35	2.548	0.7974	Layered gneiss

Cape Carnot : Leuco Gneiss

Sample	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Comments
JCI	49	I63	0.880	0.7387	
JC2	51	I30	1.134	0.7460	
JC3	43	I35	0.929	0.7432	
JC5	82	203	1.170	0.7468	
JC6	61	II4	1.610	0.7683	
JC7	69	I62	1.227	0.7507	
JC8	63	I09	1.672	0.7709	

REGRESSION RESULTS TABLE IV.

Regression Group	Number of samples	Model	M.S.W.D.	Age M.a. ($\lambda=1.39\times10^{-11}$)	Initial $^{87}Sr/^{86}Sr$
I	13	1	24.64	2535 ± 27	0.7044 ± 0.0009
		2		2537 ± 121	0.7044 ± 0.0042
		3*		2471 ± 154	0.7068 ± 0.0057
II	20	1	102.49	2434 ± 10	0.7089 ± 0.0003
		2		2426 ± 110	0.7091 ± 0.0025
		3*		2406 ± 92	0.7096 ± 0.0029
III	7	1	172.97	2802 ± 51	0.7032 ± 0.0009
		2		2675 ± 688	0.7053 ± 0.0109
		3*		2837 ± 585	0.7026 ± 0.0102
IV	11	1	18.78	2530 ± 27	0.7043 ± 0.0009
		2		2531 ± 109	0.7042 ± 0.0038
		3*		2489 ± 142	0.7058 ± 0.0053
V	11	1	12.44	2210 ± 60	0.7170 ± 0.0022
		2		2192 ± 205	0.7177 ± 0.0076
		3*		2165 ± 206	0.7187 ± 0.0077
VI	5	1	0.52	2170 ± 172	0.7182 ± 0.0064
VII	6	1	2.80	2703 ± 51	0.6999 ± 0.0016
		2*		2703 ± 82	0.6999 ± 0.0025
		3		2697 ± 103	0.7001 ± 0.0033
VIII	4	1	0.64	2703 ± 94	0.6999 ± 0.0027
IX	8	1	13.43	2644 ± 40	0.7014 ± 0.0013
		2*		2643 ± 134	0.7015 ± 0.0043
		3		2612 ± 187	0.7025 ± 0.0064
X	6	1	11.56	2616 ± 46	0.7020 ± 0.0015
		2*		2617 ± 147	0.7020 ± 0.0046
		3		2593 ± 195	0.7028 ± 0.0065

XI a	3	1	1.80	2233 ± 558	0.7101 ± 0.0098
		2		2232 ± 782	0.7101 ± 0.0136
		3 *		2233 ± 718	0.7101 ± 0.0127
XI b	4	1	0.16	2294 ± 167	0.7134 ± 0.0060
XI c	3	1	1.17	2269 ± 1690	0.7160 ± 0.0604
		2		2268 ± 1829	0.7161 ± 0.064
		3 *		2268 ± 1821	0.7160 ± 0.0651
XI d	3	1	3.89	2261 ± 203	0.7172 ± 0.0056
		2		2262 ± 447	0.7172 ± 0.0119
		3 *		2260 ± 307	0.7172 ± 0.0093

Composition of the Regression Groups is given in Appendix E.

Note : * indicates the most appropriate analysis.

data will have to be examined closer in order to extract possible geochronological significance.

6.3.1. Initial Regressions

Group I (13 samples) consists of the eleven augen gneiss and two layered gneiss samples. M.S.W.D. factor for Model 1 is 24.6, Model 3 is the most appropriate analysis for this grouping, giving an age of 2471 ± 154 M.a. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7068 ± 0.0052. It was obvious from this regression that geological variance was present in the samples, since the M.S.W.D. factor was greater than unity.

The isotopic ratios of the leuco gneiss samples were then measured (under the same procedures already described). Since the "Ruf" XRF results for these gneisses indicated lower $^{87}Rb/^{86}Sr$ ratios than those recorded for the augen and layered gneisses, it was hoped that these might help to define an isochron.

Group II (20 samples) consists of all the samples measured, the M.S.W.D. factor is 102 for Model 1, Model 3 is the most appropriate analysis for this grouping giving an age of 2406 ± 92 M.a. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7096 ± 0.0029.

Once again considerable geological variance was indicated, thus the following further regression groupings were selected in an attempt to find a more appropriate analysis of the data.

6.3.2. Regressions of the Leuco gneiss Samples

Group III (7 samples) consisted of the seven leuco gneiss samples. The M.S.W.D. factor was 173, the age calculation was 2837 ± 583 M.a. (Model 3) and the initial ratio 0.7026 ± 0.0102. No further sub groupings of the leuco gneiss appeared worth investigating.

6.3.3. Regressions of the Augen and Layered Gneiss Samples

Group IV (11 samples) consists of only the augen gneiss samples. The M.S.W.D. factor was 18.78 the age calculation was 2489 ± 142 M.a. (Model 3) and the initial ratio 0.7058 ± 0.0053.

Group V (11 samples) consisted of the augen gneiss and layered gneiss samples minus the two samples with the highest and lowest $^{87}Rb/^{86}Sr$ ratios (C255 and C252 respectively). It assumes the geological scatter may be due to these two samples. The M.S.W.D. factor was 12, the age calculated 2165 ±

206 M.a. (Model 3) and the initial $^{87}Sr/^{86}Sr$ ratio 0.7187 ± 0.0077.

Group VI (5 samples) consisted of samples C260, C256, C261, C253 and C254. This grouping was chosen in an attempt to obtain an estimate of the minimum age for the samples, that is, the shallowest isochron slope. The M.S.W.D. factor was 0.52, (a very good fit) the age calculated 2170 ± 172 M.a. (Model 1) and the initial $^{87}Sr/^{86}Sr$ ratio 0.7182 ± 0.0064.

Groups VII and VIII were chosen in an attempt to obtain an estimate of the maximum age for the samples, that is, the steepest isochron slope. For Group VII (6 samples) the M.S.W.D. factor was 2.80, the age calculated 2703 ± 82 M.a. (Model 2) and the initial $^{87}Sr/^{86}Sr$ ratio 0.6999 ± 0.0025. For Group VIII (4 samples) the M.S.W.D. factor was 0.6, the age calculated 2703 ± 94 M.a. (Model 1) and the initial $^{87}Sr/^{86}Sr$ ratio was 0.6999 ± 0.0027.

Group IX (8 samples) consisted of the samples with the following common factors:

- (i) They did not lie within close proximity to veining.
- (ii) The samples were of essentially fresh rock.
- (iii) They were located within the mapped area and hence considerable knowledge of the surrounding lithologies is known.

Samples C253, C254 and C255 were rejected under condition (i) above. Sample C251 was rejected since it was a short piece of core from near the surface, and it was doubtful whether the surface weathering had been penetrated. Sample C257 lay outside the bounds of the detailed mapping.

The nett effect was to eliminate the samples with the highest $^{87}Rb/^{86}Sr$ ratios, a process compatable with Model 2 of the regression treatment. The M.S.W.D. factor was 13, the age calculated 2643 ± 134 M.a. (Model 2) and the initial ratio 0.7015 ± 0.0043.

Group X (6 samples) had the same constraints as Group IX, but in addition the two samples of layered gneiss (C262 and C263) were excluded. The M.S.W.D. factor was 11.56, the age calculated 2617 ± 147 M.a. and the initial $^{87}Sr/^{86}Sr$ ratio 0.7019 ± 0.0046.

6.3.4. Regressions of All Samples

Group XI: The parallel isochron approach.

The samples can also be grouped into a series of four parallel isochrons. Four samples did not lie on any of these lines but two other isochrons parallel to the others can be drawn through JC1 and JC7, and JC3 and C251 respectively.

Group XI (a) (3 samples) had a M.S.W.D. factor of 1.8, the age calculated 2233 ± 718 M.a. (Model 3) and the initial $^{87}Sr/^{86}Sr$ ratio 0.7101 ± 0.0127. Group XI (b) (4 samples) had a M.S.W.D. factor of 0.2, the age calculated 2294 ± 167 M.a. (Model 1) and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7134 ± 0.0061. Group XI (c) (3 samples) had a M.S.W.D. factor of 1.2, the age calculated 2268 ± 1821 M.A. (Model 3) and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7160 ± 0.0657. Group XI (d) (3 samples) had a M.S.W.D. factor of 3.9, the age calculated 2260 ± 307 M.A. (Model 3) and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7172 ± 0.0093.

6.4. Discussion of Results

6.4.1. Points of Note

(a) A clear cut isochron yielding a conclusive age did not emerge.

(b) Apart from specific groupings of a small number of selected points all other regressions have M.S.W.D. factor greater than unity, implying that the scatter observed is attributed to a geological variance and not the experimental variance. This geological variance has been explained in terms of any or all of the following factors (Gunner and Faure 1972).

(i) Inhomomgeneous initial $^{87}Sr/^{86}Sr$ ratios.

(ii) Different ages of the samples.

(iii) Subsequent gains or losses of variable amounts of Rb and/or Sr after closure of the system to these elements.

(c) The isochronplots for the augen gneiss and layered gneiss samples, and the leuco gneiss samples individually (fig. 7 and 8) do not span a wide range of $^{87}Rb/^{86}Sr$ ratios, thus definition of these isochrons is not the best. Group II covers all twenty samples, hence on the basis of spread in $^{87}Rb/^{86}Sr$ ratios this regression group should give better definition of a meaningful isochron (fig. 9). However the M.S.W.D. factor indicates a far looser fit of the points to the proposed isochron.

(d) A comparison of Group IV, with Group I and Group X with Group IX indicates that the effect of excluding the layered gneiss samples from the augen gneiss samples when regressing, only slightly lowers the M.S.W.D. factor (but not significantly) and has little effect on the ages or initial $^{87}Sr/^{86}Sr$ ratios (within 26 mean). Therefore in a Rb-Sr isotopic sense these lithologies cannot be distinguished from one another and in further discussion will be termed "augen gneiss".

(e) Groups VII and VIII can only be considered as approximate guides to a maximum age for the "augen gneiss" since the initial $^{87}Sr/^{86}Sr$ ratios fall below geologically meaningful values (that is, 0.6999 from meteorites) when the lower limits of standard deviations are considered.

(f) Group VI provides an estimate of the minimum age. It also has a relatively high initial $^{87}Sr/^{86}Sr$ ratio of 0.7182 ± 0.0064 (c.f. other augen gneiss regression groupings) which if true could imply a source material that had spent some previous time in the crust.

(g) An highly likely age for the "augen gneiss" appears to be that calculated by Group IX. The factors which restricted the samples included in this group appear to be valid, but it should be noted that other constraints may have been applied and would have been equally valid. The initial ratio for Group IX is relatively low implying a source material that had spent very little time in the crust or by some mechanism was preferentially depleted in radiogenic ^{87}Sr.

(h) The age calculated for the leuco gneiss is significantly older than those calculated for the "augen gneiss" (despite the large standard deviation), but the initial ratio is still relatively low implying a similar origin of source materials.

(i) Group XI applies a parallel isochron approach to all the samples. The results indicate that the subdivision of the samples into four parallel isochrons, of the same age but different initial ratios, is essentially valid as seen by the closeness of the ages. However Group XI (c) has such an abnormally high error limit to the calculated age (± 1821 Ma.) that the results may be considered unrealistic in terms of a valid dating.

6.4.2. Interpretation (Meaning of Rb-Sr whole rock ages)

The whole rock isochron dates obtained on highly metamorphosed rocks can be interpreted as representing either

(1) The time of cooling after the metamorphic event

or (2) The previous history, such as sedimentation or crystallization of a magma, if igneous.

Arriens and Lambert (1969) proposed that metamorphism to granulite facies probably involved open chemical behaviour of Rb and Sr. If this is so, then isochrons obtained on granulite facies rocks relate to the age of metamorphism and not the pre-granulite facies source rocks. They also suggested that the comparitively low initial $^{87}Sr/^{86}Sr$ ratios often obtained for granulite facies rocks precludes the possibility of long periods of previous crustal life for these rocks (less than 200-300 M.a. for the Fraser Range Granulites). That is low initial $^{87}Sr/^{86}Sr$ ratios preclude the possibility of long periods of Sr isotopic homogenisation by the process of regional diffusive exchange in the crust. Longer periods of crustal life for these rocks could occur if the accumulated radiogenic ^{87}Sr was almost completely lost from the granulite facies rocks.

Heier and Compston (1969) suggested that during periods of progressive metamorphism involving dehydration and mineral reconstition, a preferential loss of the radiogenic portion of the ^{87}Sr isotope, would lower the whole rock Rb-Sr age. They also intimated that radiogenic Sr may shift with the water phase over distances of the order of kilometers and possibly into regions of lower metamorphic grade.

The preferential movement of radiogenic Sr is yet to be shown. Brooks (1968) indicated that for feldspars of the Heemskirk Granite, the displaced radiogenic Sr, at least initially was incorporated in the alteration products of feldspars such as zoisite and sericite.

Moorbath (1975), having at first regarded as improbable the process of large scale regional homogenisation of Sr isotopes at the isochron date, proposed a model of crustal accretion. This crustal accretion was interpreted as being essentially contemporaneous with the proposed geochemical and petrological differentiation required to yield a compositionally graditional crust. On such a model the Rb-Sr whole rock isochrons of granulite facies rocks gives the age of the accretion differentiation event. Furthermore it was proposed by Moorbath (1975) that the best isochron would be obtained when the differentiation event was short in relation to its actual age, i.e. a low homogeneous initial $^{87}Sr/^{86}Sr$ ratio would result from accretion of material directly from the mantle prior to granulite facies metamorphism, whilst the local and regional dispersion in Rb/Sr ratios would result from the geochemical differentiation.

Moorbath (1975) attributed significant deviations from the ideal Rb-Sr isochron to

(a) Source region heterogeneities

(b) Interaction of gneiss precursors with pre-existing crust

or (c) Lack of closed system behaviour on a whole rock scale with respect to Rb and/or Sr during subsequent metamorphism and tectonism.

6.4.3. Interpretations

The following alternatives are proposed as possible interpretations of the results

(1) Deposition of sediments in a mobile belt at approximately 2850 M.A. ago, followed by intrusion of quartz tholeiites into this sedimentary pile. The sequence was then buried and at depth granulite facies metamorphism took place.

Partial melting of some of the sediments occured, terminating at approximately 2650 M.a. with the crystallisation of the "augen gneisses". Sr isotopes were not completely homogenised at this time as is indicated by the scatter observed on the isochron plot for the "augen gneiss" (fig. 7).

Surrounding sediments which were not involved in this partial melting show even less complete Sr isotopic homogenisation, for example the wide scatter observed for the leuco gneiss (fig. 8). The age calculated for the leuco gneiss at 2837 $\pm$ 583 M.a. (Group III) is reflecting the previous sedimentary history of the paragneisses.

Initial ratios for both lithologies (0.7015 augen gneiss and 0.7026 leuco gneiss) are relatively lower than one would expect for sediments derived from essentially primary mantle material at this age. The geochemistry of the basic granulites today (e.g. 142) indicates relatively high concentrations of Sr compared to Rb, i.e. low Rb/Sr ratios. Thus it appears likely that at the time of erosion and sedimentation, basic volcanics present in the source areas of the sediments would give rise to relatively higher concentrations of Sr. In particular, since Rb is relatively low in concentration, the Sr would be more likely to have relatively larger amounts of the ^{86}Sr isotope than the ^{87}Sr isotope. Hence the sediments have relatively low initial $^{87}Sr/^{86}Sr$ ratios.

(2) Deposition of sediments in a mobile belt at approximately 2850 M.a. ago followed by the intrusion of quartz tholeiites into the sedimentary pile. The sequence was then buried and at depth granulite facies metamorphism took place.

A concordant intrusion of a granitic magma took place whilst the sequence was still at depth, crystallisation and metamorphism to form the augen gneiss occuring at about 2650 M.a. Incomplete homogenisation of this granitic magma was observed due to the inclusion of sedimentary zenoliths, as indicated by the presence of thin bands of pelitic material and the occurence of sillimanite.

The leuco-gneiss did undergo some updating at this time, but the Sr isotopes remained essentially inhomogeneous as shown by the scatter of points on an isochron plot (fig. 8). At least partially, this scatter reflects the sedimentary nature of this gneiss, and the age of 2837 $\pm$ 583 M.a. (Group III) may represent the time of sedimentation.

The initial ratio of the augen gneiss (0.7015 Group IV) implies a lower crustal to mantle origin for the magma source, with some crustal history prior to crystallisation as shown by the presence of the sedimentary zenoliths (see above). The leuco-gneiss has a slightly high initial ratio (0.7026 Group III) since it consists of sediments derived from crustal material, but due to the antiquity of these sediments the initial ratio is still relatively low.

(3) Deep seated and prolonged reworking of older crustal material under granulite facies metamorphism, ending in rapid uplift somewhere in the period 2230 to 2300 M.a. (Group XI). At the time of rapid uplift complete homogenisation of the Sr isotopes had not taken place, and a range of initial ratios was preserved, 0.710 to 0.717 (Group XI). The range in initial $^{87}Sr/^{86}Sr$ ratios and their relatively high nature is in keeping with a sedimentary origin for the source materials, in this case the source having spent considerable time in the crust.

(4) Deposition of sediments in a mobile belt at approximately 2850 M.a. ago, followed by intrusion of quartz tholeiites. The sequence was then buried and at depth granulite facies metamorphism took place.

The proposed age of the leuco-gneiss, approximately 2850 M.a., reflects the time of sedimentation.

The augen gneiss appears younger at about 2650 M.a. (Group IX). This is possibly attributible to a nett loss of radiogenic ^{87}Sr at the time of partial melting (similar to Heier and Compston 1969).

The initial ratios of both lithologies are relatively low due to the antiquity of the rocks, and the possibility of the presence of basic volcanics, with low Rb/Sr ratios (c.f. C142) and relatively high ^{86}Sr content (relative to ^{87}Sr), in the source areas for the sediments (i.e. the same reasoning as for alternative (1) above).

7. SUMMARY AND CONCLUSIONS

(1) Structural analysis suggests that the rocks in both of these areas have undergone three deformations.

(2) A petrological and geochemical analysis indicates that granulate facies metamorphism has occured, (probably to the pyroxene granulite sub facies of Turner (1968)).

Partial melting is proposed at Cape Carnot due to an increase in P H_2O at the constant Temperature. This increase in P H_2O can be explained by proposing that the Fishery Bay area was situated deeper in the crust (relative to Cape Carnot) during granulite facies metamorphism. With dehydration, the released H_2O would "rise" in the crust thus causing an increase in P H_2O at Cape Carnot and result in partial melting.

Retrogression appears to have accompanied the development of pegmatites, and a hornblende pyroxene granulite facies assemblage is apparent.

(3) Geochronological studies do not yield a clear cut Rb-Sr whole rock isochron age at Cape Carnot. The age of the rocks may be as young as 2100 M.a. or as old as 2850 M.a. Several alternatives are proposed but as yet no clear cut interpretation can be placed.

(4) The ages calculated are significantly older than those of Compston and Arriens (1968) at 1780 $\pm$ 120 M.a., for the granulites at the southern tip of Eyre Peninsula, and Flook (1975 Pers. Comm.) at 1855 $\pm$ 10 M.a. for the gneisses at Kirton Point (Flinders Group), and it appears that the Hutchison Group may be Archaean in age. This finding adds weight to the interpretation of the Flinders Series and Hutchison Series of Tilley (1921), but requires further work for a more complete interpretation e.g. Rb-Sr measurements at Fishery Bay.

(5) If the ages of the gneisses are approximately 2600 to 2850 (interpretations (1), (2) & (4) in geochron) then clearly continental crust existed in the Gawler Platform at this time, and almost certainly prior to these dates if the gneisses are of sedimentary origin.

The tectonic inferences are drastic, in particular with respect to the development of a continental craton in this area up to 1,000 M.a., prior to present theories.

Fig. 7. Isochron Plot for Augen and Layered Gneisses

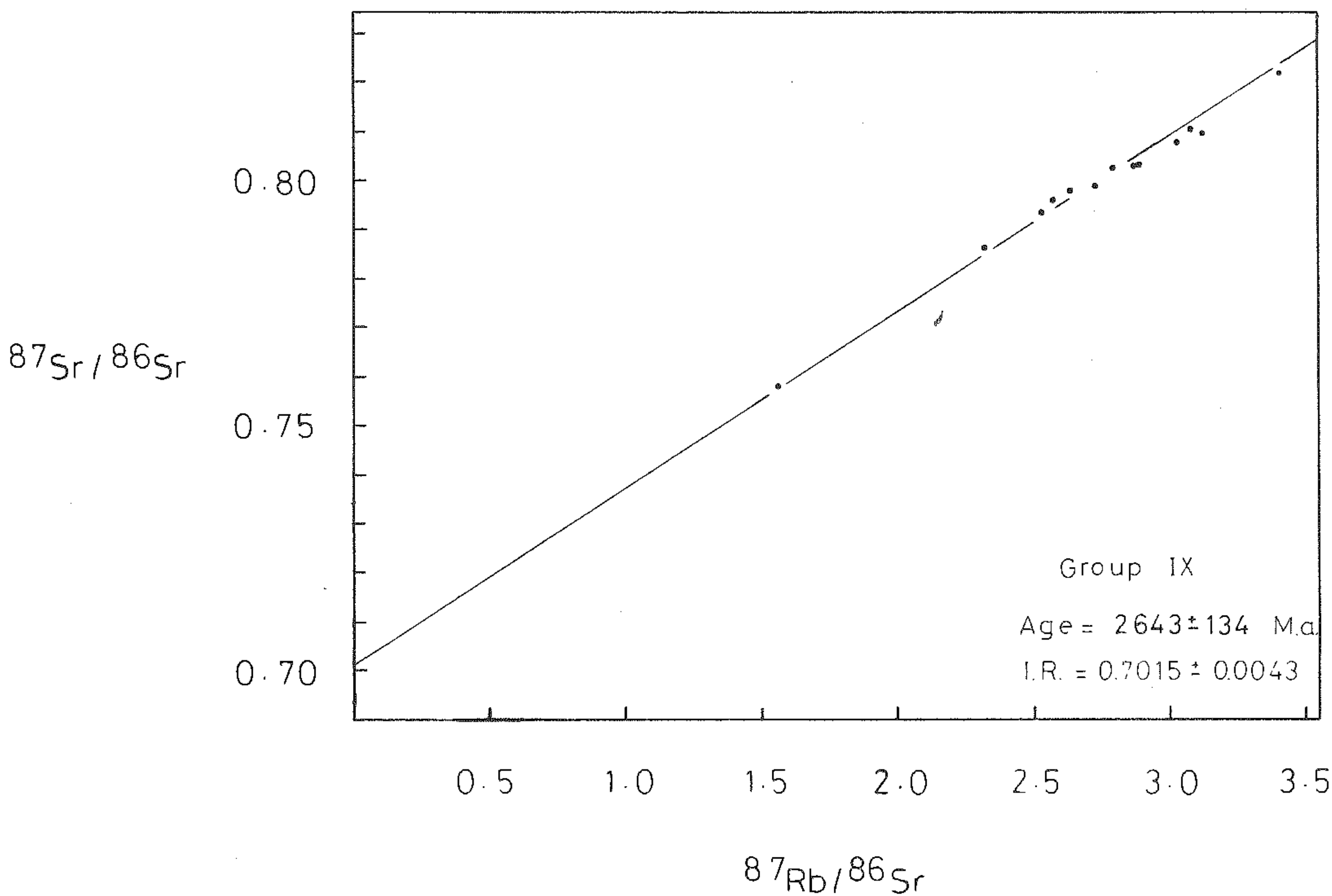


Fig. 8. Isochron Plot for Leuco-gneiss

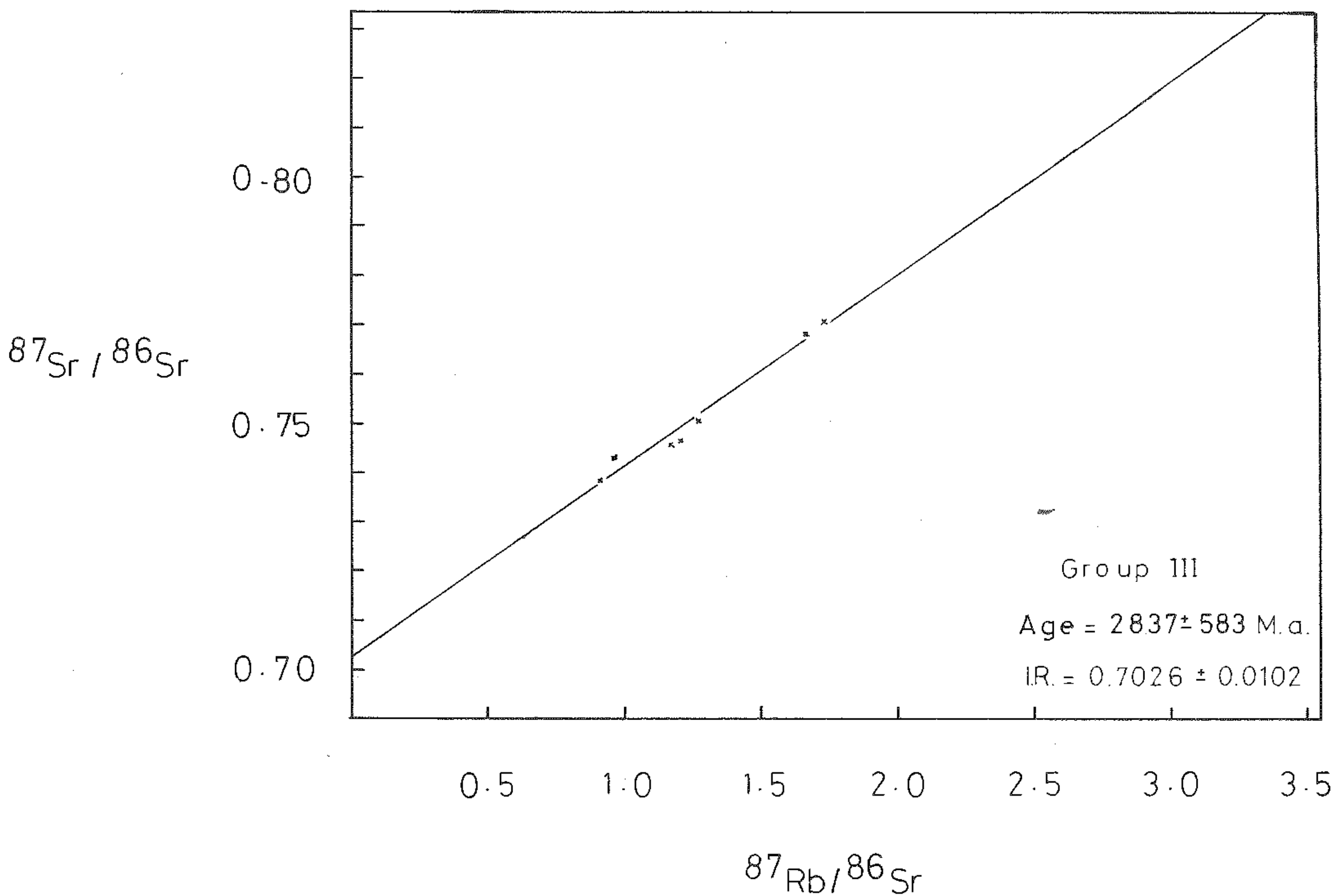
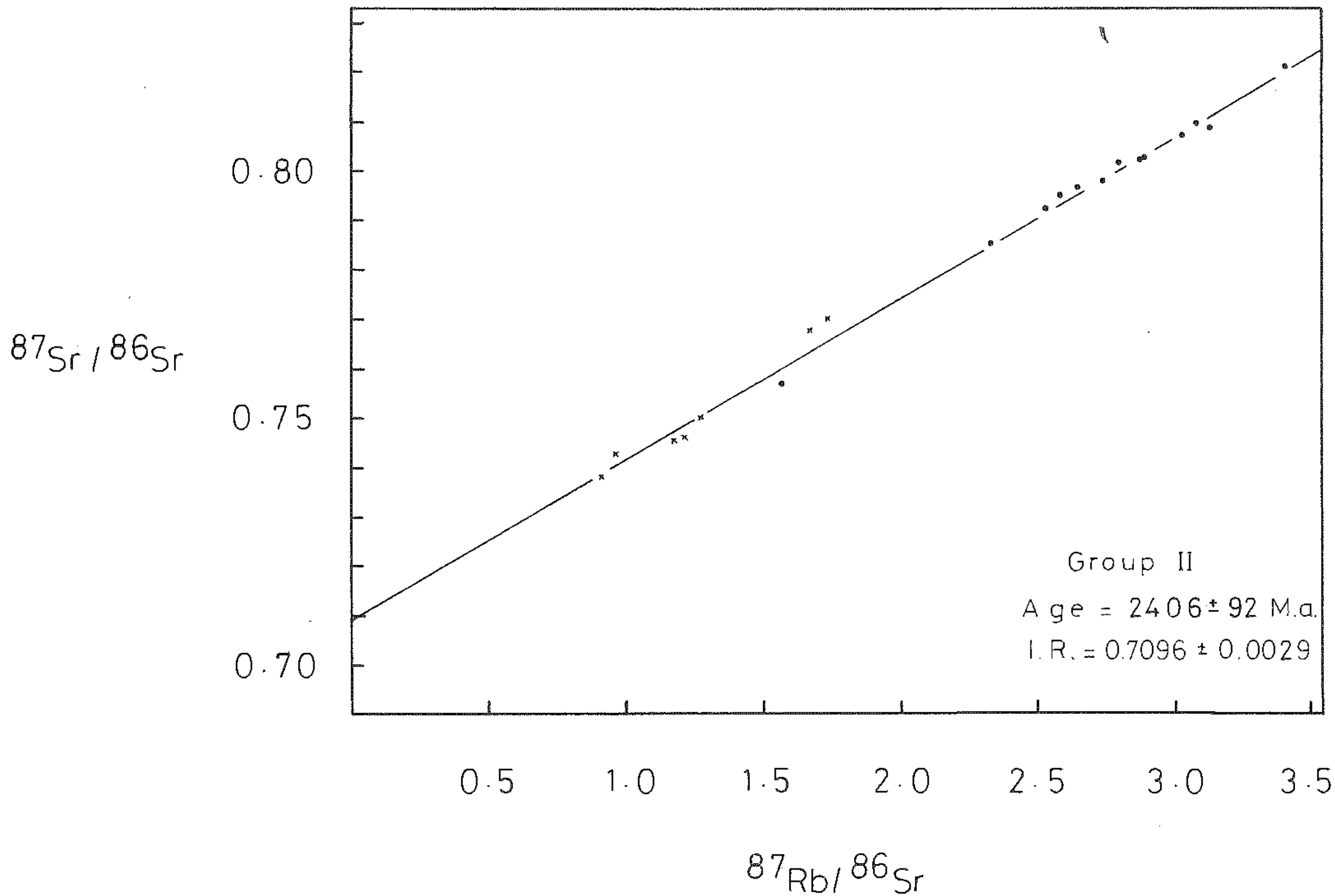


Fig.9. Isochron Plot for Leuco-gneiss, Augen and Layered Gneisses



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8. RECOMMENDATIONS

Clearly this study has barely scratched the surface with regard to a full chronology of events in the Precambrian basement.

It is proposed that future geochronological studies should include further Rb-Sr isotope measurements, but as mineral isochrons in an attempt to delineate the various events i.e. partial melting and pegmatitic developments. U-Pb measurements on the zircons are also proposed, since zircons were found to be present in sufficient quantities and widespread in terms of lithologies.

Such a proposed study would initially require further detailed mapping of the area in order to determine suitable sampling sites. In doing so the structural and petrological aspects should also be taken into account.

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PLATE I.

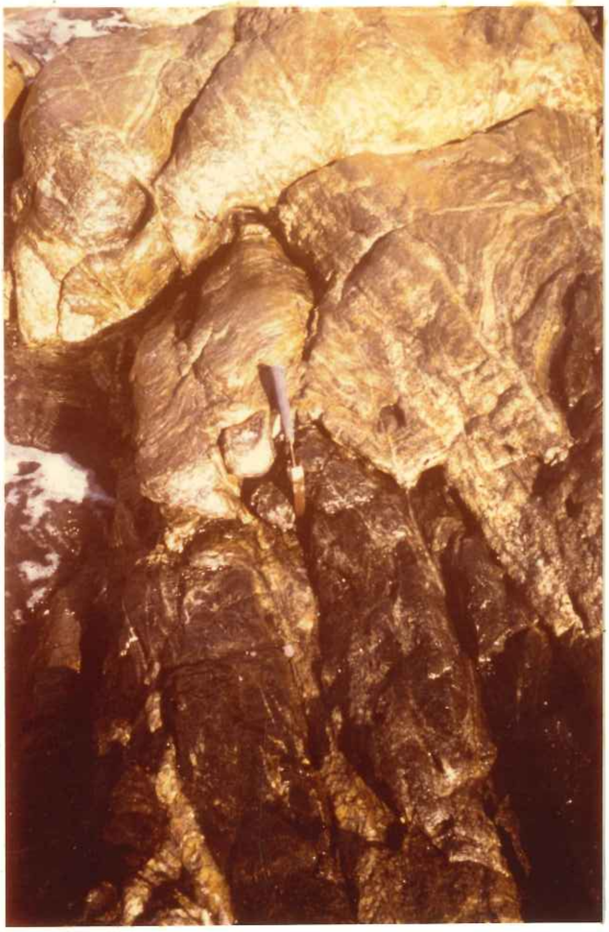
A. Syncline, typical of F_2 folding (Fishery Bay, looking South).

B. Layering S_I folded independently of the more competent basics during F_2 folding (Fishery Bay, looking South).

C. Folding of the S_I layering, conformable wth the outline of the pod of basic granulite. May represent a "flow" structure formed during partial melting (Cape Carnot).

PLATE I

A



B

C

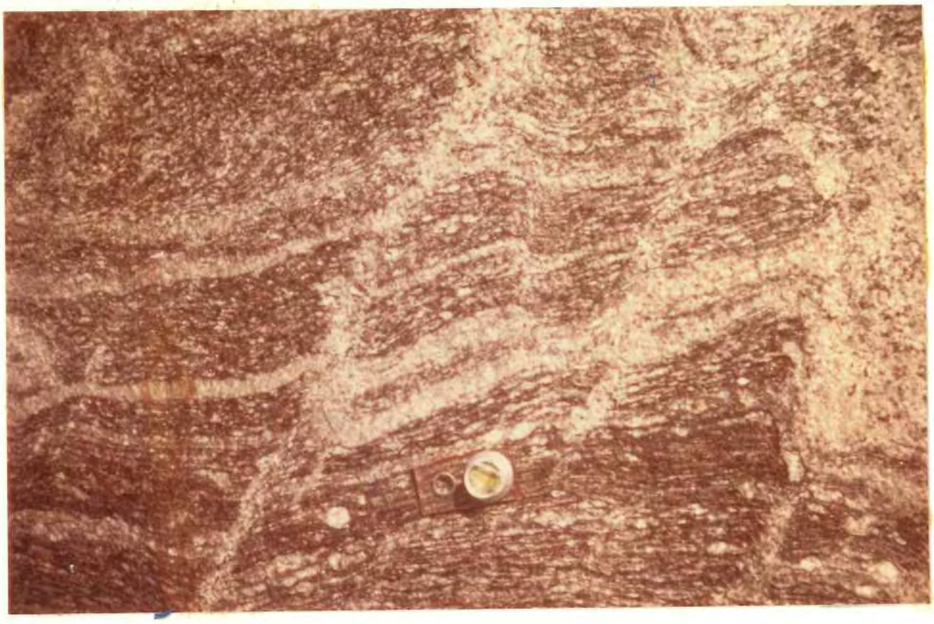
PLATE II.

A. Dextral rotation of layering during the F_3 phase. Note the development of pegmatitic veins axial plane to F_3 (Cape Carnot).

B. Shearing and left lateral displacement of the layering along the axial plane of F_3 (Cape Carnot).

C. Layered Series, Eastern end of the peninsula (Cape Carnot).

PLATE II



A

B

C

PLATE III.

A. Coarse potash feldspar zone developed parallel to the S_I layering (Cape Carnot).

B. Augen Gneiss, augens orientated parallel to the regional layering (Cape Carnot).

C. Augen Gneiss, augens in random orientation, may be reflecting a relict igneous texture (Cape Carnot).

PLATE III

A

B

C

PLATE IV.

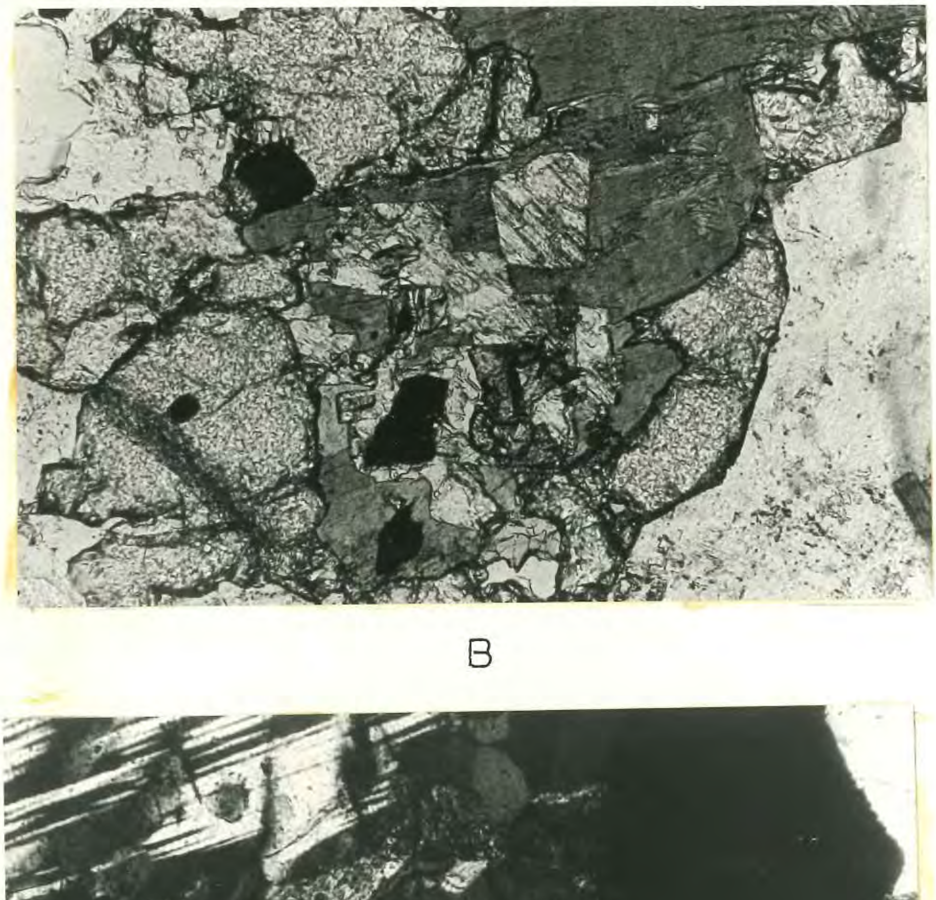
A. Intimate association of sillimanite, biotite and spinel in sample CI2I (20 X).

B. Intimate association of sillimanite, biotite, garnet and spinel in sample CI2I (20 X).

C. Cordierite, showing multiple lamellar twinning and pleochroic haloes around inclusions of zircon (40 X).

PLATE IV

A



B

C

APPENDIX A.

PETROGRAPHIC DESCRIPTIONS

1. Samples of type lithologies
2. Geochemically analysed samples
3. Samples used for the Rb-Sr whole rock geochronology

Appendix A: Petrographic descriptions

Note all sample nos. should be prefixed with the succession no. 466. Numbers prefixed with F come from Fishery Bay and those with C, Cape Carnot.

1) Samples of type lithologies

Sample F8: Layered garnet gneiss

Potash Feldspar - 50 vol. %; 2V - ve = 76^0, perthitic fine exsolution present, myrmekitic at grain boundaries with Kspar and Plag., some sericitization.

Quartz - 30 vol. %; uniaxial + ve, grainsize < 1mm., elongate grains parallel the foliation.

Plagioclase - 8 vol. %; 2V + ve = 80^0; Albite, pericline and some carlsbad twinning; some grains untwinned max. extinction angle perpendicular to (010) = 10^0 i.e. Ab_{73}, ave grain size < 0.5 mm.

Garnet - 7 vol %; round grains, isotropic, colourless, grains < 2 mm., inclusions of quartz and biotite.

Biotite - 5 vol %; orientated with elongation parallel to the foliation, strongly pleochroic - reddish brown to light brown, pleochroic haloes around inclusions of zircon. Poikilitic grains present.

Opaques - rare, irregularly shaped generally.

Zircon - up to 10 grains in thin section, high relief, colourless, high max. birefringence, grains are .01 - .02 mm.

Chlorite - trace replacing biotite.

Sample F20: Leuco-gneiss

Distinct lack of biotite, note the presence of sillimanite in stringers.

Potash Feldspar - 45 vol %; some finely perthitic, myrmekitic, trace microcline cross hatching, grain size < 1.5 mm.

Plagioclase - 20 vol %; multiple lamellar twinning albite and pericline, kinked twins, untwinned grains also present, max. extinction angle perpendicular to (010) = 10^0 i.e. Ab_{73}.

Quartz - 25 vol %; unaxial + ve, slightly undulose extinction, elongate grains parallel the foliation.

Sillimanite - 4 vol %, 2V + ve = 10^0, St. extinction, high relief, euhedral grains have a cleavage parallel to long diagonal in rhombic cross sections, grains present in stringers.

Garnet - 3 vol %; isotropic, colourless, ave 2mm. in diameter, inclusions of quartz etc.

Spinel - trace, brass green, isotropic.

Zircon, Biotite, Opaques - rare.

Sample 30: Basic Granulite.

Alignment of elongate pyroxene grains parallel to the regional foliation direction.

Orthopyroxene - 25 vol %; 2V - ve = 70^0, straight extinction, weakly pleochroic - faint pink to pale green. Hypersthene most probable composition.

Clinopyroxene - 15 vol %; 2V + ve = 60^0, inclined extinction, non pleochroic, pale green colour. Diopside most probable composition.

Plagioclase - 50 vol %; most grains have multiple lamellae, albite and pericline, some antiperthite, max. extinction angle perpendicular to (010) 32^0 i.e. An_{55}.

Opaques - 10 vol %; irregularly shaped.

Quartz, Potash Feldspar, Zircon - rare.

Sample F34: Pegmatite.

Generally coarse grained, up to 5 mm in size, finer sericitic-biotitic matrix between the coarser grains. No apparent foliation.

Plagioclase - 45 vol %; multiple twinning, albite and pericline, max. extinction angle perpendicular to (010) 13^0 i.e. Ab_{70}, present matrix and coarser grain sizes. Coarse grains heavily sericitized.

Potash Feldspar - 25 vol %; pethitic, myrmekitic, generally in coarse size fraction, heavily sericitized.

Quartz - 15 vol %; uniaxial + ve, slightly undulose extinction, some grains elongated.

Sericite - 10 vol %; colourless, high max. birefringence, forms quite large aggregates in places.

Biotite - 2 vol %; strongly pleochroic - reddish brown to straw yellow, altereted to chlorite or may be some sillimanite involved.

Opaques - trace, irregular grains.

Zircon - trace, round grains.

Sample F39: Biotite Garnet Gneiss.

Contains higher than usual amount of biotite.

Plagioclase - 35 vol %; twinned, albite and pericline, some untwinned, max. extinction angle 10^0, i.e. Ab_{73}, sericitized.

Quartz - 30 vol %; uniaxial + ve, undulose extinction elongate grains parallel the foliation.

Potash Feldspar - 20 vol %; finely perthitic, 2 V - ve = 85^0
rare myrmekite.

Biotite - 10 vol %; basal sections give psuedouniaxial - ve
strong pleochroism, reddish brown - pale straw yellow,
pleochroic haloes around zircon inclusions.

Garnet - 3 vol; colourless, isotropic.

Traces of Opaques and Zircon.

Sample F52: Layered Garnet Gneiss

A well layered gneiss consisting of intercallated layers of quartz, feldspar and garnet.

Quartz - 45 vol %; uniaxial + ve, slightly undulose extinction
are grainsize 0.5 mm.

Plagioclase 27 vol %; pericline and albite twinning, some untwinned,
max extinction angle perpendicular (010) 13^0 i.e. Ab_{69} sericitized.

Potash Feldspar - 12 vol %; finely perthitic, myrmekite not common,
sericitized.

Biotite - 5 vol %; reddish brown to pale fawn pleochroism replaced
by chlorite.

Garnet - 4 vol %; isotropic, inclusions of spinel, coronas of
sericite-ilmenite, ave grain size 1 - 2 mm.

Also present: Sericite, Chlorite, Opaques, Spinel Zircon, Rutile.

Sample C142: Basic Granulite

The parallel orientation of elongate grains gives the thin section a distinct foliation.

Onthopyroxene - 25 vol %; 2 V - ve = 60^0, pale pink to green
pleochroism, st. extinction. Probable composition is Hypersthene.
Alteration to green hornblende.

Clinopyroxene - 20 vol %; 2 V + ve 70^0 pale green colour, non pleochroic,
inclined extinction. Probable composition is Diopside. Alteration
to green hornblende.

Plagioclase - 30 vol %; twinned and untwinned, pericline and albite
twinning, max extinction angle perp (010) 36^0 i.e. An_{65}.
Ave. grain size 0.5 to 0.4 mm.

Hornblende - 15 vol %; 2 V - ve = 85^0, pale green to dark green
pleochroism. Ave. grain size 0.5 - 1 mm.
Both primary and secondary present.

Quartz - 4 vol %; uniaxial + ve, undulose ext.

Sericite - 4 vol %; alteration of plagioclase.

Opaques - 2 vol %; irregular grains, gen. association with pyroxene.

Sample C150: Aplitic Vein

Fine feldspar vein that has a biotite garnet margin. Vein:

Potash Feldspar - 40 vol %; Perthite, microcline cross hatched twinning on some grains, up to 1 cm in diameter.

Plagioclase - 25 vol %; Sericitized, antiperthite.

Quartz - 20 vol %; Undulose extinction, uniaxial + ve.

Sericite - 10 vol %; replacing the feldspars.

Biotite - 3 vol %; Usual pleochroism, altered to chlorite.

Chlorite - 2 vol; Alteration of biotite.

Zircon - trace, round.

Margin: contact with vein is sharp, does not seem to be any potash feldspar in the margin.

Biotite - 45 vol %; strongly pleochroic, deep reddish brown to pale fawn.

Quartz - 20 vol %; uniaxial + ve, undulose extinct.

Plagioclase - 9 vol %; twinned (albite-pericline) and untwinned, sericitized.

Zircon - 6 vol %; uniaxial + ve, "coarse" round grains.

Sillimanite - 4 vol %; fine grained, nearly poikiloblastic.

Opaques - 4 vol %; irregularly shaped.

Garnet - 2 vol. %; isotropic, colourless.

Sample C158: Pegmatic Zone

Consists of feldspar porphyroblasts up to 2 cm. in diameter. Matrix of finer grained felsics with high degree of sericitization.

Potash Feldspar - 40 vol %; finely perthitic, microcline, myrmekite, 2V - ve = 80^{0}.

Plagioclase - 30 vol %; pericline, albite and carlsbad twinning, antiperthite, max extinction angle perp. to (010) 10^{0} i.e. Ab_{73}. up to 6 mm in diameter.

Quartz - 20 vol %; uniaxial + ve, undulose ext., grains slightly elongate.

Sericite - 6 vol %; alteration of plagioclase, possibly some muscovite present.

Biotite - 2 vol %; red brown to pale fawn pleochroism, altering to chlorite.

Chlorite, Zircon, Opaques - trace.

Sample C179: Leuco-gneiss

Relatively coarse grained, distinct lack of biotite and garnet.

Plagioclase - 35 vol %; multiple twinning, albite and pericline, some antiperthite. Max. ext. angle perp. (010) 11^{0} i.e. Ab_{72}, one grain in excess of 6 mm in diameter, heavily sericitized.

Quartz - 30 vol %; uniaxial + ve, undulose extinction

Potash Feldspar - 25 vol %; perthitic, myrmekitic.

Biotite - 4 vol %; pleochroic - reddish brown to pale fawn, altered to chlorite in places.

Sericite - 3 vol %; colourless, high max. birefringence, replacing feldspar.

Garnet, Chlorite, Opaques and Zircon - present in accessory amounts.

Sample C180: "Mixed" Gneisses

Typical of other basic granulites examined at Cape Carnot. Layering shown by parallel elongation of minerals.

Orthopyroxene - 40 vol %; 2V - ve ≈ 70^{0}, st. extinction, weakly pleochroic pale green to faint pink. Hypersthene most probable composition.

Clinopyroxene - 5 vol %; 2V + ve = 50^{0}, inclined extinction, non-pleachroic, pale green. Diopside most probable composition.

Plagioclase - 30 vol %; twinned, albite and pericline, max. ext. angle perp (010) 30^{0} i.e. An_{54}..

Quartz - 10 vol %; uniaxial + ve, undulose extinction.

Potash Feldspar - 5 vol %; 2V - ve = 80^{0}, rare perthite.

Biotite - 3 vol %; restricted to pyroxene deficient zones.

Zircon - trace.

Sample C181: Mixed gneiss

Adjacent to sample C180, Layers of quartzo-feldspathic material and biotite rich material intercallated.

Quartz - 30 vol %; uniaxial + ve, elongate grains parallel the layering.

Potash Feldspar - 30 vol %; 2V - ve = 80 - 90^{0}, finely perthitic, myrmekitic, some microcline cross hatching.

Plagioclase - 20 vol %; albite and pericline twinning, some anti-perthite, max. ext. angle perp. (010) 17^{0} i.e. A_{65}.

Biotite - 10 vol %; strongly pleochroic - reddish brown to pale fawn.

Chlorite - 5 vol %; alteration of biotite and in some cases pyroxene.

Sericite - 3 vol %; alteration of feldspars.

Pyroxene - 2 vol %; in most cases has been completely altered, relict traces remain.

Garnet and Zircon - trace.

Sample C208: Biotite Garnet Gneiss

Foliation developed due to parallel elongation of minerals.

Potash Feldspar - 35 vol %; finely perthitic, myrmekitic.

Plagioclase - 23 vol %; albite - percline twinning, some antiperthite, max. ext. angle perp. to (010) 16^{0} i.e. Ab_{66}. In some cases poikilitic resembling cordierite, but for 2V - ve and lower R.I. than quartz.

Quartz - 29 vol %; uniaxial +ve, undulose ext., elongate grains.

Biotite - 7 vol %; reddish brown to fawn pleochroism.

Garnet - 4 vol %; isotropic, colourless, restricted to coarse biotite rich layers, inclusions of biotite.

Sillimanite ~ 1 vol %; assoc. with biotite usually as needles or prismatic grains.

Zircon, Opaques - rare.

Sample C209: Sillimanite Cordierite Gneiss

Potash Feldspar - 25 vol %; finely perthitic, myrmekitic, some microcline.

Sillimanite - 20 vol %; 2 V + ve = 30^0, colourless, subhedral generally, cleavage parallels the long diagonal in rhombic cross sections. Altered to muscovite and biotite?

Quartz - 20 vol %; uniaxial + ve undulose ext.

Sericite - 8 vol %; alteration of feldspar and cordierite.

Cordierite - 7 vol %; heavily sericitized, multiple lamellar twinning, pleochroic haloes around inclusions of zircon.

Muscovite - 3 vol %; colourless, straight extinction, high max. birefringence.

Biotite - 3 vol%; reddish brown to pale fawn pleochroism.

Spinel, Opaques, Zircon, Chlorite - present in accessory amounts.

Sample C256: Augen Gneiss

Refer to appendix A(3) Geochronology Samples

Sample C263: Layered Gneiss

Refer to appendix A(3) Geochronology Samples.

2) Geochemistry Samples

Samples F8, F30, F34 and C142 described in appendix A(1) above.

Samples C256, C261 and C263 described in appendix A(3) below.

Sample F25 Layered Garnet Gneiss

Distinctive features of the thin section are the presence of sillimanite, lack of biotite, slight elongation of quartz. Texture is granoblastic inequigranular.

Quartz - 45 vol %; uniaxial positive, undulose extinction.

Potash Feldspar - 25 vol %; perthitic, myrmekitic.

Plagioclase - 12 vol %; albite and pericline twinning max. ext. angle perp. to (010) 10^0 i.e. Ab_{73}.

Garnet - 10 vol %; isotropic, colourless, associated with biotite.

Biotite - 4 vol %; rusty brown to pale brown pleochroism.

Sillimanite - 2 vol %; euhedral grains have cleavage parallel to the diagonals.

Zircon, Spinel, Opaques - trace.

3) Samples used in the Rb-Sr whole rock geochronology

A) Augen and Layered Gneisses

Sample C250 - Augen Gniess

The longer of the two cores sampled.

Potash Feldspar - 50 vol %; 2V- ve = 80^0, perthitic and myrmekitic, inclusions of zircon, alteration to sericite.

Plagioclase - 15 vol %; albite and pericline twinning, max. ext. angle perp. to (010) 14^{o} i.e. Ab_{67}, sericitized.

Quartz - 30 vol %; uniaxial +ve, mottled colouration, inclusions of zircon, elongate in places.

Biotite - 3 vol. %; reddish brown to pale brown pleochroism. pleochroic haloes around zircon inclusions, usually associated with garnet.

Garnet - 2 vol %; isotropic, colourless, round grains

Sericite, Zircon and Opaques - trace amounts.

Sample C251 - Augen Gneiss

Shorter of the two cores sampled.

Potash Feldspar - 35 vol %; perthitic and myrmekitic, inclusions of zircon, alteration to sericite.

Plagioclase - 30 vol %; 2V +ve = 85^{o}, twinned plagioclase is more highly sericitized. Some twins kinked. Max. ext. angle perp (010) 15^{o} i.e. Ab_{67}.

Quartz - 25 vol %; Uniaxial + ve, slightly undulose extinction.

Biotite - 5 vol %; Reddish brown to pale fawn pleochroism.

Garnet - 3 vol %; colourless, isotropic

Zircon - trace, round, inclusions in biotite, feldspar, and quartz.

Opaques - trace, irregular.

Sample C253 - Augen Gneiss

Coarser grains of quartz, potash feldspar and plagioclase with finer "matrix" of quartz and plagioclase.

Potash Feldspar - 30 vol %; finely perthitic, myrmekitic, some microcline, grain size ranges up to 6-7 mm in diameter.

Plagioclase - 20 vol %; albite and pericline twinning max. ext. angle perp to (010) 11^{o} Ab_{72}. sericitized.

Quartz - 35 vol %; uniaxial + ve, undulose ext. on larger grains.

Sericite - 8 vol %; alteration product of feldspars.

Biotite 3 vol %; reddish brown to fawn pleochroism assoc. with garnet and opaques. Sericitized.

Garnet - 3 vol %; colourless, isotropic.

Zircon, Opaques - trace.

Sample C254: Augen Gneiss

Potash Feldspar - 47 vol %; 2V - ve = 85^{o}, finely perthitic myrmekitic, sericitized, up to 3.5 mm in diameter.

Plagioclase - 20 vol %; albite and pericline twinning max. ext. angle perp. to (010) 11^{o} i.e. Ab_{72}. Sericitized.

Quartz - 20 vol % uniaxial + ve, undulose extinction.

Biotite - 4 vol %; reddish brown to fawn pleochroism, pleochroic haloes around zircon.

Garnet - 3 vol %; colourless, isotropic, inclusions of spinel in one large grain.

Sericite - 4 vol %; alteration of feldspars.

Zircon, Opaques, Spinel - traces.

Sample C255: Augen Gneiss

A distinct lack of garnet in this thin section.

Potash Feldspar - 35 vol %; perthitic, myrmekitic, sericitized.

Plagioclase - 20 vol %; pericline and albite twinning max. ext. angle perp. to (010) 7° i.e. Ab_{75}. Sericitized.

Quartz - 35 vol %; uniaxial + ve, undulose ext. on coarser grains, some inclusions of biotite.

Biotite - 5 vol %; reddish brown to pale fawn pleochroism.

Sericite - 3 vol %; replacing plagioclase and K feldspar.

Garnet, Zircon, Opaques - trace amounts.

Sample C256 - Augen Gneiss

Potash Feldspar - 30 vol %; finely perthitic, myrmekitic, some microcline up to 5.5. mm. in diameter.

Plagioclase - 25 vol %; albite, pericline twinning, max. ext. angle perp. (010) 16° Ab_{68}.

Quartz - 30 vol %; uniaxial + ve, undulose ext., inclusions of needles of biotite.

Biotite - 5 vol %; psuedo uniaxial -ve, reddish brown to pale fawn pleochroism.

Sericite - 6 vol %; alteration of feldspars.

Garnet - 3 vol%; colourless, isotropic, up to 2 mm in diameter.

Zircon, Opaques - trace amounts.

Sample C261 - Augen Gneiss

Potash Feldspar - 30 vol %; finely perthitic, myrmekitic, some microcline.

Plagioclase - 25 vol %; albite and pericline twinning, max. ext. angle perp (010) 12° Ab_{70}.

Quartz - 35 vol %; uniaxial + ve, undulose extinction.

Biotite - 3 vol %; reddish brown to pale fawn pleochroism, pseudo uniaxial -ve. A rare grain has brown - pale green pleochroism.

Sericite - 3 vol %; alteration of feldspars.

Garnet - 2 vol %; colourless, isotropic

Zircon, Opaques - trace amounts.

Sample C263 : Layered Gneiss

Potash Feldspar - 35 vol %; finely perthitic, myrmekitic, some microcline, sericitized.

Plagioclase - 20 vol %; albite and pericline twinning some twins kinked. max. ext. angle perp. to (010) 15° i.e. Ab_{66}.

Quartz-30 vol %; uniaxial +ve, undulose ext.

Biotite - 5 vol %; reddish brown to pale fawn pleochroism. May be some sillimanite associated within the "Stringers".

Garnet - 3 vol %; colourless, isotropic.

Sericite - 7 vol %; Alteration of feldspars.

Zircon - trace. Opaques - trace.

b) Leuco-gneiss

Sample JC1

Relatively higher amounts of biotite in this thin section.

Potash Feldspar - 35 vol %; finely perthitic, myrmekitic, 2V -ve = 85-90^{0}, little altered.

Plagioclase - 30 vol %; albite and pericline twinning max. ext. angle perp. to (010) 16^{0} i.e. Ab_{66}. Heavily sericitized.

Quartz - 26 vol %; uniaxial +ve, undulose ext.

Biotite - 4 vol %; reddish brown to pale fawn pleochroism, pseudo uniaxial +ve, altered to chlorite.

Garnet - 2 vol %; colourless, isotropic.

Chlorite - 2 vol %; pale green, pleochroic, replacing biotite.

Sericite - 2 vol %; alteration of plagioclase.

Opaques, Zircon - traces.

Sample JC2

Potash Feldspar - 35 vol %; finely perthitic, myrmekitic, growths into plag. Microline cross hatching.

Plagioclase - 28 vol %; albite and pericline twinning, some kinked twins max. ext. angle perp. to (010) 18^{0} i.e. Ab_{63}.

Quartz - 30 vol %; uniaxial +ve, undulose ext.

Sericite - 3 vol %; alteration of feldspars.

Biotite - 3 vol %; reddish brown to pale fawn pleochroism, alteration to chlorite.

Garnet - 1 vol %; present in hand specimen.

Chlorite - 1 vol %; replacing biotite.

Opaques, Zircon - traces.

Sample JC 3

Potash Feldspar - 20 vol %; finely perthitic, myrmekitic, some microline 3V -ve = 85^{0}, relatively unaltered c.f. plagioclase.

Plagioclase - 27 vol %; albite and pericline, antiperthite max. ext. angle perp. to (010) 11^{0} Ab_{71}. Heavily sericitized.

Quartz - 20 vol %; undulose extinction, uniaxial +ve.

Sericite - 30 vol %; complete alteration of the plagioclase.

Garnet - 2 vol %; colourless, isotropic.

Biotite, Zircon, Chlorite - traces.

Sample JC5

Potash Feldspar - 35 vol%; finely perthitic, myrmekitic 2V -ve = 85^0.

Plagioclase - 30 vol %; albite and pericline, antiperthite max. ext. angle perp. to (010) 14^0 i.e. Ab_{67} . Sericitized.

Quartz - 27 vol %; uniaxial +ve, undulose ext.

Biotite - 5 vol %; reddish brown to pale fawn pleochroism alteration to chlorite.

Chlorite - 2 vol %; replacing biotite.

Sericite, Garnet, Zircon, Opaques - traces.

Sample JC6

Potash Feldspar - 40 vol %; finely perthitic, myrmekitic.

Plagioclase - 25 vol %; albite and pericline twinning max.ext. angle perp. to (010) 9^0 i.e. Ab_{73}. More sericitizrd than potash feldspar.

Quartz - 30 vol %; uniaxial +ve, undulose extinction.

Biotite - 3 vol %; reddish brown to pale fawn pleochroism.

Garnet - 1 vol %; colourless, isotropic.

Chlorite - 1 vol %; alteration of biotite.

Sericite - 1 vol %; alteration of feldspars.

Opaques, Zircon - traces.

Sample JC7

Potash Feldspar - 35 vol %; 2V -ve = 85-90^0 finely perthitic, myrmekitic some microline.

Plagioclase - 27 vol. %; pericline and albite twinning, some kinked, antiperthite max. ext. angle perp. to (010) 13^0 i.e. Ab_{69}, sericitized

Quartz - 30 vol %; uniaxial +ve, undulose extinction.

Sericite - 5 vol %; alteration of plagioclase.

Garnet - 2 vol %; colourless, isotropic.

Biotite, Chlorite, Zircon, Opaques - traces.

Sample JC8

Potash Feldspar - 40 vol %; finely perthitic, mermekitic, some microcline 2V -ve = 85^0.

Plagioclase - 30 vol %; albite and pericline twinning, some antiperthite, max. ext. angle perp. to (010) 12^0 i.e.Ab_{70} , sericitized.

Quartz - 35 vol %; uniaxial +ve, undulose.

Biotite - 2 vol %; reddish brown to pale fawn pleochroism, alteration to chlorite.

Sericite - 2 vol %; replacing feldspar.

Garnet, Chlorite, Zircon, Opaques - traces.

APPENDIX B.

Modal analyses of thin sections.

Reference :

Q	=	quartz
Pl	=	plagioclase
Ks	=	potash feldspar
Ga	=	garnet
Bi	=	biotite
Opx	=	orthopyroxene
Cpx	=	clinopyroxene
Hd	=	hornblende
Se	=	sericite
Ch	=	chlorite
Op	=	opaques
Zr	=	zircon
Sp	=	spinel
Sill	=	sillimanite

Numbers are a visual estimate of the volume percentages of the minerals present in thin section.
C.I.P.W. normative values have been included.

Sample	Q	Pl	Ks	Ga	Bi	Opx	Cpx	Hd	Se	Ch	Op	Zr	Sp	Sill
Layered Garnet Gneiss						FISHERY BAY								
F2	25	15	35	3	3				T	T	2	T	T	
F5	25	20	45	3	4						T	1		
F7	25	20	50	1	4							T		
F8	30	8	50	7	5					T	T	T		
F9	35	10	45	6	4					T	T	L	T	
F10	30	15	50	2	3						T	T	T	
F13	50	4	35	5	6						T	T		
F14	35	5	45	5	10						T	1		
F24	35	30	25	4	3				T		T	T	T	1
F25	45	12	25	10	4						T	T	T	2
C.I.P.W.	36	26	17			12					3			
F27	35	20	35	3	7						T	L		
F31	30	10	50	[illegible]	5				5	[illegible]		1		T
F32	30	35	20	4	10						T	T		T
F35	40	25	20	3	6				2		T	T		
F42	35	50	5	3	5				10	5	T	T		
F43	32	48	10	4	3						T	T	T	
F44	35	35	20	4	5						T	T		
F49	30	25	15	15	3				4		2	T	2	T
F50	30	40	10	8	5				2	1	T	T	T	T
F51	40	35	10	6	4				2		T	T	T	
F52	45	27	12	4	5				3	2		T	T	
C.I.P.W.	35	28	17			11					3			
F59	45	35	15	2	3				1		1	T		
Leuco-gneiss														
F1	20	30	40	4	4				T		1	T		T
F12	30	10	40	7	T				11	1		1		
F17	35	10	45	5	3						T	T		
F20	25	20	45	3	T						T	T	1	4
F21	25	20	50	2	3						T	T		
F22	25	10	50	3	5						T	T	T	5
F29	25	20	50	3	1							T	T	T
F38	25	35	25	6	1					4	T	T	T	2
F51	40	35	10	6	4				2		T	T	T	
F53	43	30	10	10	3				2	1	T	T	T	T
Biotite Garnet Gneiss														
F16	65	5	5	10	15						T	T		T
F19	25	40		20	3						5	T	2	5
F23	20	30	10	20	20						T	T		
F28	30	20	10	25	2				8		5	T		
F39	30	35	20	3	10						T	T		
F41	35	50	10	5	15				2	2		T		
Basic Granulite														
F4	10	30	T		3	30	20		2		6			
F15	10	40			1	12	30				5	T		
F26	5	45	2		T	25	20	T			5			
F30	T	50	T			25	15				10	T		
C.I.P.W.	4	41	1		[illegible]	27	12				10			
F36	3	60			1	18	12	2			5	T		
F56	5	35			2	40	14	2	T		2	T		
F58	4	35			1	20	28	2			10	T		
Pegmatites														
F6	15	25	35	3	3				15		T	1	T	
F11	25	10	45	3	1				15		T	T		
F18	40		40						20		T	T		

Sample	Q	Pl	Ks	Ga	Bi	Opx	Cpx	Hd	Se	Ch	Op	Zr	Sp	Sill	Remarks
Pegmatites (continued)															
F33	20	30	50		3				10						
F34	15	45	25		2				10		T	T		1	
F45	90	3	5							1		T			
F46	25	2	55		T				15	T		1			
F57	25	30	35						5	5	1	1			
Augen Gneiss					CAPE CARNOT										
C202	20	30	45	1	T				1	1	2				) Augen Gneiss i
C174	30	25	35	2	8				T		T	T			) Layered Series
C134	30	20	38	3	5				2	T	1	T		1	
C135	30	20	40	2	3				1	1	T	T		1	
C151	30	20	36	2	7				2	1	1	1		T	
C152	30	25	27	2	7				2	T	1	T		T	
C157	30	12	40	2	5				2	1	1	T		1	
C166		60	8	15	10				1		3	2	1		Peletic xenolith
C167	20	30	40	3	5				2	T	T	T		T	
C168	25	17	40	4	6				3	2	1	1		1	
C170	25	20	45	1	5				1	1	2	T			
C206	30	20	37	3	6				1	2	1	T			
C207	30	20	40	2	4				2	1	1	T			
Layered Gneiss															
C102	34	45	10	2	3				5	1		T			
C117	25	20	40	3	6				4	1	T	1			
C118	30	18	35	2	7				7	T	1	T			
C121	23	20	45	1	5				3		1	T	T	2	
C122	25	20	40	3	4				1		1	1			
C128	30	20	40	2	4				2	T	1	T		1	
C129	35	23	30	3	5				2		1	T		1	
Biotite Garnet Gneiss															
C166		60	8	15	10				1		3	2	1	1	
C208	29	23	35	4	7						T	T		1	
"Mixed" Gneiss															
C175	15	26			3	40	5	2	5		4				
C178	25	20	35	6	7	4			T	T	1	T			
C180	10	30	5		3	40	5				7	T			
C181	30	20	29	1	10	2			3	5		T			
C189	23	30	T		4	40	T				3	T			
C195	25	30	15	4	15	6			1	3	T	T			
C196	20	35	13	3	17	5			2	2	2	1			
C197	25	35	20	5	10	2			T	T	1	T)			two layers
	24	30	30		2	10			2	2		T)			
C201	30	20	35	5	7				2		T	T			
C204	30	25	35	1	5	1			2	2		T			
Leuco-gneiss															
C177	40	35	25	1									T		
C179	30	35	25	1	4				3	1	1	T			
C190	30	25	35	T	2				2	2	T	T			
C191	30	35	22	1	6				3	1	1	1			
C192	30	30	25	T	T				15						
C198	35	50	10	T	1				3	1	T				
C199	30	25	35	1					3	5		2			
C203	30	20	40	T					8	2	T	T			

Sample	Q	Pl	Ks	Ga	Bi	Opx	Cpx	Hd	Se	Ch	Op	Zr	Sp	Sill
C183	30	35	20	8	3				1	1	T	T	T	
C185	25	40	25	2	4				3	1	T	T		T
C193	50	25	15	2	6				T	T	T	T		T
C209	20	10	25		3				18	1	1	1		20 & 7% Cordierite
Basic Granulite														
C100	T	35			T	25	15	15	5		5			
C103	T	35				22	16	20	3		3			
C104		45			1	30	18	2			4			
C106	T	40				30	14	10	3		3			
C107	2	35			2	25	6	25	3		3			
C112	3	40			1	25	15	7	4		5			
C116	3	45			2	25	20	2	1		3			
C124	5	40			T	27	17	5	2		4			
C142	4	30				25	20	15	4		2			
C.I.P.W.	6	44				26	17				5			
C146	T	40				36	10	10	1		3			
C147	10	35				30	15	5	2		3			
C173	1	25	1			35	20	10		2	5			
C176	5	30				40	5	5	15		5			
C184	5	40	2		1	40	5				3	T		
C186	10	40			T	30	10	T	6		3			
C187		45			3	25	25	T			2		T	
C188	5	28	2		1	30	30	2			2			
C194	15	35				25	18	1	2		4			
C200	3	25	T		T	45	15	4	2		6			
C205	10	30			T	40	4	10	2	1	3			
Pegmatite														
C158	20	30	40	T	2				6	1	T	T		
Aplite														
C143	20	25	35	T	4				5	1	T	T		T
C150	20	25	40		3				10	2		T)		
	20	9		2	45						4	6)biotite rich margin to aplitic vein		

APPENDIX C

Geochemical Procedures

1 X-ray fluorescence

2 Flame photometry

APPENDIX C.

GEOCHEMICAL PROCEDURES

(1) X-Ray Fluorescence

(i) Whole Rock Analysis

S_iO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, T_iO_2 and P_2O_5 percentages were determined on nine samples using a Siemens Sequential Ray Spectrometer operating under a standard whole rock program (on digital tape) with a Cr 60/40 tube. Samples were prepared as described by Norrish and Chappell (1967) giving fused buttons. Water loss was determined by heating the powdered samples (< 200 mesh) to 1000^oD for at least 6 hours and calculating the ignition loss.

(ii) Rb, Sr, Y and rough Th

These elements were determined using a Siemens S.R.S. operating under a standard program. This program set the following conditions:

Measurement of the fluorescence of the elements in the sequence
Sr K_α Sr Bg, Rb Bg, Rb $K\alpha$, Y $K\alpha$, Y Bg
Primary Collimator : Fine
Analysing Crystal : LiF_{220}
Detector : Scintillation Counter.

A Mo tube was used, operating at 60 Kv and 40 mA. The samples were prepared following the procedure of Norrish and Chappell (1967) giving pelleted samples with boric acid back and edge. Calculation of the elemental ppm from the digital tape output was made on a digital computer. Mass absorption Correction was obtained by measurement of the Compton Peak.

(iii) Mn

Measurement of the fluorescent Mn K_α radiations were made with a Phillips PW 1540 X-ray fluorescent spectrometer operating under the following conditions:

X-ray tube : Mo, 60 KV, 40 mA
Angle : 62.97^o
Analysing Crystal : LiF_{220}
Detector : Flow proportional counter
EHT : 389.

Samples were prepared following the procedure of Norrish and Chappell (1967), giving fused buttons. Standard used was Fs 11, counting times were 20 sec. for all measurements.
Calculations were made using a standard program on a H.P. desk computer for calculation of Mn nominal %.

(iv) Ba

Measurement of the fluorescent Ba Lα, radiations were made with a Phillips PW 1540 X-ray fluorescent spectrometer operating under the following conditions:

X-ray tube : Cr, 60 KV, 40 mA
Collimator : Fine
Analyzing Crystal : LiF_{200}
Detector : Flow Proportional Counter
EHT : 1.39 KV.

Samples were prepared as described by Norrish and Chappell (1967) giving pressed buttons with boric acid back and edge.
Measurements were made at the following angles
: 86.05 (Ti K), 87.06 (Ba Kα) and 88.06 (Bg).
The Ti Kα peak was measured due to its interference on the Ba Lα peak and series of calibration measurements were required to determine correction factors for the effect Ti on peak and Ti on background.
The calibration measurements consisted of measurement (at the above angles) of standards G2, MgO, MgO + 0.46% Ti, and MgO + 0.96% Ti.
The correction for Ti on the Ba Lα peak was calculated at 1.35% and for Ti Kα on background was calculated at 0.2%.
These correction factors were checked for their accuracy by applying them to a series of standards (G2, Ga, BCR, AGV and Wi). A comparison of calculated Ba ppm with accepted Ba ppm indicated that the above correction factors were acceptable. The samples were then measured under similar conditions, and ppm calculated using the above correction factors and mass absorption coefficients calculated from the whole rock analysis data (Std program used on H.P. desk computer).

(2) Flame Photometry

Na_2O% and K_2O% were measured by a flame photometer using a set of standard solutions for calibrations. Approximately 0.3 grams of each ignited sample and a standard (B.H.N.) (heated to 1000°C for at least six hours) was dissolved in approximately 10 mls of H.F. and 2 ml. of 50% H_2SO_4 platinum dish. This solution was heated in a low heat sand bath overnight, then strongly heated (the next morning). Fuming occured and proceeded for 3-5 minutes before the platinum crucible was allowed to cool. The inside of the crucible was then washed and filled with water. As the resulting solution was clear, further dissolution was not required, and the contents were made up to 100 mls. before being transferred to plastic bottles.
This preparation enabled the measurement of both Na_2O% and K_2O% from the same solution. At the commencement of both analyses (Na & K) the rock solutions were sprayed into the flame and a comparison with a

variety of standards enabled crude ppm determination for each solution.
Any solution of higher concentration than 15 ppm was diluted sufficiently that ppm was in the 5-10 ppm range.
Accurate determinations of ppm were then made by bracketing the sample solutions between two standard ppm solutions.

APPENDIX D.

Methods of dating measurements

(1) Chemical separation of Sr

(2) X-ray Fluorescence measurements

(3) Mass spectrometry

(4) Regression analysis

APPENDIX D.

:METHODS OF DATING MEASUREMENTS

(1) Chemical Separation of Sr.

(i) Approximately 0.2 gm. of each sample was weighed out in platinum crucibles.

(ii) The sample was then wetted with a minimum amount of double distilled (approximately 5 drops). Five mls. of HF added and the solution mixed until most of the sample was in solution or as a colloid. The solution was allowed to stand overnight.

(iii) After warming the solution on a hot plate (set at "1") for half an hour, the HF was fumed off by increasing the heat of the hot plate. The platinum dish and residue was then allowed to cool.

(iv) Five drops of $HClO_4$ and 5 mls. of HF added and mixed with the residue. The resultant solution was warmed for half an hour on a hot plate at a low setting.

(v) The HF was then fumed off (hot plate set at 4) until dense white fumes ceased to be given off, at which stage the $HClO_4$ was fumed off by increasing the hot plate setting to 8 (maximum heat). The solution was taken to dryness.

(vi) The platinum dish and residue was heated at first gently over a flame to vapourise the last of the $HClO_4$ and others, before heating the dish to red hot to convert Al to Al_2O_3 and Fe to Fe_2O_3.

(vii) 10 mls. of 6N HCl was added and the dish warmed gently to allow dissolution, but no evaporation. The resultant solution and most of the residue was then transferred to a clean labelled plastic centrifuge tube and covered. This was centrifuged for fifteen minutes.

(ix) The supernatant solution was poured into the large ion exchange column (note: one sample per column only).

(x) 70 mls. of I N HCl was added, during which period the Rb was washed from the columns.

(xi) 20 mls. of 2.5 N HCl added and after it had passed through the column a further 30 mls. of 2.5 N HCl added. The solution that passed through the column was collected in a labelled 30 ml. beaker. (The columns were then "cleaned" by addition of the following solutions in succession 30 mls. of 6 N HCl, 30 mls. of double distilled water, and 30 mls. of 1 N HCl).

(xii) The solution was evaporated to dryness on a hot plate at a moderate setting (3-4) and allowed to cool.

(xiii) The residue was dissolved in 2 mls. of 1 N HCl and poured into the smaller ion exchange columns (one sample per column).

(xiv) 18 mls. of 1 N HCl added and after this had passed through the columns 6 mls. of 2.5 N HCl was passed through the columns.

(xv) 4 mls. of 2.5 N HCl was then added and the solution passing through collected in the same cleaned labelled beakers. (The beakers were cleaned by washing the inside with 6 N HCl, then double distilled water and finally 1 N HCl). (The columns were then "cleaned" by the addition of the following solutions in succession, 10 mls. of 6 N HCl, 10 mls. of double distilled water and 10 mls. of 1 N HCl).

(xvi) The collected solution was evaporated to dryness on a hot plate at a moderate setting (3-4). Before the beakers cooled they were sealed with a thin sterile paraffin film.

(xvii) The beakers were stored to await dissolution by phosphoric acid and loading onto the renium filament of the beads used in the solid source mass spectrometer.

(2) X-ray Fluorescence Measurements

Measurement of the fluorescent Rb, Kα and Sr Kα radiations were made with the Seimens Sequential Ray Spectrometer operating under the following conditions:

X-ray tube : Mo, 60 Kv., 40 mA.
Primary Collimator : Fine, 0.15 deg.
Analysing crystal : LiF220 Rb & Sr in "RuF" XRF
LiF200 (Sr) & LiF220 (Rb) "Acc" XRF.
Detector : Scintillation Counter
E.H.T. : 1.2 Kv.

The samples were prepared following the procedure of Norrish & Chappell (1967), giving pelletted samples with boric acid back and edge.

Initially all samples were measured "roughly" for Rb and Sr to enable selection of the best spread in $^{87}Rb/^{86}Sr$ to give good isochron definition. For each element counts were accumulated for 100 sec. on the Kα line, and for 80 sec. on the background position, the latter being chosen at 1.065 deg. 2θ on either side of the peak position. Measurements were in the sequence low angle background - peak (Sr) - high angle background - peak (Rb) - higher angle background, this being carried out once for each sample analysis.

Counting times and counts were recorded on the digital tape and p.p.m. calculated on a digital computer using a standard program for Peak - background p.p.m. determination. Nine samples were chosen for accurate X.R.F. work and mass spectrometer measurements.

For these samples both element counts were accumulated for 200 Sec. on the Kα line and for 100 Sec. on each of two background positions, the latter being chosen at 0.35 deg. 2θ for Sr and 0.38 deg. 2θ for Rb on either side of the respective peak positions. Measurements were made in the sequence low angle background - peak - high angle background, this was repeated three times for each element. Three buttons were prepared for each sample and all of these were analysed three times using the above procedure.

Pb, Th and U peaks were monitored in order to obtain a Sr background correction for the interference of these peaks on Sr background.

Counting times and counts were once again recorded on the digital tape and calculation made using a digital computer with a standard program.

This program was effectively calibrated by the previous measurements of standards NBS 70A and AGV-1 which were then compared with accepted values for p.p.m. in these samples. The program recalculated a set of normalisation factors to give the accepted p.p.m. of the standard ("Hot standard No. 3") measured, then calculated p.p.m. for these samples. The mass absorption correction was obtained by measurement of the Compton Peak.

Of the data obtained from the XRF measurements the only value used are those of p.p.m. Rb and p.p.m. Sr. The accuracy of the critical Rb/Sr ratios ranged from 0.308 % to 0.706 %.

(3) Mass Spectrometry

Isotopic ratios were measured on Thomson twelve inch radius of curvature, solid source mass spectrometer using automatic peak switching and digital output. Samples were prepared using the chemical techniques outlined in Appendix D (1), the concentrated Sr for each sample being dissolved in phosphoric acid and "loaded" onto one of the side filaments (Re in composition) of a "bead".

Operating conditions for the mass spectrometer were :

Side filament : 2.0 - 2.6 amps.

Centre filament : 4.0 amps.

Tube pressure : 4.0 to 9.0 X 10^{-9} Tors

Resistance : 10^{11} ohms.

Switching delay : 3 secs.

Range : 3 V.

Mass fractionation effects of the Sr isotopes which occurred during the mass spectrometer runs were reduced by recalculating all the measured $^{87}Sr/^{86}Sr$ ratios to the equivalent of $^{88}Sr/^{86}Sr = 8.3752$. If the final $^{87}Sr/^{86}Sr$ ratios did not agree to within two figures in the fourth decimal place the data was rejected and the sample re-run or reloaded then re-run.

(4) Regression Analysis

Regression analysis of the Rb/Sr and Sr isotopic data, to determine the age and initial $^{87}Sr/^{86}Sr$ ratio of the samples, were carried out using the computer program of McIntyre et al. (1966). A value of 9.00 was used for CONX and 0.015 for the experimental variance in the measurement of $^{87}Sr/^{86}Sr$.

Appendix E sets out the regression results for the various groupings.

The mean square of weighted deviates (M.S.W.D.) is a test of the tightness of fit of the data to the proposed regression line i.e. it is a measure of the average deviation of all samples from the proposed line of best fit.

If the data has a scatter greater than that attributable to the experimental error then there is a geological variance for the samples, due to either an inhomogeneous initial $^{87}Sr/^{86}Sr$ ratio or subsequent closure of the samples to Rb & Sr, or both. In these cases the M.S.W.D. factor is greater than one and the program proceeds to Model 2 and Model 3.

Model 2 assigns the geological variance to the $^{87}Sr/^{86}Sr$ co-ordinate and assumes that the variance is proportional to $(^{87}Rb/^{86}Sr)^2$. Thus it gives a stronger weighing to the samples of low $^{87}Rb/^{86}Sr$. Effectively this model applies to samples with the initial $^{87}Sr/^{86}Sr$ ratio but with an apparent spread of ages due to open system Rb and/or behaviour.

Model 3 assumes that the variation in $^{87}Sr/^{86}Sr$ is independent of $^{87}Rb/^{86}Sr$ and adds the same additional variance to all samples. This model effectively applies to samples of the same age but with different initial $^{87}Sr/^{86}Sr$ ratios (giving a parallel isochron effect). If the program proceeds to Model 2 and Model 3 then it determines the most appropriate of the two by examining the trend of the absolute differences between the observed and the estimated $^{87}Sr/^{86}Sr$ ratio divided by the standard errors, as a function of $^{87}Rb/^{86}Sr$ ratio. From the slopes of this trend the program recommends Model 2 or Model 3 as the most appropriate.

Model 4 of McIntyre et al. (1966) was not called upon in this investigation.

APPENDIX E.

Composition of the REGRESSION GROUPS.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
C250	x	x		x	x	x	x	x	x	x	b
C251	x	x		x	x						
C252	x	x		x			x	x	x	x	a
C253	x	x		x	x	x					
C254	x	x		x	x	x					b
C255	x	x		x							d
C256	x	x		x	x	x			x	x	b
C257	x	x		x	x						
C259	x	x		x	x		x		x	x	c
C260	x	x		x	x	x	x	x	x	x	
C261	x	x		x	x	x			x	x	b
C262	x	x			x		x		x		c
C263	x	x			x		x	x	x		c
JC1		x	x								
JC2		x	x								a
JC3		x	x								
JC5		x	x								a
JC6		x	x								d
JC7		x	x								
JC8		x	x								d

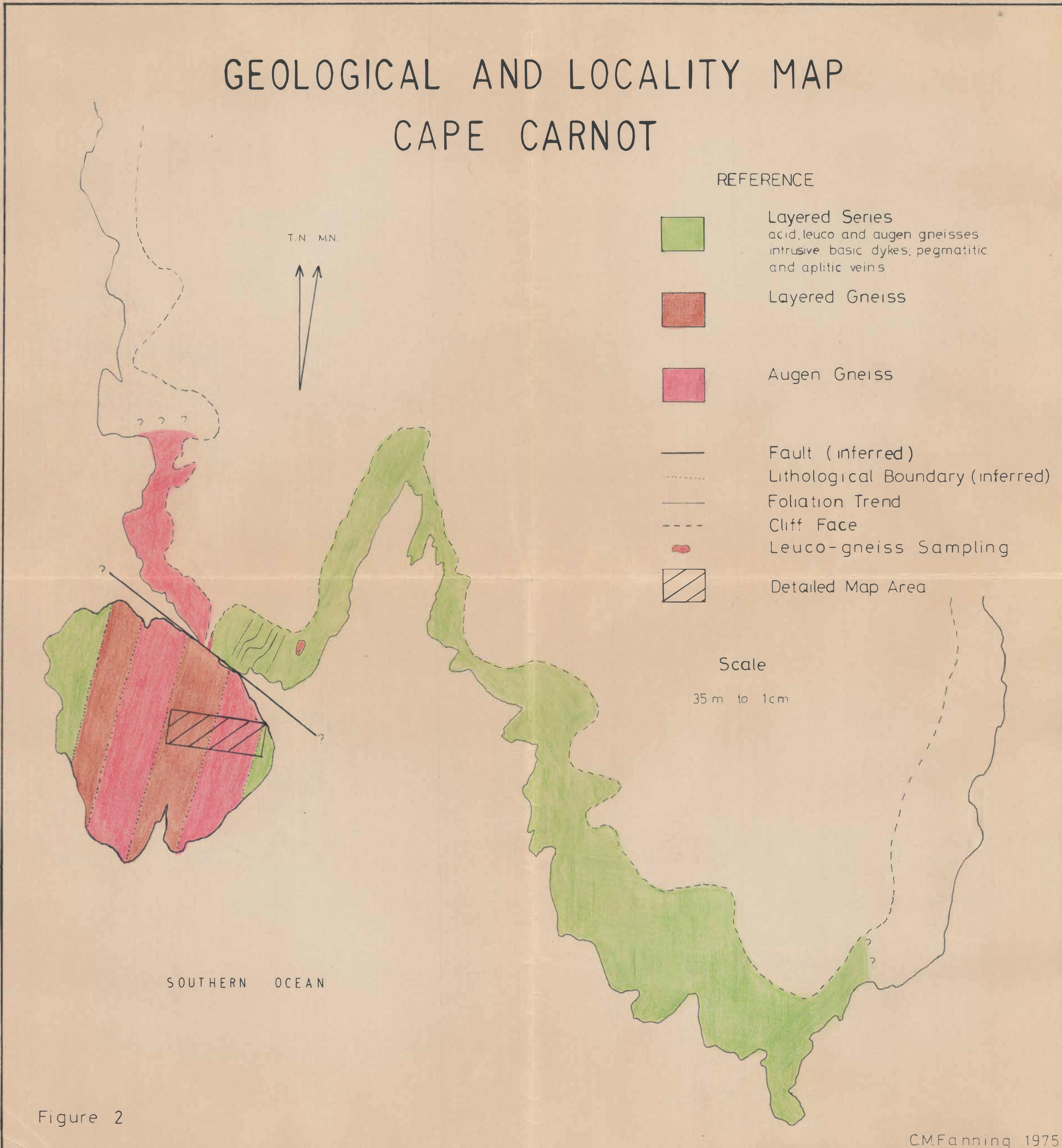

GEOLOGICAL AND LOCALITY MAP
CAPE CARNOT
REFERENCE
Layered Series
acid, leuco and augen gneisses
intrusive basic dykes; pegmatitic
and aplitic veins
Layered Gneiss
Augen Gneiss
Fault (inferred)
Lithological Boundary (inferred)
Foliation Trend
Cliff Face
Leuco-gneiss Sampling
Detailed Map Area
Scale
35 m to 1 cm
T.N
M.N
SOUTHERN OCEAN
C.M.Fanning 1975

Figure 2


GEOLOGICAL MAP
FISHERY BAY
T.N.
M.N.
basic granulite
REFERENCE
GARNET GNEISS
L Layered Garnet Gneiss
LE Leuco-gneiss
B Biotite Garnet Gneiss
BASIC GRANULITE
PEGMATITE
Lithological Boundary
Syncline
Anticline
Layering S - strike and dip
- vertical dip
Cliff Face
Outcrop Limits
23 Sample Location (466/F__ prefix to nos.)
SCALE
2 0 2 4 6 8 metres
C.M.Fanning 1975


GEOLOGICAL MAP -
CAPE CARNOT
SCREE
SCREE
SCREE
moved block
REFERENCE
AUGEN GNEISS
Augens Orientated
Augens Disorientated
LAYERED GNEISS
BIOTITE GARNET GNEISS
"MIXED" GNEISS
LEUCO GNEISS
SILLIMANITE CORDIERTE GNEISS
BASIC GRANULITE
PEGMATITIC VEINS and ZONES
APLITIC VEINS
Lithological Boundary
Fault
Layering S_1
dip and strike
trend
20 Reference Station
200 Sample Location
All sample nos. should be prefixed 466/C.....
Geochronology samples have been underlined
T.N.
M.N.
SCALE
1 0 1 2 3 4 5 metres
1:100
C.M. Fanning 1975