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THE PETROLOGY OF GRAHAM LAND

III. METAMORPHIC ROCKS OF THE TRINITY PENINSULA SERIES

By

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ABSTRACT

THE sediments of the Trinity Peninsula Series together with their cataclastic and thermal metamorphic equivalents are believed to have a wide distribution in Graham Land. They have been recorded not only in the type locality (Trinity Peninsula) but also along the east and west coasts of the peninsula as far south as latitude 75°. From the abundant evidence of highly contorted and sheared rocks in Tabarin Peninsula and Trinity Peninsula it is clear that the Trinity Peninsula Series has been subjected to severe cataclasis in pre-Jurassic times. As a result of the emplacement of the early Tertiary Andean intrusives the sediments within the thermal aureoles have undergone superposed contact metamorphism.

The cataclastically deformed argillaceous sediments have usually been transformed into fissile slates with a marked false cleavage at a high angle to the original bedding, whereas the more competent arenaceous sediments have only been shattered. A well-defined flaser structure has developed in the argillaceous greywackes but, where there are finely interlaminated shales and greywackes, micaceous schistose rocks have resulted.

The original chemical and mineralogical composition of the Trinity Peninsula Series is revealed by the mineralogical reconstitution and textural changes in the varying contact metamorphic grades. The more siliceous sediments have only undergone recrystallisation, but the shales, which were originally rich in sericite and chlorite, have been transformed into a series of biotite-hornfelses, biotite-cordierite-hornfelses, chiastolite-cordierite-hornfelses and sillimanite-garnet-biotite-hornfelses. The development of pyroxene and the recrystallisation of plagioclase have been the normal course in the hornfelses derived from the more calcareous greywackes but in the non-calcareous alumina-rich greywackes biotite and andalusite have formed at a relatively early stage. Pre-contact metamorphic foliation due to cataclasis can be detected in most of the hornfelses.

In Trinity Peninsula where the thermal aureoles surrounding the intrusive diorites and granodiorites are easily accessible, late stage hydrothermal sulphide mineralisation followed by tourmalinisation and actinolitisation has been recorded in the surrounding sediments.

A superficial investigation of the geochemistry of the Trinity Peninsula Series reveals a far wider variation of chemical composition than previously supposed.

The Trinity Peninsula Series, which has been tentatively assigned to the Carboniferous on the palaeontological evidence, can probably be correlated on the close similarity in lithology and stratigraphy with the Greywacke-Shale Series of the South Orkney Islands and the Sandebugten Series of South Georgia.

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INTRODUCTION

FROM the existing field data which has been collected throughout the length of the Graham Land peninsula, the sedimentary *Trinity Peninsula Series*[1] together with its cataclastic and contact metamorphic equivalents is believed to have a fairly wide lateral distribution and extends between latitudes 63° S. and 75° S. These beds are confined particularly to the east coast of Graham Land and available information suggests that the main occurrences of this series are in Trinity Peninsula and Joinville Island, on the Nordenskjöld Coast and along the east coast of the peninsula from Three Slice Nunatak southward to Cape Adams, in which area it forms a marginal fringe to the main batholith of the Andean intrusives (Fig. 1). A preliminary examination of material collected by the British Graham Land Expedition (1934–7) from the Graham Coast indicates the presence of highly contorted and thermally metamorphosed greywacke facies sediments, which are the probable lateral equivalents of the Trinity Peninsula Series.

Greywackes, dark grey shales, conglomerates, grits, arkoses, quartzites and calcareous shales, together with rare argillaceous limestones, comprise this series, the total thickness of which is certainly in excess of 2000 ft.[2] Clay galls, mud pellets and ferruginous concretions are commonly found throughout the succession. A few plant remains, worm-casts and tracks together with doubtful fish scales have been recovered from the type area at Hope Bay. Because of the paucity of fossil evidence it has not been possible to determine the exact age of the Trinity Peninsula Series. As a result of his careful examination of the plant material, which is quite distinct from that of the overlying Mount Flora Middle Jurassic beds, the late Mr. W. N. Croft reached the conclusion that these beds could not be earlier than Carboniferous in age.[3] It is therefore justifiable to assign the Trinity Peninsula Series tentatively to the late Palaeozoic.

In the majority of localities where these beds have been examined they have been subjected to pre-Jurassic dynamic or cataclastic metamorphism, which has undoubtedly been responsible for the severe contortion and shearing observed throughout the succession. Superposed contact metamorphism of

[1] When originally described from Hope Bay by Nordenskjöld (1905) and Andersson (1906) these sediments were referred to as the "Greywacke-Shale Series", because summary investigation of the material collected from the type locality showed it to be a succession of interbedded greywackes (used in the widest sense) and dark grey shales. Recent field and laboratory evidence, which is given in this paper, indicates a certain degree of facies variation in these sediments. It is therefore proposed that the name of this sedimentary succession should be changed but that the type locality should be retained. Henceforth this series of late Palaeozoic sediments will be referred to as the *Trinity Peninsula Series*.

[2] The stratigraphy and lithology of the Trinity Peninsula Series will be described in a later report of this series.

[3] Personal communication.

varying grades has been recorded within the thermal aureoles of a number of stocks, bosses and batholiths, all of which form part of the Andean Granite–Gabbro Intrusive Suite (The Petrology of Graham Land: II).

In the course of his mapping in Trinity Peninsula during 1946 Croft considered that some of the unfossiliferous, *cherty* strata of the Tabarin Peninsula and Mount Bransfield areas were lithologically so strikingly distinct from the type locality Trinity Peninsula Series that he named them the "Taylor Peninsula Series".[1] However, the exact field relations between the "Taylor Peninsula Series" and the Trinity Peninsula Series and their respective ages were never precisely stated. It was generally believed that the "Taylor Peninsula Series" was older than the Trinity Peninsula Series.

Investigation of the rocks previously referred to the "Taylor Peninsula Series" was only along stratigraphical and lithological lines before the present petrographical examination was undertaken. Because of insufficient laboratory work, past investigators failed to recognise the contact metamorphic effects of the Andean Intrusive Suite, and this undoubtedly gave rise to the confusion and controversy over the stratigraphy of Trinity Peninsula itself and the east coast of Graham Land south of Three Slice Nunatak. Naturally, the question arose as to whether it was legitimate to establish a new stratigraphical division on the existing evidence. It was argued that the "Taylor Peninsula Series" could reasonably represent:

(1) A new hitherto unidentified stratigraphic unit;
(2) A lateral equivalent of the Middle Jurassic succession, similar to that recorded at Hope Bay and Church Point;
(3) The Trinity Peninsula Series.

Four separate areas of Trinity Peninsula can be considered to have a particular bearing upon this problem, namely, the Mount Bransfield and Hope Bay areas, Tabarin Peninsula and Church Point. At Mount Flora (Hope Bay) and Church Point, where almost identical vertical successions occur, the Trinity Peninsula Series is unconformably overlain by the unbroken sequence of Jurassic basal conglomerates, quartzites, shales, rhyolitic tuffs and agglomerates. The Middle Jurassic beds of Hope Bay and Church Point possess quite different lithological characters from those of the "Taylor Peninsula Series" and are plant-bearing throughout the greater part of the succession below the rhyolitic tuffs and agglomerates, whereas the "Taylor Peninsula Series" is apparently barren of plant material.

North-west of Mount Bransfield the Trinity Peninsula Series is folded about north-north-east to south-south-west axes, and the "Taylor Peninsula Series", following the same structure, crops out along a synclinal axis, which could possibly be regarded as evidence of their being younger than the Trinity Peninsula Series. Though it is conceivable there may be a *disconformity* between the two stratigraphic units, no *unconformity* or *structural discontinuity* has ever been observed. It is, however, significant that in each area, where the "Taylor Peninsula Series" has been recorded, granitic and dioritic intrusions either pierce these sediments directly or occur in the immediate vicinity.

In Tabarin Peninsula both synclinal and anticlinal fold axes affect the succession. If the Trinity Peninsula Series is older than the "Taylor Peninsula Series", it would therefore be reasonable to expect the former to crop out along the crests of the eroded anticlines, as, for instance, at Cairn Hill or Ridge Peak (Fig. 2), but according to earlier mapping and interpretation this is not so.

From lithological considerations alone, Knowles (1945, p. 145) believed that the slates of the southern part of the Graham Land east coast should be correlated with the Hope Bay Mesozoic strata. He readily admits the complete absence of plant material, the abundant presence of which characterises the Hope Bay Middle Jurassic beds and the recently discovered Upper Jurassic sediments of Alexander Land. Unfortunately, Knowles does not discuss the significance of the arkoses and greywackes which are interbedded with the slates. On the basis of new evidence it is now possible to correlate this east coast succession with the Trinity Peninsula Series of the type area.

By means of a comprehensive petrographical study of the resultant metamorphics it is possible to achieve a greater understanding of their original nature. It is therefore proposed to review the metamorphic rocks of the Trinity Peninsula Series according to their original composition and in the three following areas:

A. Trinity Peninsula and the east coast of Graham Land north of Three Slice Nunatak.
B. East coast of Graham Land south of Three Slice Nunatak.
C. West coast of Graham Land.

[1] Named after Croft's type locality, "Taylor Peninsula", now renamed Tabarin Peninsula.

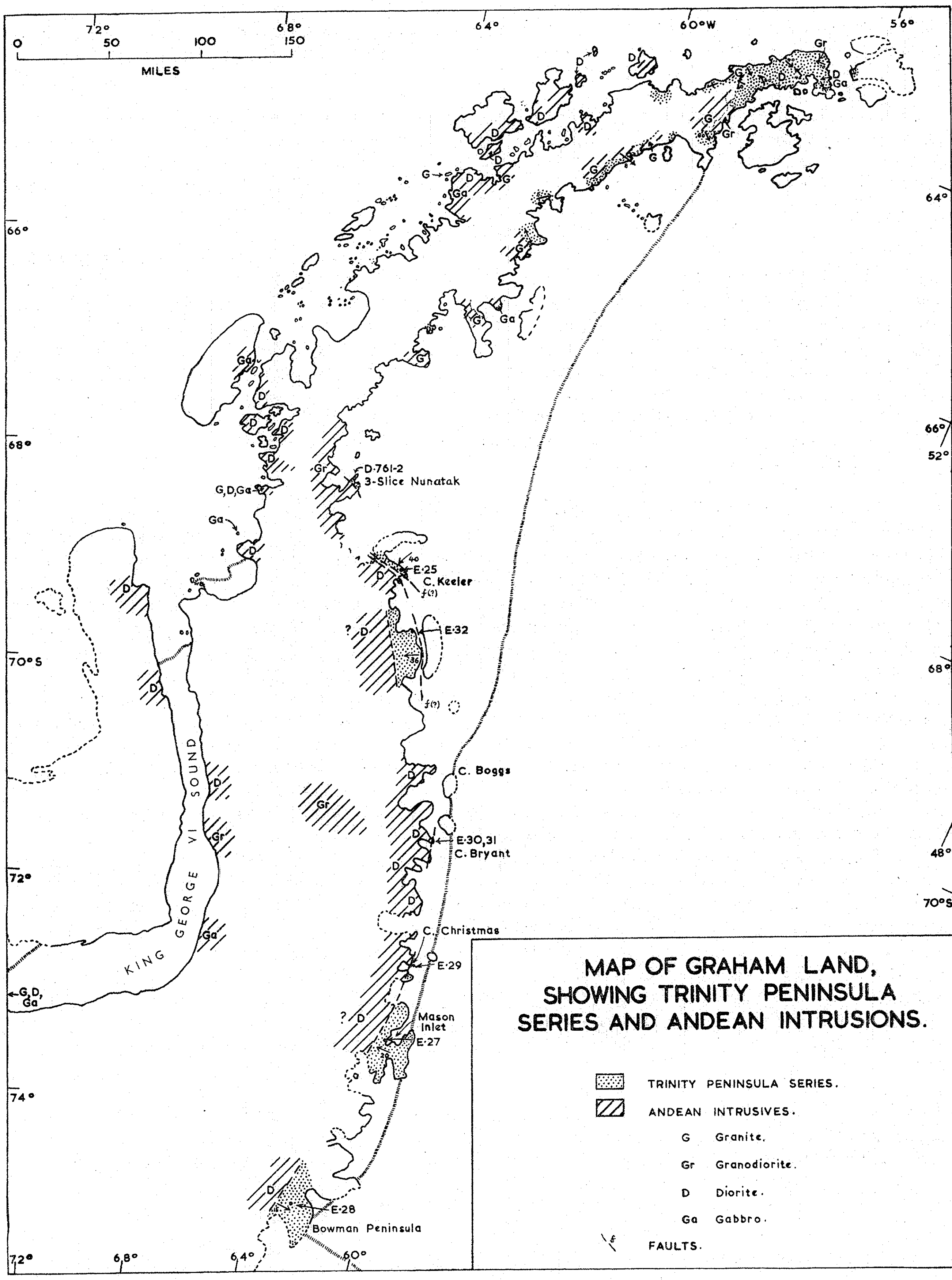

FIGURE 1

Map of Graham Land, showing the distribution of the Trinity Peninsula Series and the Andean intrusions.

The numbers given in the text in brackets, e.g. (D.47.4) and (E.25.4), refer to the official Station Lists of the Falkland Islands Dependencies Survey. The thin sections are housed in the Harker Collection, Mineralogy and Petrology Department, University of Cambridge.

The place-names used in this report will be found listed in the appendix together with the appropriate geographical positions. For further geographical information reference should be made to the series of topographical maps on scales 1/100,000, 1/200,000 and 1/500,000, which are described in the Falkland Islands Dependencies Survey Scientific Report No. 1.

A. TRINITY PENINSULA AND THE EAST COAST OF GRAHAM LAND NORTH OF THREE SLICE NUNATAK

THE Trinity Peninsula Series comprises the greater part of Trinity Peninsula and extends southward along the Nordenskjöld Coast. Between Cape Fairweather and Three Slice Nunatak only occasional outcrops have been observed in the coastal section. Though it is certain that at one time these sediments extended in a wider belt along this part of the coast, they have been almost entirely eroded away during the course of the formation of the 4000-ft. scarp along the plateau edge.

As in the coastal area south of Three Slice Nunatak, the Trinity Peninsula Series of north-eastern Graham Land shows a wide variation in grade and facies, comprising argillaceous to arenaceous types. Some of the sediments are extremely felspathic whereas others are undoubtedly the denudation products of more basic rocks.

In this area the Trinity Peninsula Series has suffered at least two stages of metamorphism: early dynamic or cataclastic metamorphism, followed by contact metamorphism by the intrusions of Andean affinity.

At present the age of the cataclastic process is not easy to define and no evidence has been put forward to prove conclusively whether it took place in pre- or post-Jurassic times. The Jurassic sediments of Hope Bay and Church Point have been gently folded, folding which is assumed to have been associated with the late Cretaceous/early Tertiary Andean foldings. In contrast with the later foldings, the degree of cataclasis suffered by the Trinity Peninsula Series is severe. In places brecciation accompanied by faulting and thrusting on a large scale has occurred. Because of their closer proximity to the Andean intrusive bodies, the degree of cataclastic metamorphism would certainly be higher than that of the Jurassic sediments. On the other hand, it is clear that cataclasis took place prior to contact metamorphism, which is directly attributable to the Andean intrusives themselves. Therefore, from both the field and laboratory evidence it would appear that the major cataclastic deformation of the Trinity Peninsula Series took place in pre-Jurassic times.

Although the majority of the late Palaeozoic sediments of Trinity Peninsula have undergone either cataclasis or contact metamorphism or a combination of the two, there are some which appear to have been relatively unaffected. Nearly all of these occur in the immediate vicinity of Hope Bay and Mount Reece where brecciation and quartz-veining of the sediments is common.

Close to the former base hut at Hope Bay coarse greywacke-conglomerates crop out. In the hand-specimen they appear to be made up almost entirely of 1–2 cm. angular to subangular fragments of slate and greywacke, arkose and vein-quartz set in a fine-grained argillaceous matrix. However, closer examination under the microscope reveals that in the finer material comprising the conglomerate there are fragments of felsite, andesite, rhyolite, quartzite, limestone, red jasper and mica-schist in addition to the rock types already mentioned. There is a general tendency towards an acid to intermediate rather than a basic assemblage in the individual detrital fragments. Often quite large angular and abraded brown tourmalines, sphenes and zircons are found in addition to foxy red-brown biotite flakes (with bent cleavage) and iron ore. There is a relatively large amount of finely granular magnetite in the matrix which also contains an abundance of sericite and chlorite.

The finer grades of the arenaceous rocks comprise mainly felspathic sandstones containing a relatively high percentage of detrital iron ore and large muscovites. The plagioclase is usually oligoclase, whereas the potash-felspar is *always* orthoclase and *never* microcline. The unmetamorphosed sediments of the Mount Bransfield area are mostly sub-greywackes of small grain-size. In thin section the larger subangular fragments are of andesine, quartz and orthoclase set in a matrix of sericite, chlorite and other material too fine-grained for identification. Detrital zircon, sphene, green-brown tourmaline and magnetite are common. Small grains of felsite have also been recorded from these sediments.

The argillaceous sediments are represented solely by very fine-grained shales throughout which quite a large amount of iron ore is disseminated.

1. Cataclastic Metamorphism

Where the Trinity Peninsula Series lies outside the thermal aureoles of the Andean intrusives it is usually cataclastically deformed. Any foliation acquired by these sediments during such deformation is often detectable in the hornfelses resulting from superposed contact metamorphism. Palimpsest structures have been noted in a number of the specimens examined in thin section.

(*i*) *Argillaceous Sediments*

In all the localities where great thicknesses of argillaceous sediments have been recorded the effect of dynamic metamorphism has only been the production of a false cleavage, which is sometimes superimposed directly on the original bedding cleavage. As at The Pyramid, Hope Bay (D.52) and Three Slice Nunatak (D.761), it is more often the case that the false cleavage is at an angle of 45° to 60° to the true bedding. They have been converted into highly fissile slates and are identical to those of the east coast south of Three Slice Nunatak. Some of the slates of the Mount Bransfield area (D.377) are considerably coarser in grain-size than those of The Pyramid. They show a distinct false cleavage superposed on the original bedding. It is quite common in the coarser grades to find that they have also undergone a certain amount of fracturing, along the planes of which narrow quartz veins have emplaced themselves. Flaser structures are not uncommon in the sediments that have been excessively sheared. Occasional calcite veins have been recorded in the View Point and Chapel Hill areas.

In thin section the slates are very fine-grained, being composed mainly of sericitic and chloritic material, a little iron ore and a fair amount of carbonaceous matter (see Table II), which now appears as graphite (D.761.1). The coarser grades of the Mount Bransfield area show quite a large amount of lenticular quartz, detrital rutile, zircon and hematite. Most of the sericite has recrystallised as larger flakes of muscovite.

In some localities where there is a succession of shales interlaminated with quartzites, for instance, the Mount Reece (D.374) and East Russell Glacier areas, the end-products of cataclasis are of interest. In each case examined the argillaceous component has been converted almost entirely to a fibrous intergrowth of quartz, muscovite and iron ore, with a distinct false cleavage (Plate I a). The arenaceous component, which is more competent, has suffered shattering but no mineralogical change. In the succeeding argillaceous bands the false cleavage is continuous whereas fractures in the quartzites are absolutely local and do not transgress from one band into another. These rocks could well be referred to as *quartz-muscovite-schists*.[1]

(*ii*) *Arenaceous Sediments*

Throughout Trinity Peninsula and along the Nordenskjöld Coast, the arenaceous sediments of the Trinity Peninsula Series range in composition from pure siliceous sandstones to relatively basic greywackes. Some of the greywackes are semi-argillaceous, whereas others are calcareous. However, the chemical composition of the arenaceous sediments plays no significant part in the end-products of cataclasis to which they have been subjected.

As in the area south of Three Slice Nunatak, the most common effect of dynamic metamorphism is the formation of sheared, almost schistose rocks from sediments possessing a relatively high initial proportion of argillaceous material. However, it is usual to find the more competent greywackes possessing a typical flaser structure (D.377); quartz grains have become elongated and are embedded in a finer-grained matrix consisting of sericite, iron ore and minute plagioclase felspar grains.

[1] These quartz-muscovite-schists should not be confused with those already described from the Basement Complex (The Petrology of Graham Land: I. The Basement Complex; Early Palaeozoic Plutonic and Volcanic Rocks, p. 5).

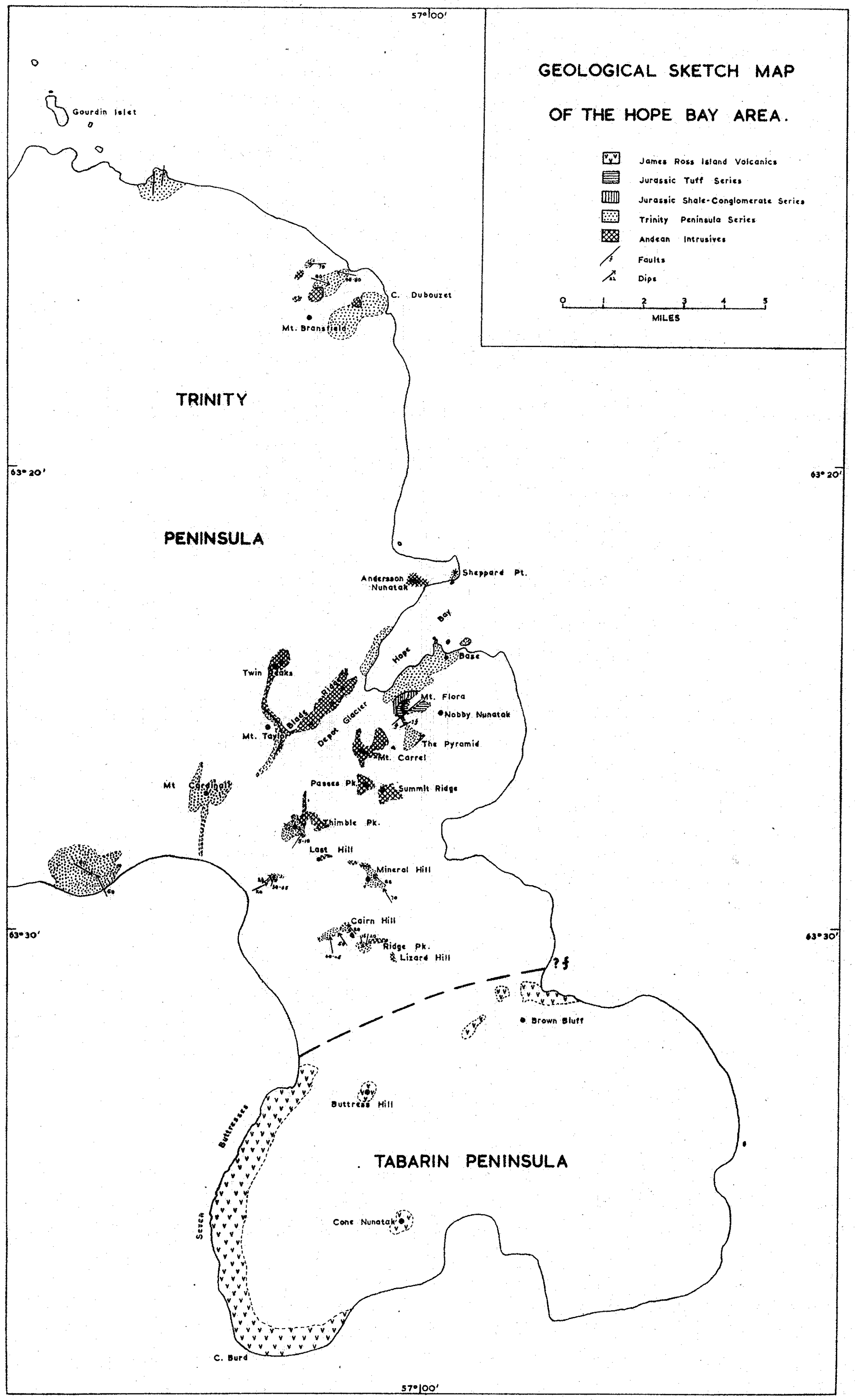

FIGURE 2
Geological sketch map of the Hope Bay area.

A higher grade of metamorphism produces more marked shearing effects and the rock is transformed into a fine-grained mylonite in which it is not easy to distinguish any of the original mineral components. In the coarser grades of the arenaceous sediments, such as the greywacke-conglomerates of the Hope Bay area (D.9), there has been a certain amount of shearing, but it is confined entirely to the finer interstitial material. Angular quartz and plagioclase fragments are certainly elongated but not to the same degree as in the rocks showing flaser structure. It might well be called "interstitial mylonitisation" in the case of the coarser greywacke-conglomerates.

Some of the sediments, which have undergone a relatively lower grade of cataclasis, exhibit quite large flakes of muscovite growing from the original detrital, finer-grained sericitic material. Chlorite and magnetite still remain, although there has been slight alteration to limonite in the latter. There is no other mineralogical change.

Great thicknesses of greywackes interbedded with purer siliceous sediments (Chapel Hill and the area north-north-west of Crystal Hill) have been subjected to small-scale shearing, also brecciation and faulting. In particular, the purer siliceous sandstones have been most affected in the latter way. Quartz veins, filling earlier fractures, ramify through the sediments over wide areas and it is difficult to distinguish them from some of the quartz-cemented conglomerates, except that the angular fragments are all of the same material.

Large-scale faulting is difficult to determine in the field on account of the heavily glaciated nature of the country. There can be no doubt that it has occurred because it can be demonstrated that there is relative displacement of "marker" horizons in the sedimentary succession.

2. Contact Metamorphism

The rocks of the Hope Bay area which are now known to be the result of contact metamorphism were first described by Nordenskjöld (1905) as "schwarzes, dichtes sedimentgestein". To this field description he added:

> Isoliert kommt in einem Nunatak am westlichen Ufer der Bucht eine dichte schwarze Varietat vor, die u.d.M. fast phyllitisch aussieht; es ist aber kein Schiefer, und das Aussehen kann vielleicht am besten als adinolähnlich bezeichnet werden.

Recent field mapping has shown that Nordenskjöld's description refers to the rocks which lie very close to the observed contact with the Blade Ridge quartz-diorite intrusive mass (Figs. 1 and 2). Since the discovery of these contact metamorphosed rocks, many more localities have been investigated in Tabarin Peninsula, the Mount Bransfield area and the southern part of Trinity Peninsula.

(*i*) *Argillaceous Sediments*

In spite of the frequent lack of good exposures along the contacts between the sediments and the intrusive diorites, it has been possible to obtain a representative selection of material from this area to illustrate the progression of contact metamorphism from near the contact to the outer limit of the thermal aureole, where slates alone appear.

In the early stages of thermal metamorphism it is possible to differentiate between the more aluminous sediments and those relatively richer in silica. Nearly all these sediments contain a significant amount of carbonaceous matter.

The first stage in the thermal metamorphism of the more aluminous, sericite- and kaolin-rich types is the appearance of small spots from which detrital iron ore is being ejected and around which fine biotite is being formed (D.361.1). In the succeeding stage the spots extend their size and become clearly outlined by aggregates of red-brown biotite (D.702.2; Plate Ib). Where iron ore is in abundance biotite formation appears to be more advanced. Now, it is clear these spots are cordierite which still contains quartz grains not yet consumed by chemical reaction. Complete mineralogical reconstitution is reserved for a further stage, in which embryonic chiastolite idioblasts begin to form and the cordierite patches are cleared of inclusions. The next phase is comparable to that of Station E.28 (Fig. 1), where the chiastolites have grown to a considerable size and possess marked iron ore rims (Fig. 3; Plate IIb). Complete idioblasts of chiastolite have not been seen anywhere.

Apparently the grade of contact metamorphism within diorite thermal aureoles seldom reaches a stage higher than that described; only in one instance has sillimanite and garnet been observed (see Section B, p. 14). In the Trinity Peninsula area the chiastolite-cordierite-hornfels stage is the highest recorded.

The argillaceous sediments with a lower alumina and higher silica content than those already described have a different early change in mineralogical composition and lack marked "spotting". A factor which may be of some significance in the progress of thermal metamorphism is the nature of the original micaceous material. In this group of shales, chlorite predominates over sericite and kaolinic matter, both of which are abundant in the first-mentioned group. Iron ore is also more common.

In the lowest grade of contact metamorphism, the chloritic shales begin to show cryptocrystalline aggregates of a greenish (probable magnesian) biotite around the iron ore patches. This is succeeded by the development of a fine-grained hornfelsic texture with an increase in granularity (D.66.3, Ridge Peak). The biotites now show quite distinctly a pleochroism scheme α = yellow-green to greenish yellow-brown and $\beta = \gamma$ = deep green-brown. The amount of iron ore tends to decrease, due probably to its adsorption into the biotite. Spotting does not seem to appear as readily as in the more aluminous sediments.

With an increasing grade the biotites lose their former greenish colour and γ = foxy red-brown (D.60.1). It is at this stage that cordierite makes its presence obvious in irregular ovoid patches, biotite starts to form poeciloblasts with quartz and iron ore inclusions, and plagioclase and quartz recrystallise. Any iron ore not hitherto consumed in the mineralogical reconstitution of the rock recrystallises in some of the biotitic aggregates as granular masses. Lenticular graphitic bodies within the hornfels are common at this stage. These are biotite-cordierite-hornfelses, the highest grade at which these metamorphics have been observed. Perhaps this is only *apparent*, because in the higher grades it is difficult to differentiate between the two original types of sediment that are discussed here.

It may be argued that the early production of greenish biotites is associated with incipient regional rather than early contact metamorphism. However, it can be shown that green biotite does not appear in the argillaceous sediments subjected to low-grade dynamic metamorphism outside thermal aureoles of this area.

Calc-argillaceous sediments are rare in the Trinity Peninsula Series, though thin calcite-rich bands have been observed. These bands were undoubtedly relatively rich in chlorite as well as calcite, since in the later stages of low-grade thermal metamorphism lenticular masses of pale hornblende appear throughout the rock where chlorite was formerly present (D.56.3, Mineral Hill). Calcite generally remains unchanged until a late stage, except in the immediate proximity of quartz veins where coarse marginal intergrowths of hornblende are common products.

Highly ferruginous bands occur within the argillaceous sediments. Here there is no change in mineralogical composition but there is entire recrystallisation of magnetite and quartz in a granoblastic mosaic.

(*ii*) *Siliceous Sandstones*

The purer siliceous sandstones which contain only a little micaceous material but some iron ore show no marked mineralogical reconstitution. The only effect is complete recrystallisation of the quartz and the iron ore (magnetite). The rock may then be considered as a ferruginous quartzite comparable with those north-north-west of Crystal Hill (D.705.4). The latter quartzites show a superficial reddish coloration due to hematite formation as a result of weathering.

(*iii*) *Calc-argillaceous Greywackes*

Among the sediments comprising the Trinity Peninsula Series the calc-argillaceous greywackes are certainly the commonest. It is seldom that they have been found in a low metamorphic grade. Their original composition was probably close to that of the calc-argillaceous sediments, though the silica content was undoubtedly higher. Unlike the purer calc-argillaceous types, the usual end-product at a medium stage of contact metamorphism is a diopsidic augite which forms a granular mass throughout the matrix of the rock (D.66.3). Some of the original subangular quartz has remained, though generally both quartz and plagioclase (andesine-labradorite) have recrystallised. Excess calcite seldom remains in the matrix; nevertheless, a certain amount of iron ore speckles the hornfels. These metamorphics may be referred to as pyroxene-quartz-plagioclase-hornfelses, closely comparable with those of the Cape Bryant area (E.31; cf. Plate IIc).

(*iv*) *Hydrothermal Iron Pyrites and Copper Pyrites*

Sulphides of iron and copper occur in small veinlets traversing the contact metamorphic rocks of Tabarin Peninsula, particularly at Mineral Hill and Cairn Hill. They do not appear to be intimately related to tourmalinisation or the introduction of actinolite as veinlets. Both the veins and disseminated pyritic masses in the hornfelses are clearly associated with the quartz-diorite intrusions, whereas tourmalinisation is of a later stage because the tourmaline veins traverse the pyritic veins. Copper pyrites veins have been traced from the hornfelses into the dioritic masses themselves.

(*v*) *Tourmalinisation*

Though tourmalinisation is generally associated with the late stages of a granitic environment, in the Tabarin Peninsula area this process, which has more especially affected the argillaceous sediments, is associated with the late magmatic stages of the intrusion of quartz-diorites of Andean affinity. At Mineral Hill (D.56) the shattered sediments of the Trinity Peninsula Series are traversed by tourmaline veins up to one inch in width. These veins are composed essentially of tourmaline with pleochroism ε = deep pink and ω = olive green. The refractive indices are $\varepsilon = 1.636$ and $\omega = 1.670$ with $\omega - \varepsilon = 0.034$. In composition this tourmaline is a fairly pure schorlite, which forms a coarse prismatic intergrowth in the veinlets. A colourless fibrous amphibole near tremolite in composition and calcite are interstitial and form a considerably smaller proportion of the veins. Sometimes there is a little iron pyrites associated.

In the surrounding sediments tourmalinisation has proceeded with less vigour and is confined to the more argillaceous bands, where green tourmaline has partially replaced contact metamorphic biotite in small granular masses. The more siliceous bands are free from the attack of tourmalinisation and the hornfelsic texture of the rock has been wholly preserved.

The rocks resulting from such a process are comparable with the "cornubianites" of Cornwall, where argillaceous slates have been tourmalinised by intrusive granites. Here, also, the original structure of the rocks is preserved.

Tourmalinisation of the metamorphic rocks of Tabarin Peninsula, although apparently associated with the quartz-diorites, as shown by field data, may conceivably be associated with later granitic rocks not yet exposed in the area.

(*vi*) *Actinolite Veins*

In close association with the tourmaline veins of Mineral Hill (D.56) there are also veins composed essentially of actinolite at the margin but largely consisting of oligoclase-albite towards the centre (D.56.2). In some of the veins of the Mineral Hill area there is a small amount of tourmaline, which is the same as that described above. A little iron pyrites, calcite and quartz are associated. Generally, the actinolite occurs in a felted aggregate with no interstitial material, but in some of the veins at Mineral Hill, where there is a less well-defined marginal contact and where the surrounding country rocks are fairly pure quartzites, large poecilitic amphiboles of a similar composition to the actinolite have formed (D.47.4). They show a typical "feather structure" with small inclusions of dusty quartz. There is a little accessory iron ore in the form of magnetite. With the exception of the scattered amphibole, these rocks are in every respect the same as the nearby quartzites which have resulted from thermal metamorphism of pure siliceous sediments. It is clear that these local "feather-amphibolites" are not to be compared with the products of regional metamorphism of slightly calcareous grits, since they contain very little or no plagioclase felspar in the granoblastic groundmass.

TABLE I

SUMMARY OF CONTACT METAMORPHISM OF THE TRINITY PENINSULA SERIES*

Grade of Contact Metamorphism	Argillaceous Sediments	Argillaceous Greywackes	Arkoses (Calcareous)	Calc-argillaceous Greywackes	Calcareous Greywackes and Greywackes	Calcite- and Quartz-veined Greywackes	Quartzites
Unaltered	E.25.4 D.36.4	D.377.3	D.359		D.377.3		D.66
Low Grade	D.361.1 D.702.2 (biotite-cordierite-hornfels) D.66.3 (green biotites) D.60.1		E.27.2	D.56.3 (hornblende)	E.27.2	E.27.1	
Low to Medium Grade	E.28.1 (chiastolite-cordierite-hornfels)				E.28.3 (biotite-cordierite-hornfels) E.32.1 (augite)	E.32.3 (pyroxene and amphibole reaction zones)	D.359.2 D.66.2 D.705.4 D.54.1
Medium Grade	E.28.1			D.66.3 (augite)	E.31.1 E.31.3 (augite)		
High Grade	E.29.7	E.29.7 (sillimanite-garnet-biotite-hornfels)					
Tourmalinisation	D.56.1						
Actinolite	D.56.2 D.359.6	D.359.6	D.66.1				D.54.1 D.47.4

* In this table only the type specimen numbers are given.

D.36.4	Scar Hills, Hope Bay
D.47.4	SW. spur, Mineral Hill
D.54.1	SE. side, Mineral Hill
D.56.1, D.56.2, D.56.3	North slope, Mineral Hill
D.60.1	NE. spur, Cairn Hill
D.66, D.66.1, D.66.2, D.66.3	West spur, Ridge Peak
D.359, D.359.2, D.359.6	Mount Bransfield
D.361.1	Mount Bransfield
D.377.3	Mount Reece
D.702.2	Base of east cliffs, Crystal Hill
D.705.4	Mountain NNW. of Crystal Hill
E.25.4	Cape Keeler
E.27.1, E.27.2	Mason Inlet
E.28.1, E.28.3	Bowman Peninsula
E.29.7	Cape Christmas
E.31.1, E.31.3	Cape Bryant
E.32.1, E.32.3	Cape Rymill

The proportions of iron pyrites in the actinolite veins varies widely from one locality to another. Often veins composed entirely of iron pyrites and actinolite cut through the fractured quartzites (D.54.1). Here small cubes of pyrites are disseminated throughout the granoblastic quartz mosaic. The accessory minerals include magnetite.

In the Mount Bransfield area (D.359) the biotite-cordierite-hornfelses are also traversed by actinolite veins containing a little calcite, but tourmaline is notably absent. In all these occurrences the actinolite is confined to the vein itself and is seldom found disseminated throughout the main body of the hornfels.

In the cases already discussed the introduction of actinolite is confined particularly to sediments with an original high silica content. However, where more calcareous sediments of the Trinity Peninsula Series are invaded by multitudes of actinolite veinlets, as for instance at Ridge Peak (D.66), reaction is more vigorous, resulting in "skarn-like" rocks. In thin section the rocks in the immediate vicinity of the actinolite veins show considerable mineralogical changes. They can be referred to as grossular-actinolite rocks consisting of an abundance of perfectly idioblastic grossular crystals set in a finely felted actinolite matrix. Xenoblastic idocrase and a little basic plagioclase are occasionally present. Where actinolite has not formed the matrix, original calcite has remained. Quartz is markedly absent.

The Ridge Peak calcareous sediments were undoubtedly hornfelsed at an earlier stage than the invasion of the actinolite, because the porphyroblastic texture has remained.

The introduction of tourmaline, iron pyrites and actinolite is associated with a late stage pneumatolytic process involving the distribution of boron and iron. Metasomatism of the already hornfelsed sediments by late percolating alkaline solutions is not recognisable in this area.

B. EAST COAST OF GRAHAM LAND SOUTH OF THREE SLICE NUNATAK

UNTIL 1940 nothing was known about the geology of the southern part of the east coast of Graham Land. Knowles (1945, p. 134 and 139), geologist to the United States Antarctic Service Expedition 1939–41, first described the geology of the east coast south of Mobiloil Inlet as follows:

> Metamorphic rocks outcrop in well-defined formations along the Weddell Coast,[1] extending south from Fleming Glacier[2] at least 90 miles. Slate, with well-developed cleavage and some concretions predominates; its composition and texture vary to a small degree.
>
> South of Cape Eielson[3] the rock cliffs have a massive igneous appearance, and at latitude 71°40′ South, longitude 60° 50′ West, a grey coarse-grained quartz-biotite-diorite forms cliffs 150 to 250 feet in height.

Knowles (1945, p. 140) examined both the slates and diorites microscopically and observed "a small amount of andalusite, which is contiguous with the deposition of quartz" in the former. No further precise or relevant comments were made concerning the degree or nature of the metamorphism which had obviously taken place. Cataclastic metamorphism was suggested in order to account for the west to east overthrusting of the Alexander Land sediments and the prominent three-dimensional cleavage in the east coast slates, but no suggestion of possible contact metamorphism was made in spite of the statement concerning the presence of andalusite in the slates.

From this time until the summer of 1947–8, when a major journey was undertaken by Butler and Mason (Falkland Islands Dependencies Survey) together with Smith and Owen (Ronne Antarctic Research Expedition, 1946–8), no further exploratory sledge journeys were made down this coast. During this latter journey Mason (1950) made a few observations on the geology and he was able to collect specimens at a number of localities. A cursory glance at this material immediately reveals that the Trinity Peninsula Series,

[1] The Bowman and Wilkins Coasts.

[2] Now called Trail Inlet.

[3] Now called Eielson Peninsula.

so well known from the Trinity Peninsula area, recurs here and is represented not only by sheared greywackes and arkoses but also by a series of secondarily contact metamorphosed rocks of various grades.

Marginal to the main granodiorite and diorite batholiths, which form the core of the mainland along this coast, interbedded arkoses, greywackes, sub-greywackes, quartzites and shales (calcareous and aluminous) occur over about 200 miles of coastline. These sediments are lithologically similar to the Trinity Peninsula Series of Trinity Peninsula and the King Oscar II Coast and they would seem to represent a southerly continuation of the same series. In this area, however, both cataclastic and thermal metamorphic effects have been responsible for extensive mineralogical and structural changes in these rocks.

A study of these specimens (E.25, E.27 to E.32) and those collected farther north between Hope Bay and Three Slice Nunatak clearly reveals the structural, textural and mineralogical changes in both the greywackes and shales, ranging from the diorite contact to the outermost zones of the thermal aureole where cataclastically metamorphosed sediments alone are present. This systematic study of the contact metamorphism of these earlier dynamically altered sediments throws new light on the hitherto unsuspected widespread nature of contact metamorphic aureoles in this area.

In Fig. 1 the distribution of the Trinity Peninsula Series in relation to the Andean intrusives is illustrated. The contacts shown in this text-figure may not be accurately determined because of the very small scale of the map.

1. Cataclastic Metamorphism

In the most easterly capes and peninsulas of this coast only the shales are cataclastically metamorphosed, being transformed into highly fissile slates with two, or sometimes three, major cleavage directions of a slip-strain type. On the other hand, the more competent greywackes have often merely suffered fracturing, which is now represented by a host of quartz and calcite veins traversing these rocks.

(*i*) *Sheared Greywackes*

Sometimes the greywackes have been transformed by low-grade metamorphism into schistose rocks of the type E.27.2, having a marked cleavage and a certain degree of shearing. There are no apparent mineralogical changes, though in comparison with other greywackes this type is richer in calcite (probably secondary, partially replacing plagioclase) and deficient in plagioclase. In this respect it therefore seems preferable to classify this group of sediments as *sub-greywackes* and not true greywackes (Pettijohn, 1949, pp. 247–61; diagram on p. 251).

Interstitial sericite and chlorite together with some iron pyrites, altered in part to limonite, comprise at least 25% of the whole rock. Angular to subangular quartz and felspar, which are the principal constituents, have undergone a certain degree of elongation perpendicular to the compression direction, imparting to the rock a flaser structure (Plate IIa). Some of the minute interstitial sericite flakes have recrystallised to form larger muscovites but there is no evidence of either of the following reactions:

$$\text{chlorite} + \text{sericite} \rightarrow \text{biotite}, \textit{ or}$$
$$\text{calcite} + \text{sericite} + \text{chlorite} \rightarrow \text{augite}.$$

It is therefore to be inferred that these greywackes have not suffered contact metamorphism.

Higher up in the succession at Station E.27 very fine-grained, more indurated greywackes make their appearance. These rocks are distinct from the lower types in that they are now represented by chlorite-sericite-calcite-rich rocks, which are heavily quartz- and calcite-veined. Incipient contact metamorphism is apparent, because throughout the rock quartz has already partially recrystallised into a mosaic, while sericite has begun to form larger composite muscovite flakes. Even so, the grade of thermal metamorphism is still very low, because widespread reaction between the abundant calcite, sericite and chlorite (see above) has not yet commenced except adjacent to the calcite veins, where chlorite itself forms in a reaction zone between the greywacke and the veinlet.

(*ii*) *Slates*

Associated slates (E.27.4), which occur lower down in the succession, are unaltered by contact metamorphism, and lie outside the thermal aureole at this place, since they retain the marked three-directional slaty cleavage induced by earlier dynamic metamorphism. They are extremely fine-grained and there is definitely no sign of spotting, which is so typical of early contact metamorphism in the Hope Bay area.

2. Contact Metamorphism

(i) *Argillaceous Sediments*

Adjacent to the diorite intrusions the slates have suffered quite extensive mineralogical alteration. The highest grade of metamorphism is represented by a hornfelsic rock (E.29.7), which contains fine sillimanite needles, garnet and biotite. Secondary sericitisation of the potash-felspar is a common feature. More generally only a lower grade of metamorphism has been attained in the slates, which are now represented by rocks of the type E.28.1 (chiastolite-cordierite-hornfelses), where chiastolite forms incomplete idioblasts but cordierite only makes its appearance as ill-defined ovoid, inclusion-filled patches. Quite often it shows good sector twinning, accompanied by the symmetrical arrangement of inclusions. This cordierite is biaxial negative with a large optic axial angle. It is colourless, has a low birefringence and possesses no obvious pleochroism.

As has already been described from the Trinity Peninsula area, the earlier developed biotite has already been absorbed by or ejected from the cordierite patches but finely crystalline iron ore remains. More usually the chiastolite appears as incomplete idioblastic forms represented by crosses (Fig. 3, Plate II b) up to 0.7 mm. across. This would seem to indicate that although the original sediment was of a chlorite-kaolin-rich composition, the metamorphic grade is still relatively low. Chiastolite frequently develops in well-defined idioblasts in close association with the cordierite patches, though both of these minerals are readily distinguishable by their relative reliefs.

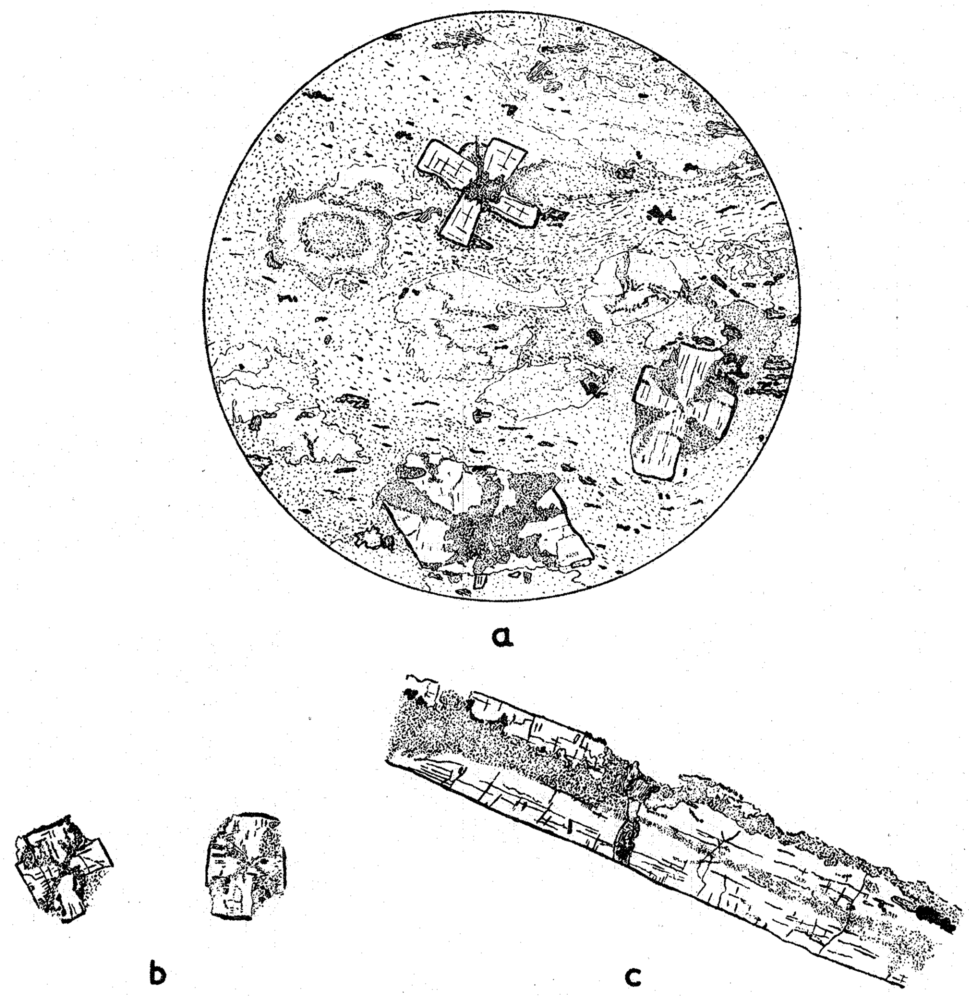

FIGURE 3

(a) Chiastolite-cordierite-hornfels with incomplete idioblasts of chiastolite and cordierites containing dusty inclusions. (b) and (c) Cross- and longitudinal-sections of chiastolites showing the distribution of inclusions and sericite veining; Bowman Peninsula (E.28.1; ordinary light; ×30).

The biotites seldom exceed a length of 0.15 mm., and are developed with their length parallel to the main cleavage direction of the rock. Their pleochroism scheme is α = colourless to pale yellow-brown, and $\beta = \gamma$ = deep golden brown. Quite often the biotite forms small segregations associated with iron ore and sometimes graphite (see Table II) marginal to the chiastolites.

Small veinlets traversing the chiastolite prisms, some of which are 3.1 mm. in length, are composed of an intergrowth of sericitic mica (muscovite) and quartz, together with a little magnetite. These clearly belong to a later stage than the contact effects responsible for the production of the chiastolite. Bands originally rich in iron ore have suffered little alteration apart from recrystallisation. In some cases where chiastolite has formed, iron ore inclusions have been thrown out to the margins of the crystals.

It is questionable whether the original iron ore has remained as iron pyrites or has since been reconstituted as pyrrhotite as observed by Neuman (1950) in the thermal aureole of the Ballachulish granite.

Nearly all detrital plagioclase felspar (oligoclase-andesine) has disappeared but original quartz has recrystallised *in situ*. In places the original minute sericite flakes have recrystallised to produce larger muscovites, but usually it has been removed in the formation of other minerals.

In the lower grades of contact metamorphism mineralogical changes are not very marked but the early development of a characteristic hornfelsic texture is always noticeable.

(*ii*) *Argillaceous Greywackes* (*non-calcareous and rich in alumina*)

At several localities, such as Cape Christmas (E.29), where the intrusive diorite is directly in contact with the Trinity Peninsula Series, a medium to high grade of thermal metamorphism is observed. Here the original rocks had a chemical composition comparable to that of argillo-arenaceous greywackes and the subsequent change in mineralogical composition has followed a corresponding course. Apparently, quartz was far in excess of plagioclase felspar ($Ab_{64}An_{36}$), whereas the interstitial argillaceous material was somewhat deficient in chlorite but rich in clay material, i.e. relatively high in alumina.

This type, represented by E.29.7, is fine- to medium-grained with a marked hornfelsic texture, and possesses a certain degree of relict mineral parallelism due to earlier cataclastic metamorphism. Original quartz and plagioclase felspar have undoubtedly recrystallised in their former positions with little marginal change. Biotite, with a pleochroism scheme α = pale straw and $\beta = \gamma$ = foxy red-brown, has frequently attained a poecilitic texture and quartz has become occluded in the interstitial growth of the biotite. Not at all infrequently muscovite is present marginal to the biotite. Idioblastic andalusite occurs in some bands throughout the rock where the alumina content was undoubtedly higher. It usually has a pleochroism scheme α = pale pink, β = colourless and γ = colourless to pale green, though pleochroism is sometimes absent. Normally the optical orientation of the andalusite is continuous throughout the thin section as is shown by simultaneous extinction. *Cordierite is notably absent.*

In rare patches and bands a pale pink almandine garnet (cf. Harker, 1939, p. 54) has developed in small idioblasts up to 0.3 mm. in size. The accessories include zircon, apatite and iron ore (magnetite and iron pyrites), the latter usually altered to pseudomorphs of limonite. A little secondary chlorite is present.

Secondary sericite often occupies the position of the former interstitial argillaceous material. It has replaced either cordierite or more probably andalusite. In these rocks cordierite could have readily resulted from the reconstitution of the original chloritic aluminous groundmass, and in turn it could have given rise to sericite by a later hydrothermal alteration process. If the matrix of these sediments was particularly deficient in ferromagnesians such as chlorite, andalusite which is observed in other parts of the thin section would have crystallised in preference to cordierite. In the thin sections that have been examined sericite is seen to be replacing andalusite marginally and along cleavage planes. Even in the felted sericitic parts of the rock some small remnant grains are readily identifiable as andalusite. However, the present evidence seems to favour the latter alteration process.

The presence of garnet would at first appear anomalous in a contact metamorphic aureole of this type, since it is associated with regional rather than contact metamorphism, but Harker (1939, pp. 54 and 72) points out that this reaction may proceed under special conditions of chemical composition (i.e. when manganese is present). This mineral may also result under such conditions and when there is a certain degree of additional shearing stress. The refractive index of the garnet (1.815) indicates that it may be manganiferous in composition. Undoubtedly the garnet did *not* result from earlier regional metamorphism.

(iii) Calcareous Greywackes (including arkoses)

Within the major division of this succession there are more calcareous arkosic lenses, which have also undergone contact metamorphism similar to that of the greywackes already discussed. The calcareous greywackes are typified by the specimen E.31.3 from Cape Bryant.

These metamorphics are characterised by the predominance of a diopsidic augite which occurs as idioblasts throughout the coarse mosaic of quartz and basic plagioclase (Plate IIc). In ordinary light the augite is almost colourless and entirely devoid of pleochroism. It has an extinction angle, $\gamma : z = 42°$, and a 2V of approximately 55°. Lamellar twinning on (100) is a particularly common feature as is the (110) cleavage direction. Plagioclase, approximating to $Ab_{46}An_{54}$ in composition, has resulted from the re-crystallisation of the original detrital plagioclase of a similar composition. Both lamellar twinning and combined Carlsbad/albite twins are not at all infrequent.

In both the coarse- and fine-grained bands of these sediments, plagioclase and quartz are intergrown and contain numerous small inclusions. However, in the less felspathic (i.e. more siliceous) parts of the rock, where the texture is finer, the matrix quartz forms a poecilitic mosaic enclosing abundant inclusions of basic plagioclase and augite. Muscovite and biotite are notably absent, whereas detrital zircon and sphene still retain their former rounded sedimentary characteristics.

At Cape Bryant (E.30 and E.31) the grade of contact metamorphism is clearly higher than that recorded at Station E.28, where the muscovite-biotite stage is found in the greywackes. The Cape Bryant specimens lie closer to the diorite/Trinity Peninsula Series contact, but the chemical composition of the unaltered greywackes is somewhat different from Station E.28 (see Table II).

The appearance of diopsidic augite, rather than biotite and muscovite, suggests that the former sediments were considerably more calcareous in composition and deficient in detrital potash felspar, thus having a closer affinity to arkoses than to greywackes. This is well borne out by the chemical analyses (Table II). Also, iron ore and ferro-magnesians are almost entirely absent from these rocks.

The formation of the metamorphic augite may reasonably be accounted for by the following reaction:

$$\text{chlorite} + \text{calcite} + \text{quartz} \rightarrow \text{augite}.$$

Supposed pre-contact metamorphic quartz veins have totally recrystallised without any reaction with the surrounding sediments. Late secondary calcite veining is also common.

(iv) Greywackes

The low to medium grade of thermal metamorphism of the arenaceous greywackes is represented in this series by E.28.3. In close association and interbedded with the greywackes are argillaceous sediments, which are now represented by chiastolite-cordierite-hornfelses.

Evidence from localities farther north and more remote from the granodiorite and diorite intrusions reveals that the majority of the original greywackes should really be considered as felspathic sandstones, with an abundance of quartz, intermediate plagioclase (oligoclase-andesine), orthoclase, interstitial chlorite and sericite, and accessory iron ore (mostly magnetite) together with zircon. Limonite appears to be secondary, as is calcite when present as small veinlets traversing the sediments.

Unlike the argillaceous rocks, there appears to have been no marked reconstitution in the mineralogical composition of these greywackes. Original minute sericite flakes have recrystallised to give either large poecilitic muscovites or felted aggregates of muscovite intergrown with biotite. Chlorite has reacted with sericite and limonite to give a pale biotite with pleochroism α = pale greenish straw and $\beta = \gamma$ = red-brown. This biotite is limited to areas where chlorite predominated and now imparts to the rock a distinct banded appearance. The reaction may be represented thus:

$$\text{chlorite} + \text{sericite} + \text{limonite} \rightarrow \text{biotite}.$$

The major constituent, quartz, has recrystallised *in situ* as a fine mosaic but interstitial biotite still remains demarcating the former inter-granular boundaries. Small, dusty iron ore inclusions have usually been ejected from the quartz. The plagioclase, though relatively insignificant in this rock, has remained in its original state in spite of recrystallisation that could possibly have taken place. Accessory magnetite and zircon are also present in relatively large amounts, the latter in especially good unabraded crystals which have retained their pyramidal terminations.

Interbedded with the coarser greywackes and arkoses are more argillaceous or calcareous facies. These are much finer-grained in texture, and now exhibit a marked schistose structure with a foliation almost parallel to their original bedding planes. Contact metamorphism has almost destroyed the original calcite, kaolin and chloritic minerals, giving rise to metamorphic clino-pyroxenes in their place. It is, however, still possible to detect some of the earlier calcite, which occurs as small isolated patches scattered throughout the groundmass. This is probably excess calcite that has failed to enter into the new stable mineralogical assemblage of the rock.

In the case of the calcareous type (E.32.1) where there is excess original calcite the following reaction has taken place:

$$\text{chlorite} + \text{calcite} + \text{quartz} \rightarrow \text{augite},$$

and small aggregates of calcite have been left closely associated with the newly-formed clino-pyroxene. This particular rock was apparently deficient in clay minerals (kaolinite) otherwise epidote would undoubtedly have formed thus:

$$\text{kaolin} + \text{calcite} \rightarrow \text{epidote}.$$

This clino-pyroxene is an *augite* with extinction angle, $\gamma : z = 45°$, and a 2V approximately 60°.

From the above evidence it may be inferred that this rock was originally a fine-grained calcareous greywacke with an argillaceous matrix relatively rich in chlorite but deficient in clay material.

The coarser schistose calcareous greywackes, typified by E.27.2, show no later mineralogical reconstitution due to contact metamorphism.

The more argillaceous facies, rich in sericite and chlorite but deficient in calcite, reacts differently in this stage of contact metamorphism. Usually a biotite-cordierite-hornfels results.

The competent greywackes, which have been fractured in the earlier cataclastic process, usually exhibit quartz and calcite veining, but this is not so common among the argillaceous members of this series which have been plastically deformed. Later contact metamorphism of the calcite-veined rocks (E.32.3) produces some rather interesting reaction products marginal to the calcite veins, but the quartz vein margins remain unchanged mineralogically apart from later secondary alteration.

Away from the calcite veins no marked change has taken place other than recrystallisation of pale brown biotite aggregates from interstitial chlorite, sericite and iron ore, a little detrital sericite and chlorite remaining. Occasionally, where calcite was originally present, a pale green tremolitic amphibole has formed.

Along the margins of calcite veins a reaction zone up to 3 mm. in width is always present. In this zone both amphibole and pyroxene have developed in a fine felted intergrowth, the former in pale green fibrous crystals and the latter as squat prismatic forms of higher refractive index. The amphibole, with faint pleochroism α = colourless, β = pale yellow-green and γ = pale bluish-green, has an extinction angle, $\gamma : z = 12–15°$, a positive elongation and a 2V of approximately 80°. From the optical data it would appear that this is an amphibole intermediate between tremolite and actinolite in composition.

The colourless pyroxene forming the coarser prismatic crystals has an extinction angle, $\gamma : z = 48°$, and a 2V approximately 50–60°. This is an augite close to the hedenbergite end of the diopside-hedenbergite series.

Sometimes fine fibrous aggregates of chlorite are associated with quartz veins, though occasionally amphibole aggregates are also present. Pyroxene is *never* present here but only along the margins of calcite veinlets.

At first it may seem anomalous to have both amphibole and pyroxene occurring in close association as in the present case. Two possible explanations of their origin present themselves:

(1) That the tremolite-actinolite amphibole is a secondary product derived by hydrothermal alteration of augite;

(2) That both amphibole and pyroxene were formed almost contemporaneously, under very similar conditions but with a deficiency of lime.

The rare presence of greenish tinges of amphibole along cleavage cracks in the pyroxene is the only evidence in support of the first hypothesis. None of the pyroxenes possess amphibole reaction rims surrounding them. The excessively felted nature of the pyroxene/amphibole intergrowth is itself evidence supporting the contemporaneous recrystallisation of both amphibole and pyroxene with perhaps a little late secondary alteration of the pyroxene to amphibole.

At this stage it is possible to summarise the mineralogical changes that have occurred in the greywacke facies due to low grade contact metamorphism as follows:

(1) The early appearance of minutely crystalline interstitial biotite aggregates;

(2) The recrystallisation of sericite to form larger flakes of muscovite;

(3) Reaction between calcite veins and interstitial argillaceous material to produce amphibole (tremolite-actinolite) and pyroxene (augite).

From the field relations and structure of the Trinity Peninsula Series on the east coast of Graham Land it may be inferred that superposed or repeated metamorphism has taken place. Early low grade cataclastic or dynamic metamorphism has converted the former shales to low grade slates showing slip-strain cleavage without appreciable mineralogical change. This has been followed by contact metamorphism of the slates giving rise to the present chiastolite-cordierite-hornfelses, etc. In every case where micro-structures and mineral assemblages indicative of contact metamorphism appear, indications of previous dynamic metamorphism, such as slaty or slip-strain cleavage, have been almost entirely destroyed.

This sequence of repeated metamorphism is confirmed by the argillo-arenaceous and arenaceous sediments and their corresponding metamorphics.

C. WEST COAST OF GRAHAM LAND

BECAUSE of the paucity of field work, the distribution of the Trinity Peninsula Series along the west coast of Graham Land is not yet completely known. On the basis of a preliminary examination of the British Graham Land Expedition (1934–7) collections from the Graham Coast it now appears that phyllitic schists and biotite-hornfelses, which are closely associated with intrusive granites in the south-eastern part of Beascochea Bay, may indeed represent the Trinity Peninsula Series. From the structural relations between the Trinity Peninsula Series and the Andean intrusives in other areas it seems likely that further exploration may reveal the presence of these late Palaeozoic sediments along the more northerly and less severely dissected parts of the west coast.

The metamorphosed sediments from Beascochea Bay can be divided into two distinct groups on their appearance in the hand specimen:

(1) Those with a marked phyllitic banding or schistosity;

(2) Those with the appearance of a massive hornfels and possessing a prominent three-directional cleavage.

As will be seen later, these two divisions seem to correspond to the individual metamorphic histories of these rocks; the first group has been only subjected to cataclastic deformation, whereas the second group has suffered contact metamorphism following earlier cataclasis.

The cataclastically deformed argillaceous sediments are represented by *quartz-muscovite-biotite-schists* or *banded phyllites* (B.G.L.E. Nos. 87 and 88), which are highly contorted and possess a very prominent false cleavage almost perpendicular to the contortions (cf. Plate Ia). In both the light and dark bands ragged and felted masses of red-brown biotite and sericite (muscovite) are elongated parallel to the contortions in the phyllite. The light-coloured, more quartzitic bands are devoid of iron ore and coarser-grained than the dark ones, which themselves are characterised by an abundance of granular iron ore and a well-defined false cleavage. Quartz veins, which cut the rock parallel to the false cleavage, are composed partly of large *strained* quartz grains and partly of small *unstrained* quartz grains with wisps of sericite/biotite following the contortions across the veins, thus giving the impression of replacement of the phyllite by quartz. Small lenses and streaks of opaque material which also follow the foliation are undoubtedly composed of graphite. A greenish brown detrital tourmaline is common in these rocks.

An erratic *quartzitic schist* (B.G.L.E. No. 184) recovered from an iceberg near B.G.L.E. Stations 87 and 88 is of some interest, because it clearly belongs to the same group of metamorphics being discussed here. In thin section it is composed of narrow bands and streaks of granular quartz with minor orthoclase alternating with bands of finely granular quartz, more orthoclase and little flakes of muscovite and chlorite. Occasionally, where the latter minerals become more abundant and are associated with granular iron ore, they give rise to phyllitic bands similar to those in the rocks described above.

In many respects these rocks can be compared with the cataclastically deformed quartz-veined argillaceous sediments in the Mount Reece and East Russell Glacier areas of Trinity Peninsula (see p. 6).

In the hand specimen the grey-brown to purplish coloured biotite-hornfelses (B.G.L.E. Nos. 130, 134 and 138) are massive in appearance and are traversed by numerous quartz veins. Three distinct cleavages, giving rise to triangular fragments, have been frequently observed. Under the microscope the true biotite-hornfelses (B.G.L.E. No. 134) are composed essentially of abundant, small angular quartz grains with minor orthoclase and plagioclase embedded in a very fine-grained matrix, which consists of sericite and pale red-brown biotite flakes, cryptocrystalline quartz and felspar. The irregular finer-grained streaks and patches, which seem to be related to a former foliation, are richer than usual in biotite and appear to represent the more argillaceous parts of the original sediment. The quartzo-felspathic hornfelses (B.G.L.E. Nos. 130 and 138) also possess remnants of foliation. They are coarser in texture than the rocks described above and contain large quartz grains, but there is always less biotite and very little or no sericite in the matrix. In the matrix tiny prisms of epidote and clinozoisite form numerous small aggregates. Iron ore and sphene are the most important among the accessories. Throughout the rock there are thin black streaks and lenses which are graphitic in composition.

The quartzose veins which cut the hornfelses almost at right angles to the foliation are of particular interest. Scattered flakes of chlorite and biotite together with a little granular epidote are present in the coarse quartz mosaic. The fact that the mica and chlorite flakes almost bridge the veins and clearly follow the foliation direction is strong evidence for postulating that these quartz veins may be of a replacement origin.

In these rocks there is sufficiently strong evidence of residual foliation to infer that they suffered cataclasis prior to contact metamorphism. The biotite-hornfelses described here are undoubtedly the low grade contact metamorphic equivalents of chlorite- and sericite-rich argillaceous sub-greywackes, comparable in composition to those described from other parts of Graham Land (see p. 15).

South of Marguerite Bay *no definite* occurrences of these sediments have been recorded. Knowles (1945, p. 141) has referred briefly to buff-coloured hornfelses which crop out in the coastal hinterland of the east coast of King George VI Sound. He described this rock as being composed of subangular quartz fragments, felspar, muscovite, hornblende and some apatite. It has an allotriomorphic texture approaching that of an igneous rock and is probably the contact metamorphic equivalent of a greywacke. Mineralogical and textural comparison with some of the thermally metamorphosed greywackes of the east coast, especially those of a slightly calcareous composition, shows there is a close similarity.

THE GEOCHEMISTRY OF THE TRINITY PENINSULA SERIES

ACCORDING to Nordenskjöld's original description (1905) of the sedimentary succession lying unconformably beneath the Middle Jurassic plant-bearing beds of Mount Flora (Hope Bay), it was composed entirely of shales and greywackes. However, exploration over a wider area of Graham Land has shown that such a description of the series is not quite accurate in the light of recent definitions of greywackes.

From a chemical viewpoint the majority of the argillaceous sediments are of a greywacke facies, whereas the arenaceous sediments vary from relatively pure quartzose sandstones to true greywackes, arkoses and sub-greywackes. According to Pettijohn (1949) true greywackes should contain no more than 65% silica and up to 10% $FeO+Fe_2O_3+MgO$, but arkoses should be considerably richer in silica with 75% and deficient in ferromagnesians with about 3%. Sub-greywackes are intermediate in chemical composition between true greywackes and arkoses. From data based on average chemical analyses of various sediments, Pettijohn has drawn up a curve illustrating the chemical relationship between the igneous rocks and the corresponding derived sediments. It shows there is usually a concentration of silica and loss of ferromagnesians during the transport process of detrital material from its source to terminus.

In Table II (see Fig. 4) the analyses of four selected specimens from the Trinity Peninsula Series are set out with a view to illustrating the wide variation in the chemical composition of this series. One of the analyses (E.28.1) is of a chiastolite-cordierite-hornfels (described on page 14) from the Bowman Peninsula.

A cursory inspection of the analysis reveals it is much richer in soda than either E.32.1 or E.25.3. This does not seem to be due to soda-metasomatism following contact metamorphism but is present in the original plagioclase. It will also be noticed that this same rock is richer in alumina than the calcareous greywacke.

TABLE II

CHEMICAL ANALYSES OF TRINITY PENINSULA SERIES SEDIMENTS AND METAMORPHICS

	E.32.1	E.28.1	E.25.3	D.705.4
SiO_2	52.35	63.81	75.50	95.06
TiO_2	0.61	0.70	0.33	0.10
Al_2O_3	17.07	20.39	11.79	2.86
Fe_2O_3	0.31	1.19	0.43	0.50
FeO	4.17	4.89	1.41	0.03
MnO	0.28	0.02	0.002	—
MgO	1.63	1.29	0.51	0.04
CaO	18.12	0.77	1.71	0.77
Na_2O	0.96	3.44	1.92	0.40
K_2O	0.09	0.43	2.99	0.12
H_2O+	0.16	0.99	0.90	0.08
H_2O-	0.11	0.19	0.12	—
P_2O_5	0.35	0.42	0.40	—
CO_2	1.14	—	0.57	tr
S	—	tr	—	—
C	2.38	1.52	1.49	—
TOTAL	99.73	100.05	100.072	99.96

E.32.1 Sheared calcareous greywacke, Cape Rymill (anal. R. J. Adie).
E.28.1 Chiastolite-cordierite-hornfels, Bowman Peninsula (anal. R. J. Adie).
E.25.3 Arkose, Cape Keeler (anal. R. J. Adie).
D.705.4 Red quartzite, mountain north-north-west of Crystal Hill (anal. R. J. Adie).

The calcareous greywackes are less uncommon in these sediments than might be supposed from their environment of deposition. Contact metamorphism of the sediments by the Andean intrusives has revealed their diversity of chemical composition in the end-products. It is indeed unfortunate that the more calcareous sediments have not been subjected to a higher grade of contact metamorphism, since some interesting rocks would have resulted. Some almost pure limestones have been observed in the succession but they are relatively free from recrystallisation and they can in no way be compared with the Basement Complex limestones of Signy Island, South Orkney Islands.

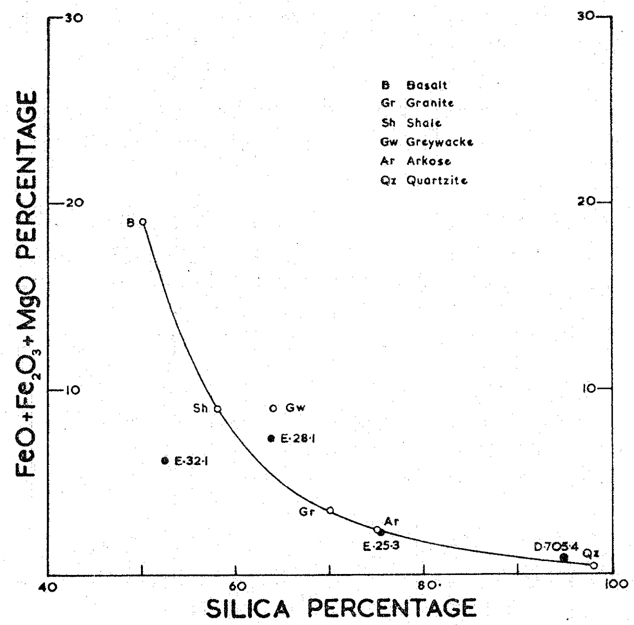

FIGURE 4

Graphical representation of the chemical composition of some argillaceous and arenaceous sediments of the Trinity Peninsula Series, the analyses of which are given in Table II (after Pettijohn, 1949).

An important point is that nearly all the sediments of the Trinity Peninsula Series that have been examined contain free carbon (Table II), which appears in thin section as graphitic films in the metamorphic equivalents of these rocks. This clearly indicates the presence of organic remains in the original sediments.

From a chemical aspect true greywackes are relatively uncommon in the Trinity Peninsula Series and the quartzo-felspathic types seem to predominate. In this respect there is a close resemblance between these rocks and those described by Tilley (1935) and Stewart (1937) from the South Orkney Islands.

THE IDENTITY OF THE TRINITY PENINSULA SERIES OF GRAHAM LAND WITH THE YOUNGER GREYWACKE-SHALE SERIES OF THE SOUTH ORKNEY ISLANDS

FOLLOWING Nordenskjöld's original description (1905) of the folded greywackes and shales (Trinity Peninsula Series), on which the Hope Bay Jurassic beds rest unconformably, Andersson (1906) has compared the Graham Land succession lithologically with that described by Pirie (1905, 1913) from Laurie Island in the South Orkney Islands. More recent work on the petrography and stratigraphy of the South Orkney Islands (Tilley, 1935) shows that there are *two* clearly recognisable divisions of the "Palaeozoic" rocks:

(1) An older metamorphic series with schists, gneisses and crystalline limestones, and

(2) A younger series of *quartzo-felspathic greywackes* interbedded with shales and associated with a younger conglomerate resting on the greywackes.

On the basis of his discovery in the shales of a graptolite (identified as belonging to the genus *Pleurograptus*) and a Phyllocarid crustacean allied to *Discinocaris*, Pirie assigned the Laurie Island Greywacke-Shale Series to the Ordovician-Silurian. The fragmentary plant material recovered from the Trinity Peninsula Series of Hope Bay was considered by Croft to be *definitely not earlier than Carboniferous in age.*

Therefore, in examining the possibility of a correlation between the Trinity Peninsula Series of Graham Land and the Younger Greywacke-Shale Series of the South Orkney Islands, not only the meagre fossil evidence but also the lithological identity requires careful evaluation.

Pirie's fossil material, which has now been discovered in the Royal Scottish Museum, Edinburgh, has been re-examined by Dr. I. Strachan (Department of Geology, University of Birmingham) who has expressed the following opinion:

> The fragmentary specimens from the South Orkney Islands (O.14 and O.15=R.S.M. Nos. 1954.2.28 and 29) are extremely poorly preserved. No thecae can be seen on the supposed graptolite stipes and the markings on the other organic fragments can be explained in several ways. There is no positive evidence for an Ordovician-Silurian age for the shales although, of course, the specimens can be interpreted to agree with such an age. They could, however, equally well be identified as plant fragments and assigned to the *Carboniferous*.

The petrography of the corresponding argillaceous and arenaceous sediments from both these regions is identical; for instance, the greywackes from both localities contain small fragments of felsitic, rhyolitic and andesitic material. The presence of fragmental material derived from an older metamorphic series in the Hope Bay greywacke-conglomerates is additional evidence for both series of sediments having been derived from the same source.

After a careful examination of all the available stratigraphical, lithological, petrographical and palaeontological evidence from both these regions, it appears that the two successions are probably contemporaneous and may thus be tentatively correlated. These sediments are certainly late Palaeozoic in age and it seems most probable that they are *Carboniferous*.

The detailed work of Trendall (1953, 1957) has clearly shown a close petrographic similarity between the greywacke facies sediments of the Sandebugten Series of South Georgia and the Trinity Peninsula Series of Graham Land. From his petrographic investigations, Tyrrell (1930, p. 53) has already suggested a correlation between the greywackes of the South Orkney Islands and South Georgia. Before a final conclusion can be reached on the precise correlation of the greywacke facies sediments of Graham Land, the South Orkney Islands and South Georgia, it seems that further detailed stratigraphic work and more fossil evidence are required in each region.

SUMMARY

THE predominantly non-fossiliferous late Palaeozoic sediments of the Hope Bay area, previously called the "Greywacke-Shale Series" by Nordenskjöld, and the "cherty rocks" described by Croft from Tabarin Peninsula and the Mount Bransfield area (the "Taylor Peninsula Series") are members of the same sedimentary succession, which is now referred to as the *Trinity Peninsula Series*.

In the three main regions of Graham Land that have been investigated the metamorphic rocks belonging to the Trinity Peninsula Series have been divided into two major groups according to their respective metamorphic histories:

(1) The cataclastically deformed argillaceous and arenaceous sediments;

(2) The hornfelses and recrystallised rocks resulting from superimposed contact metamorphism by the Andean intrusives.

The effects of pre-Jurassic dynamic metamorphism are always more easily detectable in the argillaceous than in the arenaceous sediments. Particularly in the lower metamorphic grades, the rocks resulting from cataclasis are generally a direct function of the size-grading rather than the chemical composition of the original sediments. The shales have been transformed into highly contorted and fissile slates with a distinct false cleavage at a high angle to the bedding planes, but the coarser-grained greywackes have only been sheared and fractured. The greywackes with a fine-grained, chlorite-rich argillaceous matrix have tended to develop a marked flaser structure, an advanced stage of which can be likened to "interstitial mylonitisation". Where coarse-grained greywackes are finely interbedded with shales rich in either chlorite or sericite, schistose rocks showing shattering in the coarse bands and false cleavage in the fine bands have resulted. Mineralogical reconstitution is rarely noticeable in these rocks.

Remnants of an earlier foliation due to cataclasis can be seen in the majority of the hornfelses, although they have reached various individual stages of recrystallisation and mineralogical reconstitution. In a contact metamorphic process of the type described here the initial chemical composition of the sediment involved is important and indeed governs the final stable mineralogical assemblage for a specific metamorphic grade, whereas the original grain-size is more closely related to the rate of chemical reaction or the formation of new mineral assemblages. Hence, in the fine-grained argillites it is easier to follow the exact course of metamorphic reconstitution stage by stage than in the coarser greywackes. In the majority of cases discussed here quartz-diorites are the agents of thermal metamorphism, a fact which is important from the aspect of comparing thermal grades in different localities.

In the alumina-rich argillaceous sediments of the Trinity Peninsula Series contact metamorphism follows a definite pattern, beginning with the early development of "spotting" and minute interstitial biotite flakes and followed by the crystallisation of clearly defined cordierite and embryonic chiastolite. With increasing grade the overall texture of the hornfels becomes coarser; chiastolite and cordierite form complete idioblasts. It seems that the sillimanite-garnet-hornfelses recorded on the Graham Land east coast may represent the highest grade close to the contact. There is no sign of early "spotting" in the chloritic shales but instead a green magnesian biotite forms. With progressive metamorphism and the adsorption of detrital iron ore the biotite becomes foxy red-brown in colour and cordierite begins to make its appearance. The rock is then a biotite-cordierite-hornfels and is indistinguishable from that derived from the alumina-rich argillites. The presence of excess lime in these sediments gives rise to local aggregates of pale hornblende in addition to the normal mineral assemblage.

Of the arenaceous sediments belonging to the Trinity Peninsula Series, the purer siliceous sandstones are the least important, because they only recrystallise to quartzites in the thermal aureoles.

The alumina-rich non-calcareous argillaceous greywackes are in many respects akin to the sericitic argillaceous shales, since the fine-grained matrix follows the same trend of mineralogical reconstitution. Where there are zones especially rich in alumina highly pleochroic andalusite with optical continuity crystallises at a low to medium grade. However, the calc-argillaceous greywackes, calcareous greywackes, sub-greywackes and arkoses, all of which contain a certain amount of free calcite and varying proportions of chlorite, show signs of reactivity only at a low to medium grade. At first finely granular diopsidic augite develops in the matrix of muscovite and biotite but at a medium to high grade when the texture becomes coarser the rock becomes an augite-quartz-plagioclase-hornfels. The greywackes of the Trinity Peninsula Series are frequently quartzo-felspathic but they contain a small amount of interstitial chloritic material and calcite. After the early crystallisation of interstitial biotite there is only additional formation of granular augite in the low to medium grade biotite-augite-hornfelses. Especially where calcite veins traverse the greywackes reaction is directed towards the formation of felted masses of pale green actinolite-tremolite amphibole associated with a small amount of clino-pyroxene.

In the immediate vicinity of the smaller quartz-diorite intrusions of Tabarin Peninsula and the Mount Bransfield area late stage hydrothermal sulphide mineralisation of the sediments and the emplacement of copper and iron pyrites veins has taken place. At an even later stage, tourmalinisation and actinolitisation processes have been so vigorous that in some places local "skarn-like" rocks and "feather-amphibolites" have been produced.

In a brief survey of the chemical affinities of the Trinity Peninsula Series sediments and metamorphics it has become clear that the greater part of this succession comprises quartzo-felspathic greywackes interbedded with shales. The majority of these sediments, irrespective of whether they have only suffered cataclasis or superposed contact metamorphism, contain significant amounts of free carbon as graphite, thus indicating a certain content of organic material in the original sediments.

From detailed petrographic studies of the various groups of metamorphic rocks and a knowledge of their respective structural and stratigraphic relations with other units of known age, it is now evident that all these rocks can be included in the Trinity Peninsula Series and hence correlated with the succession investigated in the type locality of Hope Bay.

On the basis of palaeontological evidence the Trinity Peninsula Series is certainly known to belong to the late Palaeozoic and is probably Carboniferous in age. Comparisons of stratigraphy, lithology, petrography and additional palaeontological data indicate there are grounds for tentatively correlating the Trinity Peninsula Series of Graham Land with the Greywacke-Shale Series of the South Orkney Islands and the Sandebugten Series of South Georgia, but further detailed research in all these areas is required to confirm this opinion.

ACKNOWLEDGMENTS

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APPENDIX

A LIST OF PLACE-NAMES, THEIR CO-ORDINATES AND THE APPROPRIATE MAP SHEETS

NOTE: Only the mid latitude and longitude of each feature is given.

Adams, Cape	75°04′S., 62°20′W.	1/200,000 Sheet 74 62
Alexander Land	70°45′S., 70°00′W.	1/500,000 Sheets F, G & K.
Andersson Nunatak	63°22′S., 57°00′W.	1/100,000 Sheet 63 56 NW.
Beascochea Bay	65°30′S., 63°56′W.	1/500,000 Sheets C & D.
Blade Ridge	63°25′S., 57°05′W.	1/100,000 Sheet 63 56 NW.
Boggs, Cape	70°33′S., 61°23′W.	1/200,000 Sheet 70 60
Bowman Coast	68°15′S., 65°30′W.	1/500,000 Sheets C & G.
Bowman Peninsula	74°47′S., 62°22′W.	1/200,000 Sheets 74 60, 74 62
Bransfield, Mount	63°17′S., 57°06′W.	1/100,000 Sheet 63 56 NW.
Brown Bluff	63°32′S., 56°55′W.	1/100,000 Sheet 63 56 SE.
Bryant, Cape	71°12′S., 60°55′W.	1/200,000 Sheet 71 60
Burd, Cape	63°39′S., 57°09′W.	1/100,000 Sheet 63 56 SW.
Buttress Hill	63°34′S., 57°03′W.	1/100,000 Sheet 63 56 SW.
Cairn Hill	63°30′S., 57°04′W.	1/100,000 Sheets 63 56 NW, SW.
Cardinal, Mount	63°27′S., 57°10′W.	1/100,000 Sheet 63 56 NW.
Carrel, Mount	63°26′S., 57°03′W.	1/100,000 Sheet 63 56 NW.
Chapel Hill	63°41′S., 57°58′W.	1/100,000 Sheet 63 56 SW.
Christmas, Cape	72°20′S., 60°41′W.	1/200,000 Sheet 72 60
Church Point	63°41′S., 57°54′W.	1/100,000 Sheet 63 56 SW.
Cone Nunatak	63°37′S., 57°01′W.	1/100,000 Sheet 63 56 SW.
Crystal Hill	63°39′S., 57°44′W.	1/100,000 Sheet 63 56 SW.
Depot Glacier	63°25′S., 57°03′W.	1/100,000 Sheet 63 56 NW.
Dubouzet, Cape	63°16′S., 57°02′W.	1/100,000 Sheet 63 56 NW.
East Russell Glacier	63°44′S., 58°17′W.	1/100,000 Sheet 63 58 SE.
Eielson Peninsula	70°37′S., 61°52′W.	1/200,000 Sheets 70 60, 70 62
Fairweather, Cape	65°00′S., 61°05′W.	1/200,000 Sheets 64 60, 65 60
Flora, Mount	63°25′S., 57°01′W.	1/100,000 Sheet 63 56 NW.
Gourdin Islet	63°12′S., 57°18′W.	1/100,000 Sheet 63 56 NW.
Hope Bay	63°24′S., 57°00′W.	1/100,000 Sheets 63 56 NE, NW.
Joinville Island	63°15′S., 55°45′W.	1/200,000 Sheets 63 56, 63 54
Keeler, Cape	68°51′S., 63°13′W.	1/200,000 Sheet 68 62
King George VI Sound	71°00′S., 68°00′W.	1/500,000 Sheets G & K.
King Oscar II Coast	65°50′S., 62°20′W.	1/500,000 Sheet D.
Last Hill	63°28′S., 57°05′W.	1/100,000 Sheet 63 56 NW.
Laurie Island	60°44′S., 44°37′W.	1/500,000 South Orkney Islands
Lizard Hill	63°31′S., 57°01′W.	1/100,000 Sheet 63 56 SW.
Marguerite Bay	68°30′S., 69°00′W.	1/500,000 Sheet G.
Mason Inlet	72°59′S., 60°25′W.	1/200,000 Sheets 72 60, 73 60
Mineral Hill	63°29′S., 57°03′W.	1/100,000 Sheet 63 56 NW.
Mobiloil Inlet	68°37′S., 64°14′W.	1/200,000 Sheet 68 64
Nobby Nunatak	63°25′S., 56°59′W.	1/100,000 Sheet 63 56 NE.
Nordenskjöld Coast	64°39′S., 60°00′W.	1/500,000 Sheet A.
Passes Peak	63°27′S., 57°03′W.	1/100,000 Sheet 63 56 NW.
Pyramid, The	63°26′S., 57°01′W.	1/100,000 Sheet 63 56 NW.
Reece, Mount	63°50′S., 58°32′W.	1/500,000 Sheet B.
Ridge Peak	63°31′S., 57°03′W.	1/100,000 Sheet 63 56 SW.
Rymill, Cape	69°30′S., 62°25′W.	1/200,000 Sheet 69 62
Scar Hills	63°25′S., 57°01′W.	1/100,000 Sheet 63 56 NW.
Seven Buttresses	63°36′S., 57°10′W.	1/100,000 Sheet 63 56 SW.
Sheppard Point	63°22′S., 56°58′W.	1/100,000 Sheet 63 56 NE.

Signy Island	60°43′S., 45°38′W.	1/500,000 South Orkney Islands
South Georgia	54°20′S., 36°40′W.	1/500,000 Separate Sheet
South Orkney Islands	60°40′S., 45°15′W.	1/500,000 Separate Sheet
Summit Ridge	63°27′S., 57°02′W.	1/100,000 Sheet 63 56 NW.
Tabarin Peninsula	63°30′S., 57°00′W.	1/100,000 Sheets 63 56 NE, NW, SE, SW.
Taylor, Mount	63°26′S., 57°07′W.	1/100,000 Sheet 63 56 NW.
Thimble Peak	63°28′S., 57°06′W.	1/100,000 Sheet 63 56 NW.
Three Slice Nunatak	68°02′S., 64°58′W.	1/200,000 Sheet 68 64
Trail Inlet	68°05′S., 65°21′W.	1/200,000 Sheet 68 64
Trinity Peninsula	63°30′S., 58°00′W.	1/500,000 Sheet B.
Twin Peaks	63°24′S., 57°07′W.	1/100,000 Sheet 63 56 NW.
View Point	63°33′S., 57°22′W.	1/100,000 Sheet 63 56 SW.
Wilkins Coast	69°30′S., 62°30′W.	1/500,000 Sheet H.

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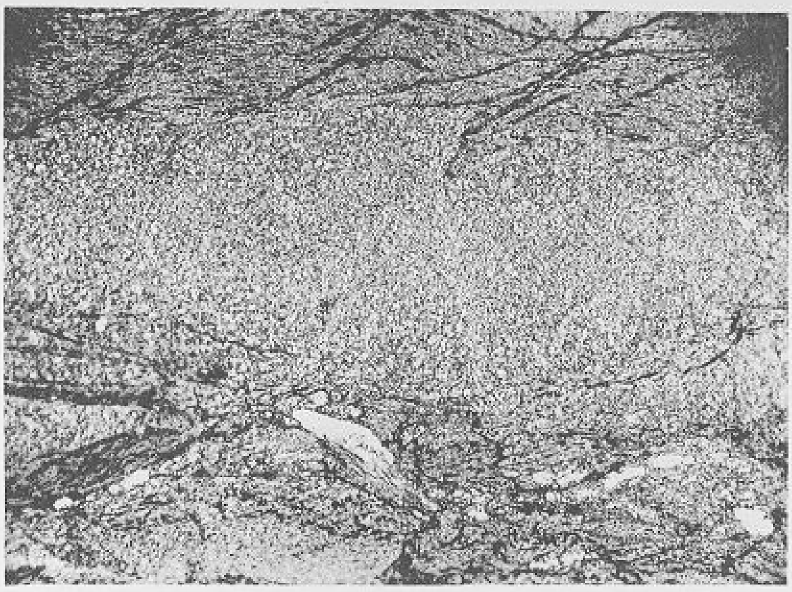
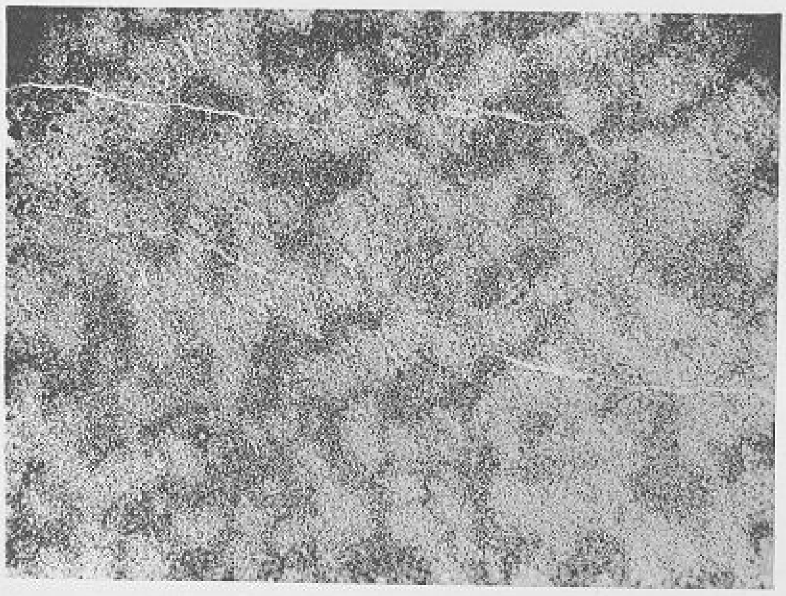
PLATE I

a. Cataclastic deformation of interlaminated argillaceous and arenaceous sediments of the Trinity Peninsula Series, showing false cleavage in the muscovite-rich bands but not in the quartzitic bands; Mount Reece area (D.374.5; ordinary light; ×26).

b. Spotting at an early stage of contact metamorphism of shales. Light cordierite patches are surrounded by finely divided biotite in a biotite-cordierite-hornfels; Crystal Hill (D.702.2; ordinary light; ×26).



a



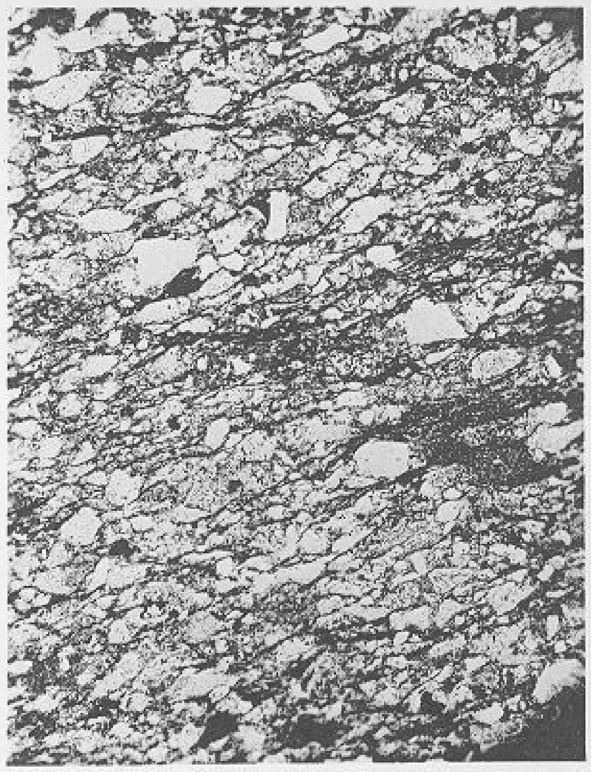
b

PLATE II

a. Flaser structure in a sheared calcareous greywacke; Mason Inlet (E.27.2; ordinary light; ×26).

b. Chiastolite-cordierite-hornfels, showing idioblastic chiastolite and sector-twinning in the cordierite; Bowman Peninsula (E.28.1; X-nicols; ×26).

c. Augite-quartz-plagioclase-hornfels showing idioblastic augite. This rock is the medium grade contact metamorphic equivalent of the calcareous greywackes; Cape Bryant (E.31.1; ordinary light; ×26).



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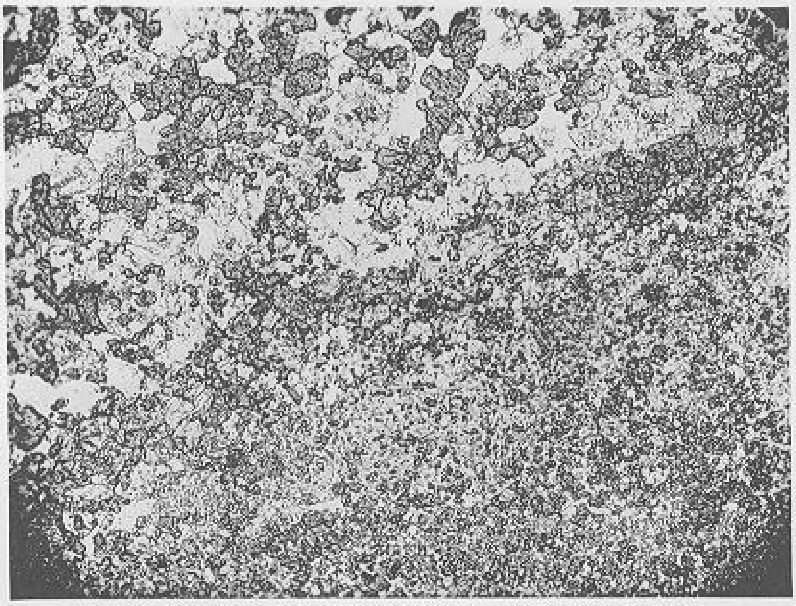

c