THE TILTING IGNEOUS COMPLEX

FOGO DISTRICT, NEWFOUNDLAND

H. WILLIAMS

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THE TILTING IGNEOUS COMPLEX, FOGO DISTRICT, NEWFOUNDLAND

by

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ABSTRACT

Tilting is situated on the northeast corner of Fogo Island which lies off the northeast coast of Newfoundland. Fogo Island has an area of approximately 110 square miles and the Tilting area which encloses the settlement of Tilting has an area of approximately 5 square miles. Many diverse rock types occur within the Tilting area where a diorite gabbro complex is intruded by the Fogo granite batholith.

In several places the basic rocks of the diorite gabbro complex show marked primary banding accompanied by primary foliation. The writer feels that this primary banding originated through rhythmic differentiation and that the primary foliation is a sedimentation structure. A review of the literature and description of classic areas are presented.

Intrusion breccias and gradational rock series are of common occurrence. Hybrid rocks characterized by abnormal mineral associations are discussed.

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THE TILTING IGNEOUS COMPLEX, FOGO DISTRICT

A. Introduction

Area Studied:

The Tilting Igneous Complex is situated on the northeast corner of Fogo Island and is approximately 2 square miles in extent. Fogo Island which is the largest island in the district has an area of 110 square miles and is situated off the northeast corner of the mainland of Newfoundland.

In this part of Newfoundland, as in most of the coastal regions travel is entirely by water. A secondary gravel road, however, connects Tilting with other settlements on the island. Fogo, the largest settlement, is the terminus of a weekly steamer service from Lewisporte. Joe Batts Arm, 5 miles distant from Tilting, is visited twice weekly by cruiser-type motor boats which ply between this settlement and Lewisporte. The critical area surrounding Tilting is completely accessible by foot.

Scope and Purpose of Investigation:

This report presents the results of field work carried out during a six week period in the summer of 1956, and laboratory studies made during 1956 and 1957. The Tilting Igneous Complex, most commonly referred to as "the diorite gabbro complex" (Baird, 1950), contains many varied rock types ranging from intermediate to basic in composition. These rocks provide perfect examples of primary banding. The complex is intruded by granite, thus forming extensive intrusion breccias. The purpose of the investigation is to describe and interpret these features, thus aiding in the interpretation of the geology of Fogo Island. The usual purposes of the Geological Survey, the prospecting of new areas and the investigation of known prospects, were also carried out.

Execution of Field Work:

The area was completely traversed by foot, except in the case of Pigeon Island and Black Rock where a boat was necessary, an ordinary row boat being quite sufficient. The Geological Survey of Newfoundland provided the base map which was an ozalid reproduction of an original tracing obtained from a large scale aerial photograph, in turn obtained by enlarging an original negative. Large scale aerial photographs were used in the field. Both map and photographs proved to be most satisfactory.

Previous Work:

Fogo Island was first visited by J.B. Jukes during the summer of 1841 (1842, Vol. II p. 295). The island is not mentioned in the early reports of the Geological Survey of Newfoundland by Murray and Howley, and we do not hear of the area again up to the time of the Princeton University Expedition 1916-1918, the notes of which are not available.

The first major geological work of the area was done by D.M. Baird of the Geological Survey of Newfoundland in 1946, (1950). Accompanied by two non-technical assistants he performed the reconnaissance mapping of Fogo Island which also included the smaller adjoining islands. This work was carried out in the hope that the understanding of this map area might aid considerably in the interpretation of the geology of northeastern Newfoundland. The island was revisited by Baird during 1955 and

1956 in order that the contacts might be defined more accurately with the aid of aerial photographs and new base maps. In 1953 a geophysical survey of the Tilting area was made by the Newfoundland and Labrador Corporation and the field notes taken at that time proved to be of assistance.

Acknowledgements:

Professors D. M. Baird and B. W. Lee, of Memorial University, gave much in the preparation of this report through their interest and knowledge of the subjects in question.

The writer was ably assisted in the field by Denny Christian of Grand Falls. The writer is indebted to many residents of the Tilting area for their assistance and courtesies. He wishes particularly to mention the cheerful assistance of Messrs. Ronald and Martin Burke.

To Mr. Thomas Northcott, who gave much time and effort when needed most, toward the preparation of maps, thanks are extended.

Physiography:

The Tilting area is largely comprised of rolling topography with bare or sparsely covered hills not exceeding 300 feet in altitude. There is no pronounced grain to the topography since the underlying rocks are generally quite massive. However, a crude lengthwise arrangement of outcrops runs from northeast to southwest across the map sheet. This rough lineation, running parallel to a fault separating Pigeon Island from the mainland and passing through the northwest head of Sandy Cove, is caused by the particular distribution of overburden which is probably controlled by tension joints. The open joints form grooves as a result of weathering, and thus localize patches of glacial drift. Several peat bogs occur in the area and are the only places where good exposures were not encountered.

The coastline consists mainly of bedrock with minor pebble beaches and a beautiful compact sand beach at Sandy Cove. There are no outstanding sea cliffs which are so common a feature along the coast of Newfoundland, and bedrock immediately overlooking the sea rarely reaches elevations exceeding 75 feet. Present day wave erosion is demonstrated splendidly by the "Blow Hole", which occurs to the south of the map area and which can be entered during calm periods in a motor boat; also by "Spout Gulch" of Wild Cove Head which directs oncoming swells directly into the air. This present cycle of wave erosion is in a youthful stage, since waves are advancing on a recently glaciated surface.

The largest pebble beach of the area is found in Olivers Cove, where the pebbles are mainly derived from surrounding igneous rocks and rounded by wave action. By far the most outstanding beach of the area, and one of the most beautiful of Newfoundland, is found at Sandy Cove. The beach is composed of a very fine sand, hard-packed within the borders of tidal waters, and loosely packed elsewhere. At times of high winds the sand particles are blown about and quite frequently form perfect wind ripple marks. The origin of the material forming this beach presents a problem since the sand is made up almost entirely of rounded quartz grains with minor percentages of fragmented sea shells. Sandy Cove is the only locality on Fogo Island which contains such a beach.

Sandy Cove Beach appears to be a post glacial feature, for if the sands accumulated before glaciation they would most likely be removed by that process. Since a post glacial origin is postulated, then the sands must have accumulated as glacial outwash.

Gently sloping hills surround Sandy Cove Pond forming a shallow depression. This depression might well have been the site for accumulation of glacial debris which could later be transported toward the coast. Reworking of this glacial outwash by the sea would then give rise to the sands of Sandy Cove Beach.

Glaciation:

The effects of glaciation are evident in the Tilting area. Striae and roche moutonbes are not very common, but the fact that they are present at all points to glaciation. At Olivers Cove Head a patch of granite boulders were accumulated by glacial action.

The average direction of glacial striae is north 5° east or approximately north-south, the movement being toward the north as shown by drift patterns. This direction and movement agrees with the generally prevalent theory that Newfoundland was last glaciated by ice which moved outward from a central plateau toward the coasts.

B. General Geology

Geologic Setting of Fogo Island:

The rocks of Fogo Island include Paleozoic sedimentary and volcanic rocks which have been intruded by igneous rocks of a wide range of composition. The core of Fogo Island is a granite batholith, with an area of approximately 75 square miles, which consists of pink to grey microcline granite, alaskite-type granite and granodiorite. All rock types exposed throughout the island are cut by numerous dykes of different compositions. The southern and northeast edges of Fogo Island consist of a complex of dioritic and gabbroic intrusions which are cut by a host of dykes largely of granitic composition. Intrusion breccias are very common within the intermediate to ultrabasic igneous complexes, the most common variety being a breccia consisting of intermediate to basic inclusions enclosed in a lighter granitic rock. Numerous granitic dykes intrude the sedimentary rocks of the district, (Baird, 1950).

Diorite Gabbro Complex and Fogo Granite:

The whole of the Tilting map area is made up of granite of the Fogo Batholith and rocks which are more basic than granite. The latter, which are usually referred to as the diorite gabbro complex, are intruded by the granite and range in composition from intermediate through basic and at times toward ultrabasic. The diorite gabbro complex occurs for the most part along the coast, and the contacts between it and the Fogo granite terminate at the water's edge. However, rocks belonging to this complex also occur as isolated patches within the Fogo granite and, when occurring as such, may be thought of as large inclusions.

Throughout the Fogo granite it is not uncommon to find such inclusions reaching dimensions up to 1,000 feet across. The contacts surrounding the isolated masses are in some places marked by intrusion breccias, while in other places the boundaries are quite gradational and one can pass from diorite into granite without any perceptable break. Also, within the Fogo granite it is not uncommon to find intrusion breccias which do not indicate any contact between the granite and the intruded rock. Sedimentary inclusions also occur beyond the

Tilting map sheet and well within the Fogo Batholith. All the above evidence suggests that the present erosional surface is very near the roof of the Fogo Batholith.

Granite:

Several varieties of granite are found within the Tilting area and all belong to the Fogo batholith. The most common granitic rock type in the Tilting area contains from 20% to 30% dark minerals. These are most commonly biotite and hornblende, the biotite usually being twice as abundant as the hornblende. The rock has an equigranular allotriomorphic texture with a medium grain size ranging from 3 mm to 5 mm. The quartz occurs in irregular interstitial blebs up to 5 mm in diameter, and the feldspar, although occurring in anhedral crystals, is often found as laths. In a characteristic specimen from location M-13 (see map grid), on the western shore of Olivers Cove, the mineral composition is as follows; alkali feldspar 40 percent, quartz 30 percent, biotite 20 percent, hornblende 8 percent, with accessory pyrite, magnetite and zircon. On the weathered surface the rock is a pale orange, which color is entirely produced by the feldspars. Iron stain, originating from the oxidation of accessory pyrite, commonly occurs in small patches.

With an impoverishment of dark minerals the above rock grades into a typical alaskite-type granite. This granite is almost entirely composed of quartz and feldspar with a medium grain size ranging from 2 mm to 4 mm. Quartz occurs in anhedral vitreous crystals and the feldspar, usually a little larger than the quartz grains, occurs as subhedral laths and irregular blebs. A specimen taken from Wild Cove at location A-7 has the following mineral composition; alkali feldspar 50 percent, quartz 45 percent, with accessory hornblende, biotite, and pyrite. The rock is lighter on the weathered surface than on a fresh, but the quartz does not show its usual vitreous luster. This particular type of granite, containing less than 10 percent mafic minerals, comprises approximately 20 percent of the granite shown on the Tilting map sheet. The most widespread occurrence is directly west of Wild Cove.

Granodiorite, which is inseparable from the granite of the area, is also a commonly occurring rock. The occurrence of the granodiorite within the granite is probably because of incomplete differentiation, or perhaps the granodiorite arrived at its present composition by the assimilation of more basic rocks which were digested by the granitic magma. This rock differs from the more acidic types mainly because it contains much less quartz and the discrepancy is counteracted by a greater abundance of dark minerals. The rock is of medium grain size ranging from 3 mm. to 4 mm., and the apparent equigranular texture is best described as hypidiomorphic since the feldspars occur most frequently as vitreous subhedral laths. The mineral composition of a specimen taken from an outcrop approximately 1,000 feet north of the north shore of Olivers Cove, at location K - 14, is as follows; alkali feldspar 45 percent, hornblende 20 percent, biotite 15 percent, quartz 17 percent, with accessory pyrite and magnetite. The feldspars are a pinkish orange to white on the weathered surface and in general this rock seems to weather more rapidly than the more acidic types.

In several places, rocks of the granitic group and also of the diorite gabbro complex show spheroidal weathering. This type of weathering at places forms pseudo-intrusion breccias. The weathered spheroidal scales, when removed from the exposed area, leave fresh surfaces surrounded by weathered rock and from a distance these fresh patches resemble inclusions.

The Diorite Gabbro Complex:

The diorite gabbro complex of the Tilting area is but one occurrence of many similar masses found throughout Fogo Island bordering the Fogo Batholith. The largest mass is about 12 square miles along the southern coast of Fogo Island. A smaller mass of diorite lies about 1 mile south of the head of Hare Bay, and Copper Island in the Wadham group is underlain by basic rocks. The Tilting Complex occupies an area of 1½ square miles on the northeast corner of the island.

The term "Diorite Gabbro Complex", (Baird 1950) has been assigned to the intermediate and basic rocks of the Tilting area because of the difficulty in separating the individual rock types. This difficulty mainly arises because of multiple intrusions of consanguineous rocks and the effects of differentiation in place.

The rocks of the diorite gabbro complex have a wide range of chemical and mineralogical composition. They include granodiorite, quartz diorite, diorite, quartz gabbro, gabbro, hornblende gabbro, norite, anorthosite, and also varieties of perknite and peridotite. Baird (1950, p. 42) has noted that the rocks of the diorite gabbro complex are rich in silica and deficient in alkalis, resulting in such rocks as the quartz gabbros, quartz perknites, and quartz-rich diorite. This is true, however, only near the granite mass or near minor intrusions of granite, for it was found that basic rocks somewhat distant from granite contained no quartz.

A common basic rock found within the diorite gabbro complex is a pyroxene gabbro. The rock is characterized by abundant feldspar phenocrysts which are in the composition range of labradorite. The phenocrysts are lath shaped and sometimes reach lengths of 2 cm. The feldspars commonly show simple twinning, and polysynthetic twinning is nearly always present. In a typical specimen taken from the road approximately 2,000 feet west of Sandy Cove beach at location G-6, the mineral composition is as follows; plagioclase feldspar 60 percent, pyroxene 28 percent, biotite and hornblende 5 percent, chlorite 5 percent, with accessory pyrite and magnetite. Hornblende and biotite have apparently been formed by the action of the late magma on the pyroxene. The rock is best described, then, as a coarse-grained porphyritic gabbro. The appearance on a weathered surface is very anorthositic and the rock is not always obviously porphyritic.

A more intermediate rock type is found immediately west of the gabbro and still within location G-6. This rock is best designated as a hornblende diorite. The rock contains the following minerals; soda plagioclase 50 percent, hornblende 30 percent, pyroxene 10 percent, chlorite 6 percent, with accessory pyrite, magnetite, apatite, and also a little interstitial quartz. Feldspars commonly occur in subhedral laths but the overall majority of the composing minerals are in the form of anhedral crystals, giving the rock an allotriomorphic equigranular texture. The rock is medium grained, with average grain size ranging from 2 mm. to 3 mm. and is lighter on the weathered surface than on a fresh surface.

On the western side of the entrance to Tilting Harbour, within location H-13 and near a beacon light, the rocks of the diorite gabbro complex show excellent primary banding. A commonly occurring rock of this area is one made up almost entirely of hornblende and pyroxene, warranting the name perknite. The average grain size is from 4 mm. to 6 mm. and the hornblende is very easily distinguished in hand specimen. At times this rock shows a crude glomeratic texture due to the spaced segregation of light weathering feldspars which are of smaller grain size than the hornblende or pyroxene. The majority of the crystals are subhedral. This is a rock of marked individuality and easily distinguished from other intrusive rocks of the area. The rock is very dark on both the weathered and fresh surface.

South of Wild Cove, at location D-8, there occurs a rock whose composition is that of a typical gabbro. The rock is of medium grain size, 1 mm. to 3 mm. and is roughly equigranular, the feldspars being usually a little larger than the other minerals with a grain size ranging from 2 mm. to 3 mm. This rock is characterized by an abundance of magnetite, and from this particular locality the mineral composition is as follows; plagioclase feldspar (labradorite?) 50 percent, pyroxene 30 percent, magnetite 15 percent, with accessory biotite, hornblende and pyrite. This rock weathers a brownish color which aids in its recognition.

On the northwest shore of Sandy Cove, at location F-9, there is an occurrence of gabbroic anorthosite. The rock shows a crude banding and an alignment of the feldspar laths which lie roughly in the same plane but occur in all directions within that plane. The rock is of medium grain size and shows an equigranular hypidiomorphic texture. At this type locality the mineral composition is as follows; plagioclase feldspar 70 percent, pyroxene 15 percent, hornblende 10 percent, with accessory biotite, magnetite, pyrite and also a little chloritic alteration.

The occurrence of perknite in the Tilting area is common. Some of the areas of occurrence are as follows: J-15, on the seacoast directly east of the inner pond of Tilting Harbour; D-8, on the southern shore of Wild Cove; H-15, on the south east tip of Pigeon Island; and I-13, on a peninsula which protrudes into Tilting Harbour. A representative sample is one taken from a small island which is a continuation of the peninsula in Tilting Harbour. Here, the perknite has a poikilitic texture and is characterized by the presence of large hornblende oikocrysts which average about 1 cm. to 2 cm. in length. The remaining minerals occur in relatively smaller sizes ranging from 2 mm. to 3 mm. The mineral composition of the rock from this locality is as follows; hornblende 50 percent, pyroxene 30 percent, olivine 10 percent, plagioclase 5 percent, with accessory biotite, pyrite and magnetite. The rock is usually mottled on the weathered surface because of differential weathering. On sunny days the cleavage faces of the phenocrysts of hornblende reflect the sun as brilliantly as pieces of broken glass. This rock has by far the most marked individuality within the district and is easily recognized from other intrusive rocks.

Age:

The exact age of the Fogo granite Batholith is unknown. Baird (pers. comm., 1957) dates the Fogo granite as post Ordovician, since numerous interfingering granitic dykes cut rocks which are included within the Fogo group, which group is of probable Ordovician age.

Granites of Newfoundland are nowhere known to cut Carboniferous Strata (Baird, pers. comm., 1957). Heyl (1937, p. 18) in his report on the Geology of Sops Arm, White Bay, states, " in the Sops Arm area the available evidence indicates that the granite and related intrusions are mid-Paleozoic in age, and that they were intruded after middle Silurian time and before the Mississippian period. By comparison and analogy with other areas of northern Newfoundland it seems most probable that the intrusions are of Caledonian age".

Fairbairn, of the Massachusetts Institute of Technology (letter to Baird, May 6, 1957), has given two definite ages for two particular acidic rocks of Newfoundland. A quartz monzonite which occurs at Duffs, Conception Bay, is dated as being 545 million years old (late Precambrian). Also, the St. Lawrence granite found at St. Lawrence on the Burin peninsula is dated as being 360 million years old (late Ordovician).

It seems, then, that the granites of Newfoundland are of many different ages.

Because of the absence of layered rocks within the Tilting area the author cannot add any information concerning the age of the intrusions of that locality.

Along the western shore of Wild Cove, at location A-7, there occurs a perfect example of an intrusion breccia and a characteristic example of multiple intrusion. On the seaward side there is a small mass of gabbro which has been vigorously intruded by granite, the contact being marked by a deep intrusion breccia. This intrusion breccia is quite extensive as can be noted on the accompanying map sheet, and is composed of inclusions of gabbro and of a dyke rock found extensively throughout the area. This intrusion breccia, and more notably the adjacent alaskite-type granite are cut by an intermediate, fine grained dyke which extends well into the granite and is lithologically similar to the dyke fragments included into the intrusion breccia. This dyke is itself both brecciated along its sides by intruding granite and cut by many veinlets of the same acidic rock.

Because the dyke bears a direct cutting relationship with the original intrusion breccia and the adjoining granite, and also because the dyke is itself brecciated by the granite, we are forced to the following conclusions; (1) At this particular locality the granite was introduced in at least two pulsations, (2) the granite experienced a solid phase between pulsations. Were this not so the dyke in question would not show such a sharp continuous cutting relationship. That is, if the dyke were intruded while the granite was still mobile we would expect it to be somewhat contorted and not take the form of a dyke sheet, also the contacts would probably be very shadowy.

Further south along the shore of Wild Cove a similar condition prevails. At location C-7 a dyke lithologically similar to that mentioned above was observed. This dyke is continuous over the greater part of its length and terminates in an intrusion breccia in which dyke fragments are enclosed by granite. In this way the dyke grades into a local intrusion breccia which, when traced, merges into the more extensive intrusion breccia so characteristic of this area (see Figure 1, below). Again, an explanation suggesting multiple intrusions of the granite is in order.

Illustration I

The diorite gabbro complex also shows effects of multiple intrusion of consanguinious rocks. The main evidence supporting this view is found in the occurrence of fragments within intrusion breccias which are themselves composed of two different rock types in sharp contact. A typical example of this phenomenon is found on Pigeon Island where a light weathering anorthositic gabbro encloses a fragment which is composed of a gabbro and a melanocratic ultrabasic rock which present a sharp contrast (see figure 2 below).

The nature of such fragments suggests that they once marked the contact between the particular rock types which they show. Multiple intrusion again furnishes an explanation.

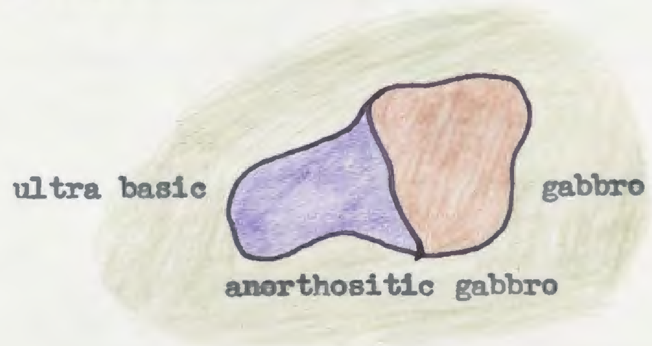


Illustration 2.

Primary Banding and Pattern

Rocks of the diorite gabbro complex commonly show a well developed primary banding which is accompanied by a primary foliation. The foliation is due to the lining up of prismatic minerals, which are usually feldspar laths and hornblende. In plan view the banded rocks do not show this foliation since although the prismatic minerals lie in the same planes they point in all directions within these planes. The banding noted in those rocks is an alternation of mineralogically unlike layers or flat lenses. The layers range in thickness from one inch to tens of feet. The texture of one band is very little different from the texture of adjacent bands and the minerals interlock across the contacts which may be sharp or gradational. In most cases there is no great difference in the mineral constituents of the bands but only in the relative abundance of the minerals. The views of the author concerning primary banding and a review of the literature will be found toward the end of this paper.

The most notable areas where primary banding occurs are Pigeon Island, on both sides of the entrance to Tilting Harbour and along the southern shore of Sandy Cove. The structural pattern presented by the banding is that of a smooth curve which begins on Pigeon Island where the strike is northeast and swings around toward the southern shore of Sandy Cove where the strike is northwest. The banding dips toward the sea at a high angle which ranges from 70° to 90°. The contact between the diorite gabbro complex and the main granite mass toward the south is roughly concordant with the structure presented by the primary banding.

A particular gabbro outcropping on Sandy Cove beach shows a structure which is somewhat different from primary banding. It shows the usual foliation accompanied by a larger scale lineation which is produced by the alignment of large needlelike inclusions. These inclusions are generally 6 to 12 inches long and approximately 1 inch wide. The lineation produced by them is parallel to the foliation of the outcrop and also concordant with the overall primary banding pattern. Those inclusions appear to be of the same composition as the enclosing rock but of a much finer grain size, which is accompanied by an aplitic or sugary texture. Because these inclusions weather more rapidly than the enclosing rock they consequently cause depressions therein. This same structure was also observed at Seldom, which is situated on the southwest portion of Fogo Island. No plausible explanation concerning these needlelike inclusions can be advanced at this time.

Nature of Contacts

The major contact between the diorite gabbro complex and the adjacent granite is in most places gradational, showing little evidence of intrusion. This is also true to some degree along the contacts between the granite and the isolated patches of the diorite gabbro complex. Yet, intrusion breccias do occur in several places along the contacts and are composed of diorite gabbro inclusions enclosed by granite or, more commonly, by granodiorite. In other places near the borders of the two masses the rock types are gradational and the bordering intermediate to basic rocks are quartz rich, while still farther within these quartz rich rocks there may be found small plugs of granite, less than 20 feet wide, which can only be logically explained by intrusion of the granite. The quartz rich basic bordering rocks also point to this conclusion. It is concluded from the above evidence that the granite is younger than the diorite gabbro complex.

At location G-5 a gradational contact between typical granite and the diorite gabbro complex was observed. Apart from a 3-foot break the contact was completely exposed and along the contact there occurred an aureole approximately 6 feet wide. This aureole graded into granite on one side and quartz rich anorthositic gabbro on the other. This aureole rock is fine grained with a sugary or aplitic texture. Plagioclase feldspar, showing albite twinning and a composition of Ab_{54} An_{46} (labradorite), is the main constituent. Potash feldspar is also present with commonly occurring carlsbad twins and zoned crystals usually showing a white, scaly, alteration product. Biotite is the only mafic mineral present and is pleochroic in brown to straw yellow. The remaining minerals are interstitial quartz, pyrite and magnetite. The percentages of the individual minerals present are as follows; plagioclase (Ab_{54} An_{46}) 60 percent, potash feldspar 15 percent, biotite 15 percent, quartz 5 percent, with accessory iron ores. The evolution of this rock is imperfectly understood and its occurrence seems to throw little light toward the problem concerning the order of intrusions.

The widespread occurrence of intrusion breccias indicates that the granite is of the juvenile type and not emplaced by metasomatic processes. Metasomatic granites are most often associated with migmatites and acidic gneisses and devoid of such structures as intrusion breccias. The occurrence of quartz rich, bordering, basic rocks might well be explained by a youthful granitization process by which quartz was introduced by the granite. However, this phenomenon is local and bears little significance toward the origin of the granite after one has considered its juvenile characteristics.

Dyke Rocks

Dykes of wide lithologic range intrude the rocks of the Tilting map area. The greater percentage of those dykes are intermediate to basic in composition although several granitic dykes were observed. Dykes longer than 400 feet were rarely encountered and thicknesses range from 1 to 6 feet. Characteristically the dykes are thin, persistent, tabular masses and are concordant and discordant in the rocks showing foliation and primary banding. Local intrusion breccias are commonly formed by the intrusion of granitic dykes.

The dyke rocks of the Tilting map area may conveniently be divided into granitic and more basic types. The granitic dykes are more common in the immediate neighbourhood of the granite mass and the intermediate to basic varieties are more common near the diorite gabbro complex.

Granitic Dykes:

Granitic dykes intrude all rocks of the Tilting area and usually occur as resistent ribs weathering less quickly than the intruded rock. These dykes range from medium grained normal granite, similar to that of the Fogo Island Batholith, to fine grained aplites, graphic granites and micropegmatite, and fine grained porphyrys.

An example of a granitic dyke similar to the Fogo granite is found at location H-12. This dyke rock has a medium grain size ranging from 1 to 3 mm. and an equigranular, allotriomorphic texture. In thin section the rock is seen to be composed of irregular interstitial blebs of quartz and accompanying feldspar. The main bulk of the feldspar is of the alkali type and is commonly coated with a white scaly alteration (kaolin?). Microcline feldspar showing grating structure is also present along with biotite which is pleochroic in dark brown to light brown. The mineral composition at this location is as follows; quartz 45 percent, alkali feldspar 30 percent, microcline feldspar 15 percent, biotite and accessory magnetite combined make up remaining 10 percent. This rock is a light pink on the weathered surface.

An example of an aplite or sugary textured granitic dyke is found at location J-14, near a region of intrusion breccia. At this locality the particular dyke rock cuts another dyke of intermediate to basic composition. The dyke is of fine to medium grain size consisting mainly of quartz with approximately 40 percent feldspar and also conspicuous flakes of black biotite mica. The rock weathers to a light grey color.

At location K-14 small granitic dykes are found cutting granite and associated granodiorite. These dykes weather a light pink to white and are only conspicuous because of their occurrence as resistant ribs of higher relief than the granite and granodiorite. This dyke rock is generally fine grained and shows micrographic and graphic intergrowths which occur at different intervals. These dykes, then, are examples of micropegmatite or graphic granite depending upon the grain size shown within a particular specimen, and this intergrowth texture explains the resistant character of the dykes.

Intermediate to Basic Dykes:

The most widespread dyke rock of the Tilting area is a melanocratic diorite which is most commonly found within the granite, associated with intrusion breccias. It is in places itself brecciated by later upsurges of the granitic magma. The dyke is fine grained to aphanitic in hand specimen and in thin section it is seen to be slightly porphyritic with slender lath shaped phenocrysts of feldspar. These feldspar laths show a rough lineation on the border of the dyke which shows a sharp contact against the granite. Plagioclase feldspar is the chief constituent and is always obscured by a heavy white alteration (kaolin?). Biotite is also common showing pleochroism in dark brown to light brown and, under the microscope, is easily distinguished from the accompanying hornblende which is usually pleochroic in light greens. Magnetite is almost always present. At location L-6, the mineral composition is as follows; plagioclase feldspar 50 percent, biotite 25 percent, hornblende 10 percent, magnetite 10 percent, with minor interstitial quartz and accessory pyrite.

A more unique dyke rock is encountered at location C-2, well within the Fogo granite. This dyke is obviously porphyritic with plagioclase phenocrysts, ranging in length from 5 to 8 mm, surrounded by an aphanitic groundmass which was found under the microscope to consist of closely packed feldspar laths. Plagioclase phenocrysts are most often beautifully zoned and commonly show combined carlsbad and albite twinning. The composition of these phenocrysts is (Ab_{15}, An_{85}), which is in the range of bytownite. Biotite which is pleochroic in dark to light brown is also present. The mineral composition at this locality is as follows: bytownite phenocrysts 25 percent, feldspathic groundmass 55 percent, biotite 15 percent, with accessory magnetite and pyrite. Patches of white alteration product are associated with the feldspars and chloritic alterations can also be seen.

Often associated with the perknite member of the diorite gabbro complex is a narrow, quartz bearing pegmatite dyke not exceeding 6 inches in width. The most striking occurrence of this dyke rock is at location I-14. The pegmatite is from 4 to 6 inches wide and has a gradational contact with the enclosing perknite. The main constituent of this dyke rock is a green amphibole (actinolite?) which occurs in prismatic crystals up to 2 inches in length. Quartz and feldspar are also present along with minor pyrite. The mineral composition of a typical specimen of this pegmatite is as follows: green amphibole 80 percent, feldspar 10 percent, quartz 8 percent, pyrite 2 percent. The occurrence of visible quartz both in the pegmatite and to a lesser extent in the parent rock raises a problem concerning excess of silica within the rock. Assuming the presence of quartz in the parent rock as due to a failure in reacting of the Bowen reaction series (Bowen, 1928), the pegmatite dyke, because of its more acidic nature and similarity to the parent rock, might be explained by lateral secretion (Ramberg, 1952), whereby the more mobile ions diffuse throughout the rock toward centres of lower chemical potential.

Order of Intrusions

The order of intrusions within the diorite gabbro complex is complicated and imperfectly understood. The following sequence is based mainly upon the occurrence of dyke rocks and the relationships of different rock masses observed within the area. The sequence in order of decreasing age is as follows;

1. Diorite Gabbro Complex; diorite, gabbro and more basic types commonly bear cutting relationships toward one another but also occur contemporaneously as bands.
2. Main mass of Fogo granite.
3. Intermediate to basic dykes.
4. Younger upsurges of granite which often brecciates the intermediate to basic dykes.
5. Granitic dykes of several varieties.

The order of intrusions is explained, to some extent, at location J-14. In this region there is a sharp contact between perknite and granite. The contact is somewhat obscured by the presence of disintegrated perknite which weathers more rapidly than the granite. However, the contact is visible in one place. Different rock types can be observed within inches of one another and no cutting relationships, chilled zones or other phenomena connected with igneous intrusions can be seen. Consequently, it is very difficult to conclude which rock type is the younger. Immediately toward the northeast of this contact and following a linear (tension joint) which presumably produces a zone of weakness, there occurs an intrusion breccia between perknite and intruding granite. This breccia also includes fragments of a basic dyke cutting the perknite near the linear break and this basic dyke is in turn cut by a granitic dyke.

It is believed by the author that the granite forming the intrusion breccia along the linear is younger than that which defines the limits of the perknite mass. This belief is based mainly upon the occurrence of the basic dyke that is brecciated by the granite, since such dykes are usually found to be post initial granitic intrusion. This is further proof that upsurges of granitic magma occurred following the intrusion of basic dykes. This is also the only locality where a granitic dyke of respectable dimensions was seen to cut a basic dyke.

Faults and Minor Shears

Only one major fault occurs within the Tilting map area. This fault was at first inferred from a linear topographic expression and later investigated on the ground. The fault in question separates Pigeon Island from the mainland and passes through the northern head of Sandy Cove, where a deep gulch is found, then traverses an area overlain by string bogs and extends out into Wild Cove. Inspection of the gulch formed on the north head of Sandy Cove showed that the rocks were somewhat shattered. The rocks were not brecciated or badly sheared but were, however, closely fractured and veins of calcite, which were not found anywhere else within the Tilting area, filled some of the fractures.

The broken rocks do not show any slickensides which are so common in fault zones and apparently it seems as if there were but little movement. The continuous relation of the primary banding on Pigeon Island with that of the mainland and also the continuation of a perknite member assist in showing that little displacement occurred along the fracture.

Minor shears occur throughout the Tilting area. These shears, mainly within the diorite gabbro complex, are marked by a more intense green appearance of the involved rock types because of the introduction of chlorite. These structures are of little significance. Tension joints are also fairly common throughout the area.

C. Petrology and Petrography:

Petrographic discription of granite occurring within the Tilting area:

Approximately 3 square miles of the Tilting area is composed of granite, and associated acidic rocks belonging to the Fogo Island Batholith. This granite is well exposed and the higher parts of the mass are nearly everywhere devoid of vegetation.

The rock is characteristically a pink, equigranular, medium grained granite, weathering light pink, grey, white buff. Medium grained facies of the granite are the most common and no notably coarse grained rock was observed. Varieties having a marked porphyritic texture are also rare. Fine grained facies are sometimes encountered but the granite along the contacts is generally not fine grained as might be expected. There is no evident structure within this rock such as foliation or platy flow structure, indeed, it would not be expected since the persistent equigranular texture provides little opportunity for the alinement of platy minerals.

The granite consists of potash feldspar, either microcline or orthoclase, quartz, soda plagioclase with associated labradorite, biotite, and hornblende. Common accessory minerals are magnetite pyrite, apatite, zircon and sphene.

In thin section the crystalline constituents generally show anhedral outlines. Subhedral cyrstals are also fairly common but crystals which are anhedral are very rare. The feldspars generally comprise the largest crystals ranging from 1 mm. to 1 cm. in length. In some specimens they are interstitial and in others they appear as discrete crystals of subhedral outline. Twinning according to the albite and pericline laws is very common and carlsbad twins are generally always present. Zoned plagioclase is also of common occurrence. Graphic and myrmekitic intergrowths of quartz and feldspar are generally present, along with perthitic intergrowths of potash and plagioclase feldspar. In some specimens the feldspars are covered with a white scaly alteration product while in others they are not. Quartz comprises from 20 percent to 50 percent of the rock, and occurs in grains and masses not exceeding 8 mm. in diameter. The quartz is everywhere interstitial to the feldspar crystals.

Among the acidic rocks of the Tilting area the following types have been recognized: alaskite type granite containing less than 10 percent dark minerals, normal Fogo granite, granodiorite and associated quartz diorite, the last being of minor extent. These types are indicated throughout the map sheet by spaced numbers which represent the particular types of acidic rock found within the area where the number occurs.

A typical specimen of alaskite type granite is one taken from Wild Cove at location A-7, and consists of quartz, potash feldspars, plagioclase, and biotite, with accessory minerals. The potash feldspars include both orthoclase and microcline which occur in crystals up to 4 mm. in length. The microcline, under crossed nichols, usually shows a characteristic grating structure caused by the crossing at nearly right angles of the twin lamellae formed according to the albite and pericline laws. Large Carlsbad twins are common and most of them are subhedral. Plagioclase showing albite twinning ranges in composition from albite (An_{10}) to andesine (An_{35}), occurring in irregular grains up to 3 mm. in diameter. A white scaly alteration product sometimes obscures the feldspars. Quartz occurs as interstitial blebs. Myrmekitic intergrowths of wormy quartz in potash feldspar occupy some interstitial spaces. Biotite, pleochroic in brown to straw-yellow, occurs in irregular wisps and shreds and generally contains pleochroic holes which inclose accessory zircon. Magnetite fills fractures in the biotite and also occurs along cleavage lines as trains of inclusions. Some chloritic alteration is present. The majority of the composing crystals are anhedral characterizing an equigranular allotriomorphic texture. The mineral composition expressed as percentages is as follows; quartz 45 percent, potash feldspar 32 percent, plagioclase feldspar 15 percent, biotite 5 percent, with accessory pyrite, magnetite, and zircon.

Granite, similar to that described above, occurs at location A-5. In thin section this granite shows lacy streaks of iron stain caused by the weathering of accessory pyrite.

A specimen of granite taken along the Tilting-Joe Batts Arm road and near the contact of the diorite gabbro complex (location F-5) is a typical example of normal Fogo granite. The mineral composition of this rock is as follows: potash feldspar 40 percent, quartz 30 percent, biotite and hornblende 15 percent, plagioclase feldspar 10 percent, with accessory pyrite, magnetite, and zircon. Microcline showing grating structure composes part of the potash feldspar present. Mykmekitic intergrowths are present to some extent and perthitic intergrowths of plagioclase, showing albite twinning, and potash feldspar can also be seen. Biotite, which is pleochroic in browns, is readily distinguished from hornblende which is pleochroic in light to dark green and also showing a slight chloritic alteration. The crystals of feldspar and the interstitial quartz generally have anhedral outlines. Magnetite is most often associated with the mafic minerals.

Rocks belonging to the Fogo batholith and containing less than 20 percent quartz have been described as granodiorites. Such rock types are quite inseparable from the normal Fogo granite and are, consequently, acknowledged and grouped within it. A specimen of granodiorite taken near Sandy Cove Pond, at location K-7, has the following mineral composition: potash feldspar 32 percent, hornblende 25 percent, plagioclase feldspar 15 percent, quartz 15 percent, and biotite 10 percent. Common accessories of this rock are magnetite, pyrite, sphene, and pyroxene. Some microcline is present and shows a grating structure. The plagioclase feldspar ranges in composition from andesine to labradorite. Feldspars are often partly obscured by a white alteration. Zoned feldspars are not uncommon. Hornblende, which is pleochroic in light green to light brown and yellow occurs in crystals of subhedral outline up to 4 mm. in length. Biotite, which is pleochroic in light to dark brown is also conspicuous. Accessory magnetite occurs everywhere throughout this rock, its distribution not being controlled by the occurrence of mafic minerals. The average grain size ranges from 1 mm. to 5 mm. and the greater percentage of the crystals have subhedral outlines characteristic of an equigranular, hypidiomorphic texture. The feldspars weather to a light grey giving the rock a lighter color on the weathered surface than on a fresh one.

A granodiorite similar in mineral composition to the preceding one occurs at location L-5. In hand specimen this rock is seen to have a porphyritic texture with phenocrysts of hornblende up to 1.5 cm. long. This particular granodiorite is readily recognized having a marked individuality as compared with other granodioritic types.

A very common granodiorite is one which occurs near Olivers Cove Head at location K-15. The mineral composition of this rock is as follows; plagioclase feldspar 30 percent, hornblende 20 percent, quartz 20 percent, potash feldspar 15 percent, biotite 10 percent, with accessory pyrite, apatite and magnetite. This rock has a very fresh appearance in thin section with little alteration which, when present, is confined to the feldspars. The grain size ranges from 1mm. to 4mm. characterizing a medium grained rock. The composing crystalline constituents generally show anhedral outlines. The plagioclase feldspar showing albite twinning is within the labradorite range ($Ab_{40}An_{60}$). Perthitic and myrmekitic intergrowths are common among the potash feldspars and zoned crystals also occur. Hornblende and biotite generally occur together and cracks and cleavage lines within these minerals are commonly filled with magnetite.

Dark weathering quartz diorites are commonly associated with the granodiorite. These rocks often contain quartz in higher proportions than the granodiorite, but are characterized by a larger percentage of mafic minerals and an impoverishment of potash feldspars. Such rock types could possibly be separated from the granite, but the nature of their occurrences with completely gradational contacts makes the problem of separation impractical. A representative sample taken near Olivers Cove Head, at location L-13, has the following mineral composition, quartz 30 percent, hornblende 20 percent, plagioclase feldspar 20 percent, biotite 15 percent, potash feldspar 10 percent, with accessory magnetite and apatite. Quartz which is readily seen in hand specimen occurs in blebs and vitreous eyes up to 1 cm. in diameter. A heavy white alteration almost completely obscures the feldspars, yet, in some cases zoned crystals can be detected below this covering. Hornblende, which is pleochroic in greens, is generally surrounded by a chloritic alteration which is much more extensive than that found in the average granodiorite. At least some part of a black opaque accessory present is thought to be ilmenite, because of the occurrence of a white alteration, probably leucoxene, which surrounds the opaque mineral. This particular specimen was taken very near an acidic granite and associated intrusion breccia, and it is believed that this particular rock arrived at its present status by the effects of silica rich, intruding magmatic fluids.

East of the southeast corner of Tilting Harbour Pond a suite of specimens was taken to illustrate the phenomenon of rock series within the granite. These specimens are from a gradational sequence which is marked by alaskite type granite on one extremity with granodiorite on the other. Beginning at the alaskite end of the series the percentages of dark minerals increase toward the granodiorite member with an accompanying impoverishment of quartz and potash feldspar.

One of the few fine grained varieties of granite occurs at location P-7. The average grain size ranges from less than 1 mm. to 2 mm. The mineral composition of the rock is as follows: quartz 35 percent, potash feldspar 30 percent, plagioclase feldspar 17 percent, hornblende 10 percent, biotite 5 percent, with accessory pyrite and magnetite. The potash feldspars including both orthoclase and microcline generally comprise the largest crystals but the rock is not obviously porphyritic. Interstitial areas between larger crystals consist of quartz and feldspar of finer grain size. The plagioclase feldspar present has a composition between bytownite and labradorite ($Ab_{30}An_{70}$) but varieties richer in soda are also present. The rock is pink on the fresh surface and provides a contrasting background for the black biotite which occurs in disseminated shreds and wisps. On the weathered surface the rock is a greyish white and a weathered zone approximately 3 to 5 mm. thick can be seen surrounding the pinkish interior in hand specimen.

Petrographic Description of Diorite - Gabbro Complex:

The essential primary minerals of the Tilting diorite gabbro igneous complex are plagioclase, hornblende, pyroxene and olivine. Different combinations of these minerals, plus the addition of common accessories, leads to quite a diverse array of rock types. For convenience of description, however, the rocks will be divided into the following series.

(1) Intermediate Series - rocks composed essentially of soda plagioclase and hornblende with accessory pyroxene, biotite, and quartz. This series includes such rock types as pyroxene diorite, anorthositic diorite, diorite, quartz diorite and granodiorite.

(2) Basic Series - rocks composed essentially of lime rich plagioclase and pyroxene with accessory hornblende, soda plagioclase and olivine. This series includes such rock types as anorthosite, anorthositic gabbro, gabbro, and hornblende gabbro.

(3) Ultra basic Series - rocks composed essentially of pyroxene olivine, hornblende and lime rich plagioclase. This series includes such rock types as lherzolite, perknite and peridotite.

<u>Intermediate Series:</u>

The most general type of diorite contains approximately 50 percent to 60 percent plagioclase and 20 percent to 30 percent hornblende. Pyroxene and biotite are usually also present in varying proportions.

A specimen taken near the Tilting - Joe Batt's Arm road, at location G-6, has the following mineral composition: plagioclase feldspar 60 percent, hornblende 25 percent, pyroxene 10 percent, with accessory apatite, quartz, magnetite, pyrite, and chlorite. The feldspars, occurring in irregular crystals and subhedral laths range in composition from labradorite to andesite. Andesite (Ab_{56} An_{44}) is the most common variety. The feldspars are generally obscured by a white alteration product but albite and carlsbad twinning can be detected beneath this alteration. Pyroxene, which is mainly augite, is generally associated with hornblende, which is pleochroic in brown to straw yellow. Cores of pyroxene are often found within hornblende crystals indicating that the hornblende has apparently been formed by the action of late magma upon the pyroxenes. Accessory chlorite shows anomalous interference colors of green and Berlin blue, and also contains bent lamellae. This rock has an overall medium grain size and most crystals are subhedral in outline.

A coarser grained variety of diorite is found within location D-9. The grain size ranges from 5 to 7 mm. and the outlines of most crystals are subhedral. The mineral composition of this particular diorite is similar to that of the preceding one with plagioclase feldspar ($Ab_{50}An_{50}$) 50 percent, hornblende 35 percent and pyroxene 8 percent, with accessory zircon, quartz, magnetite, chlorite and epidote. Chlorite which is pleochroic in light greens shows radial or wandering extinction which, upon rotation of the mineral, describes an arc relative to the spherulitic shape.

When diorite contains more than 15 percent pyroxene the assigned name is pyroxene diorite. This rock type approaches gabbro but contains too much hornblende and soda rich plagioclase to warrant that name. Such a rock type is found at location J-14 and is medium grained with a porphyritic texture. Hornblende crystals occur up to 1 cm. in length and are generally mottled with sutured outlines. The mineral composition of this specimen is as follows; plagioclase feldspar 50 percent, hornblende 30 percent, pyroxene 16 percent, with accessory magnetite and quartz. The plagioclase lies within the labradorite composition range ($Ab_{40}An_{60}$) and the pyroxenes present are mainly augite.

The name anorthositic diorite is here used to describe diorites which contain large percentages of plagioclase feldspar, generally within the labradorite range. Such a rock type occurs on Pigeon Island at location G-14. The rock consists mainly of plagioclase feldspar of labradorite range with some hornblende and minor pyroxene. This rock is medium to coarse grained with a grain size ranging from 2 to 6 mm. Feldspars are the largest crystals present and may be described as phenocrysts but the rock is not obviously porphyritic. Other characters of the rock are similar to those described under normal diorite specimens.

Quartz diorites occur frequently throughout the diorite gabbro complex but are most abundant near granite masses. A representative specimen of quartz diorite taken near a granite contact is one from location J-14. The rock is medium grained with a grain size ranging from 4 to 6 mm. Feldspars generally occur as the largest crystals and have subhedral outlines which are also characteristic of other minerals present. The mineral composition of the rock is as follows; plagioclase feldspar 50 percent, hornblende and chloritic alteration 30 percent, quartz 15 percent, with accessory magnetite, apatite, and feldspar alterations. The feldspars are completely obscured with a heavy white alteration in which sericite is visible. Chlorite is invariably associated with hornblende and occurs mainly in foliated and scaly aggregates, but also in spherulitic forms. Quartz is easily seen in hand specimen on a weathered surface and in thin section it is seen to occur in interstitial blebs which sometimes show strain shadows. The quartz is believed to have been induced by the intruding granitic magma since quartz often protrudes into foliated chlorite causing curved lamellae which give an impression of secondary quartz. The exposed surface of the rock has been weathered extensively and on this surface the feldspars show a deep alteration to kaolin which has a strong earthy smell when breathed upon.

A quartz diorite of marked individuality is found at location J-8 and

J-9 near Sandy Cove Pond. This particular rock shows a marked primary banding but the equidimensional character of the composing minerals does not permit a foliation structure, characterized by an alignment of prismatic minerals. This banding is also on a larger scale, than that encountered on Pigeon Island and near the entrance to Tilting Harbour, and the bands are generally thicker than 1 foot. A representative sample taken from location J-9, east of the east side of Sandy Cove Pond, has the following mineral composition; hornblende 50 percent, plagioclase feldspar 30 percent, quartz 12 percent, with accessory magnetite, pyroxene and biotite. The rock has a medium grain size ranging from 3 to 5 mm. and most crystals occur in subhedral shapes but euhedral outlines are not uncommon amongst the hornblendes which are readily recognized in hand specimen. Hornblende, pleochroic in light green, brown and straw yellow, apart from occurring in euhedral crystals also occurs in grains of 1 mm. or less in diameter and when combined with feldspar fills interstitial areas between the larger crystals. The plagioclase is somewhat obscured by a white alteration product making it difficult to obtain a composition determination. Chloritic alteration is present to some extent showing anomalous interference colors. Simple twinning and polysynthetic twinning are common among the hornblendes. The occurrence of granodiorite is not a very common one within the diorite gabbro complex. However, this rock type is found in certain localities but always in small amounts. Such an area of occurrence is found at location K-4, where the mineral composition is as follows; plagioclase feldspar 35 percent, potash feldspar 30 percent, biotite 15 percent, quartz 15 percent, with accessory chlorite and magnetite frequently associated with the biotite.

Plagioclase occurs in tightly interlocked crystals, showing zoning and twinning and with a composition within the andesite range of $(Ab_{54}An_{46})$. Some microcline is present among the potash feldspars and shows grating structure and myrmekitic intergrowths due to the immisibility of quartz and feldspar at low temperatures. The centres of feldspars are often covered with a minor white alteration whereas the edges are not and in some cases within a zoned crystal the alteration is peculiar to one specific ring only. Some zoned feldspars also show albite twinning within the core and not in the outward zones. Biotite occurs in disseminated wisps and shreds which are easily seen in hand specimen. In thin section it is seen that some biotite flakes are surrounded by reaction rims of chlorite being pleochroic in greens and therefore in sharp contrast with the biotite which is pleochroic in browns. This particular specimen has a medium grain size ranging from 1 to 3 mm. and most crystals have subhedral outlines.

Varieties of diorite are by far the most widespread rock types found within the diorite gabbro complex and compose approximately 50 percent of it.

Basic Series:

Anorthosite, or more precisely gabbroic anorthosite, since the amount of feldspar rarely exceeds 85 percent, is a rock type of minor importance and limited extent occurring within the diorite gabbro complex.

A coarse grained variety occurs at location G-10 and the feldspar crystals which are usually subhedral in outline reach lengths ranging from 5 to 8 mm. The mineral composition of the rock is as follows: plagioclase feldspar 80 percent, pyroxene 15 percent, with accessory hornblende, biotite, magnetite and quartz. The plagioclase lies within the labradorite range ($Ab_{32}An_{68}$) and generally contains small, lenticular, opaque inclusions which cross the albite twinning at an oblique angle. The pyroxene present also contains trains of magnetite inclusions aligned in one direction only. Accessory magnetite, carrying wormy inclusions of pyroxene, is believed to be of secondary origin. A white alteration aligned in fine needlelike shapes is often found on the feldspar.

At location H-7 the rocks bordering Sandy Cove Pond have been sheared and chloritized. Shearing has induced a schistosity within those rocks. A specimen taken at this locality has the following mineral composition, plagioclase 65 percent, chlorite 25 percent, with accessory quartz, magnetite, hornblende, biotite and alterations. The plagioclase is obscured by a white scaly alteration among which sericite can be seen and the plagioclase crystals themselves generally have no sharp outlines. The latter observation is believed to be a direct acknowledgement of the shearing. Chlorite occurs throughout the rock in lacy, mosaic patterns and also in foliated aggregates up to 1 cm. in length. The chlorite shows anomalous interference colors of Berlin blue, greenish grey and brownish red. The high percentage of chlorite present is believed to have been formed at the expense of pre-existing mafic minerals which now are found only in accessory quantities. The rock has a medium grain size ranging from 1 to 2 mm. Apart from the chlorite and other alterations the chief constituent of the rock is plagioclase and, therefore, the name chloritized anorthosite has been assigned to it.

Anorthositic gabbro occurs near Sandy Cove at location F-9. This rock has a foliation structure due to the alignment of feldspar laths and is medium grained with an average grain size from 1 to 4 mm. The texture is best described as equigranular, hypidimorphic. The mineral composition of the rock is as follows; plagioclase feldspar 70 percent, pyroxene 20 percent, with accessory magnetite, chlorite, pyrite, and biotite. The composition of the plagioclase is within the labradorite range ($Ab_{42}An_{58}$) and contains trains of inclusions which are parallel to the albite twinning when present. The chief pyroxene is hypersthene which is pleochroic in pink and generally shows trains of fine needlelike inclusions and reaction rims of chlorite.

A rock type occurring along the road near Sandy Cove Pond at location G-6, furnishes us with a representative sample of normal gabbro. The mineral composition of this rock is as follows; plagioclase feldspar 55 percent, augite 25 percent, magnetite 10 percent, chlorite 5 percent with accessory apatite and biotite. The rock is medium to coarse grained and has a somewhat porphyritic texture characterized by the presence of feldspar phenocrysts up to 2 cm. in length. The feldspar is again within the labradorite range ($Ab_{40}An_{60}$) and albite and carlsbad twinning is common. Augite occurs, in crystals up to 1 cm. across which show perfect grating structure, caused by the oblique crossing of trains of magnetic inclusions. Chlorite is found in spherulitic shapes, showing radial or wandering extinction, and also in wisps and shreds showing anomalous interference colors. Accessory biotite which is pleochroic in deep brown is invariably associated with chlorite and augite. Straight boundaries of the biotite are often lined with magnetite which seem to have been pushed aside by the force of crystallization of the biotite.

A magnetite rich gabbro or ferro-gabbro, with a fresh appearance, occurs at location D-8. The rock is medium grained and the average grain size ranges from 2 to 3 mm. Most of the crystals have anhedral outlines. The mineral composition of the rock is as follows: plagioclase feldspar 45 percent, pyroxene 35 percent, magnetite 15 percent, with accessory hornblende and biotite. The plagioclase lies within the labradorite range ($Ab_{36}An_{64}$) and shows combined carlsbad and albite twinning, generally with some zoning. Pyroxenes are mainly augite with some hypersthene and generally contain trains of magnetite inclusions which are aligned obliquely to both cleavage directions. Lacy networks of iron stain traverse the thin section.

A gabbro of marked individuality occurs near the entrance to Tilting Harbour at location H-13. This rock is characterized by a combination of different textures. In hand specimen a glomeratic texture can be seen due to the segregations of lighter colored minerals which occur at regular intervals. In thin section, however, the texture is in places equigranular allotriomorphic but where oikocrysts of plagioclase and hornblende enclose chadocrysts of pyroxene we have a poikilitic texture. The mineral composition of the rock is as follows; pyroxene 40 percent, plagioclase feldspar 30 percent, hornblende 20 percent, olivine 5 percent, with accessory magnetite and iron stain. The plagioclase feldspar ($Ab_{40}An_{60}$) often contains cracks filled with iron stain. The pyroxene is mainly augite and at times has surrounding reaction rims of hornblende due to the reaction of the pyroxene with late magma. Hornblende invariably occurs in oikocrysts and is pleochroic in light brown to straw yellow. This rock occurs within an area noted for containing beautifully banded igneous rocks.

The term hornblende gabbro is used to describe rocks which have been enriched in hornblende with an accompanying impoverishment of pyroxenes. Such rocks are fairly widespread throughout the diorite gabbro complex and generally contain accessory quartz. A gabbro of this type composed mainly of anhedral crystals occurs at location E-8. The rock has a medium grain size ranging in extreme from 1 to 4 mm. The mineral composition of the rock is as follows; plagioclase feldspar 60 percent, uralitic hornblende 20 percent, pyroxene 10 percent, quartz 8 percent, with accessory apatite, chlorite, biotite and microcline. The plagioclase lies within the labradorite range ($Ab_{36}An_{64}$) and markedly zoned crystals are common. Uralitization of augite is also an important feature. Quartz occurs as interstitial blebs and sometimes forms myrmekitic intergrowths with the feldspar. Accessory microcline shows a grating structure and chlorite occurs in the usual spherulitic and aggregate forms.

Ultrabasic Series

Rocks more basic than gabbro which occur within the diorite gabbro complex are mainly perknites consisting of hornblende, pyroxene and olivine. However, several occurrences of lherzolite are known throughout the area. At location E-8 we find such an occurrence of lherzolite. The rock is medium grained ranging from 1 to 4 mm. with an equigranular hypidiomorphic texture. The mineral composition of the rock is as follows; olivine 40 percent, clino-pyroxene 20 percent, orthopyroxene 20 percent, plagioclase 15 percent, with accessory magnetite and iron stain. The rock then is composed almost entirely of olivine and pyroxene, the latter consisting of hypersthene and augite in equal amounts. Olivine generally occurs in anhedral crystals showing deep, gaping cracks which are most often filled with accessory magnetite. The pyroxenes sometimes contain trains of magnetite inclusions which are usually aligned in one direction, either parallel or oblique to the cleavage. Less commonly, the trains of magnetite inclusions are aligned in two directions forming a grating structure. Plagioclase occurs interstitially and is within the bytownite range ($Ab_{20}An_{72}$). Simple twinning is fairly common among the large pyroxene crystals and are sometimes surrounded by reaction rims. In outcrop this rock is generally covered with brownish weathering, angular pebbles.

Perknite with a characteristic poikilitic texture is the most extensive rock type of the ultrabasic series. It is primarily a hornblende-pyroxene rock with lesser quantities of plagioclase. This rock usually shows a large scale, primary banding with no foliation structure and also occurs within the banded rocks of the diorite gabbro complex. A specimen taken from a small island in Tilting Harbour at location J-12, has the following mineral composition; hornblende 50 percent, pyroxene 25 percent, plagioclase 15 percent, olivine 5 percent, with accessory biotite, magnetite, chlorite, and potash feldspar. The rock shows a marked poikilitic texture with oikocrysts of hornblende up to 3 cm. in length. These oikocrysts of hornblende occur in irregular patterns with sutured outlines, but are at times continuous in places from 2 to 3 cm. in a direction perpendicular to the cleavage. Trains of tiny magnetite inclusions are not uncommon within the hornblende. The pyroxenes present are generally augite and hypersthene, bounded by subhedral and euhedral outlines and reaching dimensions of 2 to 3 mm. in diameter. Some pyroxenes have a green chloritic reaction rim. Plagioclase feldspar, hardly visible in hand specimen, is seen to occur in thin section as oikocrysts which are at times fairly continuous and enclose olivine and pyroxene. The order of crystallization can be plainly seen within this rock. Hornblende and plagioclase enclose pyroxene, olivine, and magnetite, and are two of the last constituents to have crystallized under conditions permitting large growth.

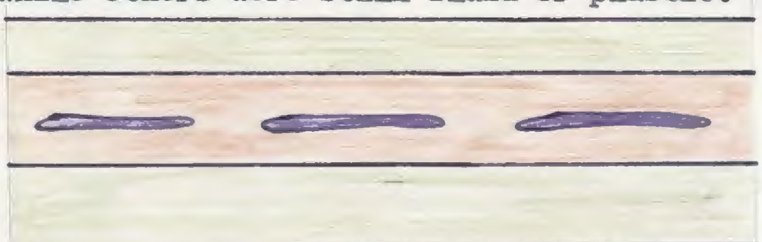
PRIMARY BANDING

Primary banding due to the alternation of mineralogically unlike layers is a world wide phenomenon among basic plutonic rocks. To explain this banding numerous explanations have been advanced, many of which involve either deformation or change of physico-chemical conditions during crystallization.

Description of Primary Banding Encountered within the Tilting Map Area.

The following description of primary banding pertains to "local banding" which is an arrangement of alternating layers on a more or less hand specimen scale. This type of orientated structure is in contradistinction to "regional banding" by which is meant the large scale repetition at different horizons of thick sheets or lenses of highly specialized differentiates. Local banding is outstandingly well shown in the gabbros and related rocks on the northwest tip of Pigeon Island and on the western head of the entrance to Tilting Harbour. Banding occurs in many other localities throughout the diorite gabbro complex but it is not of such marked character.

The banding noted in the igneous rocks of the diorite gabbro complex is an alternation of mineralogically unlike layers or flat lenses. In some cases the layers are all thin, but in others they have a wider range of thickness, at times approaching 50 feet. The lines of division between the bands may be sharp or gradational. They can, however, also be sharp and straight on one side and gradational and jagged on the other. The texture of one band is generally very little different from the texture of adjoining bands, except where poikilitic texture occurs within some perknitic bands. Minerals often interlock across the contacts. In most cases there is no great difference in the mineral constituents of the bands but only in the relative abundance of the minerals. The colors of adjacent bands may be only slightly different, or in some cases show a strong contrast. In a rock mass containing a variety of minerals any one of them may be quite completely segregated in a single band. Differential weathering, among the bands, often forms grooves or ridges in the surface. There are no basic rocks, similar to those found within the bands occurring as dykes across the bands. However, some granite sills, approximately one inch in thickness occur along and across the bands being a direct acknowledgement of the nearby granite. Some bands and lenses have a boudinage structure as seen in figure 3. This shows that some bands were solid enough to be coherent while others were still fluid or plastic.



Boudinaged Layer

Illustration 3.

The bands are generally statistically homogeneous, but, in some bands the proportion of light to dark minerals shows a progressive increase toward the top. On the other hand abundant examples of quite the reverse were also observed.

Primary foliation is invariably associated with the banding when the mineral constituents of the bands are of a prismatic shape, thus permitting such a structure. As previously stated needlelike inclusions occur within primary foliated rocks at Sandy Cove Beach, ranging in length from 6 to 12 inches. These inclusions are somewhat different from boudinaged banding in that they do not lie in a continuous line. However, this may represent a special arrangement of this structure. A similar structure was seen in the settlement of Seldom on the southwest tip of Fogo Island.

Banded diorite and quartz diorite were encountered near the south end of Sandy Cove Pond. The banding in these rocks, although of the local type is on a larger scale. The bands generally vary in thickness from one to four feet but bands of smaller thicknesses were also seen. The bands may have sharp or gradational boundaries and are usually continuous along exposure. There is no primary foliation, which is a very important feature within the banded gabbros, running parallel to the banding. The absence of such a structure is the result of the equidimensional shape of the composing minerals which could not show a primary foliation any more than rounded sand grains settling in a stream bed.

The following table shows the composition of some of the more common bands. These bands do not occur in any particular order, and the listed percentages, of the minerals present, pertain to volume.

PERCENTAGE BY VOLUME

Plagioclase	Hornblende	Pyroxene	Olivine	Magnetite	Miscellaneous
80	2	15		3	
70		20		5	pyrite, apatite
60	25	10		3	apatite, chlorite
55		25		10	" "
45		35		15	hornblende

PERCENTAGE BY VOLUME continued:

Plagioclase	Hornblende	Pyroxene	Olivine	Magnetite	Miscellaneous
30	50	4		5	biotite qts.
30	20	40	5	3	chlorite, apatite
15		40	40	3	chlorite
15	50	25	5	3	biotite

Summary of Classic Areas Showing Primary Banding.

In the Duluth Gabbro Grout (after Coates, 1936) describes mineralogically unlike layers or flat lenses which may show minor undulations or bunches, but rarely do they curve or finger into each other. There are no traverse dykes or connections but the layers may break and split.

Adams (1903) has described small scale vertical banding in volcanic plugs of the Monteregian Hills, due to the alternation of mineralogically unlike layers already differentiated before the magma reached its present position.

Harker (1904) in describing the banded gabbros of Skye, writes of patches and streaks clearly referable to either separation in place or to inhomogeniety at the time of intrusion. The bands may wind and pucker considerably. Whether or not he believed the magma to have had any quantity of suspended crystals in it at the time of intrusion is not quite clear. In discussing the same occurrence, Gaikie and Teall, as quoted by Harker, "write of alternating light and dark bands, varying in thickness from a foot downward, with thin black seams rich in titaniferous iron ores. Adjoining bands may in some cases grade into each other, or be shapely bounded. Crystals interlock at the boundaries between the bands", (after Coates, 1936).

Hall (1932) in describing the banding of the Bushveld Complex, distinguishes between regional and local banding. "The former is found at many points throughout the entire zone but met with rather more abundantly in the lower portion, and is expressed in a banded appearance of the rocks, due to which they are streaked in layers of different mineralogical composition. The latter range in thickness from a few inches down to a fraction of an inch and in many cases darker layers, much richer in pyroxene etc., than normal massive norite, alternate with light colored ones rich in plagioclase. The banded anorthosites of the critical level afford very fine examples, eg. in northern Sekukuniland. Split along a plane of banding the minerals of a layer (eg. bronzite) are seen to lie in all azimuths within that plane, but on cross fracture the tabular habit gives rise to an approximately linear disposition in the direction of the longer edges, comparable to the sub-parallel arrangement of a large number of closely packed logs of wood floating down a stream".

According to Wagner's (1924) description of the same phenomenon, this orientation is found in both prismoid and tabular crystals. He states that this structure, which is common to the norites and also to the harzburgites, is thus not a true flow or fluxion structure, for in that case, a majority at any rate of the prismoid crystals would have been swung into a parallel or sub-parallel position following the directions of the stream lines of the magma. The above structure has been termed by Bowen as a sedimentation structure.

In the Kokortokites of Greenland, Ussing (after Coates, 1936) has recognized a well developed banding, nearly horizontal throughout, but showing slight undulations. The sheets are of variable, thickness and the banding disappears near the intrusive contact with the older rocks.

Suggested Theories and Discussion.

Grout (1918) gives a valuable summary and discussion pertaining to the banded structures of igneous rocks. Of the possible causes of banding, the following tabulation includes the chief suggestions.

1. Partial assimilation of inclusions, forming schlieren.
2. Lit par lit, or fluidal gneiss.
3. Deformation during solidification.
4. Deformation just after solidification.
5. Streaked differentiation, with reference to rhythmic cooling or intrusive action.
6. Successive intrusions.
   (a) Cooling separately and successively.
   (b) Cooling later, all together.
7. Heterogeneous intrusion.
8. Grout adds "Convection during crystallization differentiation".

He dismisses the partial assimilation of xenoliths and the lit par lit injection of wall rock, as an explanation of banding, on the grounds of lacking field evidence. He defends the dismissal of these theories by referring to the Duluth Gabbro where the floor and roof of the structure are rocks of about the same composition as the average gabbro and the bands range from anorthosite to peridotite, with compositions that could hardly be synthesized from any rocks in the region.

Streaked differentiation, with reference to rhythmic cooling or intrusive action is dismissed because none of the theories of differentiation outline a process that will result in the combination of gravitative arrangement, parallel banding, and parallelism of grain. To uphold this rejection an example is presented concerning the settling of crystals in a magma. Grout states that this process might be thought of as analogous to the settling of mica plates in a sediment. Those falling on a flat bottom might adjust themselves in horizontal and parallel positions, whereas those settling on rough surfaces might assume any orientation. Grout clinches this argument by considering the structure found at Mount Johnson in the Monteregian Hills where orientation is vertical and parallel to the sides of a volcanic plug as if dragged upwards by eruptions through the channels.

Grout's argument concerning streaked differentiation is not indisputable, since neither gravitative arrangement nor parallelism of grain are necessary for primary banding in basic igneous rocks. For instance denser rocks may overlie rocks which are less dense, as in the Tilting area, and parallelism of grain in the sense of a primary lineation, similar to a tight stack of pencils, is not always present, indeed, a primary foliation as described by Wagner and Hall is much more common.

Grout's explanation of primary banding is centred around heterogeneous composition and differential movement. Of the listed suggestions those which fulfill those two conditions are successive intrusions, heterogeneous intrusion, and deformation during crystallization. Grout states that successive intrusions of slightly varying magma are undoubtedly able to produce banded rocks and may even give a crude gravitative arrangement; but the intrusion of successive layers of alternating composition, a few inches to a few feet thick, until the whole had a thickness of thousands of feet is inconceivable. The process would have to be extremely minute and often repeated in order to explain the detail of some outcrops. Heterogeneous intrusion is also excluded because of the stirring effect which would be associated with such a process, thus, destroying sharp, straight bands. Grout favors convection currents but finds it necessary to call in "rhythmic effects in the way of cooling intrusive action, or gas emanations" in order to explain the banded change in mineral composition. (after Coates, 1936).

Bowen (1936) criticized the assumption of rhythmic crystallization with plagioclase and augite alternating, and has suggested that the banding results from deformation of a crystallizing mass in which crystal accumulation is occurring. He supposes "an intrusion of the more completely liquid portion into rifts in the crystal mesh of that part of the mass in which the proportion of crystals is much greater".

The principal difficulty with the above hypothesis seems to be the production of the rifts in the crystal mesh which would approach in regularity and horizontal extent the bands observed in many large plutonic bodies. Further Bowen's suggestion, that the basining of the floor would cause the upper layers of the crystal mesh to separate from the lower, requires the assumption of a greater rigidity in the upper portion of the mass of crystals separating out of a liquid than in the lower portion of the same mass which is more closely compacted. His hypothesis also requires that these two portions separate along a horizontal tabular surface of discontinuity with considerable regularity. It seems much more probable that in the event of the basining of the floor, the crystal mesh would fail by local crushing in the upper part and experience tensional separation along rifts normal to the floor in the lower part, rather than by shear along a neutral surface. Bowen also criticizes Grout's hypothesis of convection currents as being unable to accomplish anything that settling could not do as well or better. (after Coates, 1936).

Harker believes that the banded gabbros of Skye were intruded as a non uniform mass, the different portions being drawn out as a result of flow movement. As previously stated, however, this process could hardly be expected to produce continuously straight bands over considerable distances. Neither could such a hypothesis explain the presence of primary foliation as opposed to primary lineation. The latter being the more expected structure.

Wagner (1924) and Hall (1932) explain the banding in the Bushveld Igneous Complex on a rhythmical differentiational theme. The process requires a rhythmical rain of specific minerals leading to local piles of accumulation.

Daly has recently suggested a slow basining of the magma body, causing temperature to vary more or less rhythmically along a fixed vertical line in the liquid so disturbed, with a resultant rhythmical showering of early formed crystals and development of banding in depth (after Coates, 1936).

Coates (1936) who has done experimental work with dry melts produced primary banding in the laboratory. He also suggests a mechanism which he believes will account for the production of some types of banding by the differential settling of two or more crystalline phases continuously separating from a liquid, the specific gravity of which is slightly less than that of the lightest crystalline phase, at the temperature of separation. Coates describes the mechanism which he terms rhythmic differential settling as follows: if two sorts of crystals with different densities are settling in a liquid, the density of which is but slightly less than that of the lighter sort of crystal, both varieties will settle toward the bottom. As those two kinds of crystals aporoach the bottom, the proportion of crystals to liquid will increase. When a certain limiting value is reached, since the sinking of the heavier crystals tends to displace the adjacent fluid upwards, this liquid because of its viscosity and the slow rate of settling of the lighter crystals, carries them upwards. There is thus produced a layer rich in the lighter crystalline constituent over one rich in the heavier. Crystals of the heavier variety continuing to fall upon the loose mesh of the lighter crystals will slip through the interstices of the mesh until, by the settling of the lighter crystals relative to the liquid, this mesh becomes too tight to permit the passage of any further crystals of the heavier variety. The process then repeats itself, another layer of heavier crystals being formed on top of the layer of light crystals.

The operation of this process depends upon the co-presence of several essential factors.

1. The density of the liquid must be somewhat less than that of the lighter of the two varieties of crystals.
2. The viscosity of the liquid must be enough to carry upward the lighter crystals, but not so great as to prevent their settling before crystallization is complete as in many banded laccoliths.
3. The two kinds of crystals must be approximately the same size, or one kind will slip through the crystal mesh of the other kind to a disproportionate extent.
4. The specific gravities of the two kinds of crystals must not be too close together.

Coates goes on to show how certain basic magmas fulfill these conditions. The photographs which he shows to convey the results of experimental work are not to be compared with banding in the field which is more well defined not showing shadowy contacts with little contrast. This mechanism is undoubtly effective to some extent with two substances of different densities immersed in a required liquid, yet one must consider natural magmas containing several constituents which are crystallizing under unfavorable conditions.

Conclusions

It is apparent from the diversity of theories and conflicting field evidence that there is as yet no completely satisfactory explanation to account for the primary banding often found in basic igneous rocks. Most theories, however, consider rhythmical crystallization as an explanation of the bands. The conflicting arguments arise when the exact causes of the rhythmical effects are discussed and also when orientation of grain is in question.

Within the Tilting Area the banding is accompanied by a primary foliation similar to that described by Wagner and Hall in the Bushveld Igneous Complex. It is well said that such a structure is a sedimentation structure, the foliation being produced as the crystals settled, the prismatic crystals coming to rest in a stable horizontal position. It is hard to conceive of the production of such a structure under conditions causing rapid crystallization or also if convection currents were in play, for in the latter case a primary lineation would be expected. The most favorable conditions would seem to be slow crystallization in a quiet environment.

The sharp, distinct banding of the Tilting Area does not suggest that this structure was formed under catastrophic conditions such as heterogeneous intrusion or even successive intrusion. On the contrary, the banding seems to convey the impression of elapsing time between the formation of each band and the different types of contacts between the bands such as sharp and gradational are probably due to the varying time interval experienced before the deposition of the adjoining band. The curved shape of the banding within the Tilting area as seen on the accompanying map is a syngenetic structure, the bands probably following the shape of the floor within the magma chamber.

The banded diorites and quartz diorites encountered near the south end of Sandy Cove Pond do not show primary foliation accompanying the banding. This is a direct acknowledgement of the equidimensional shapes of the crystals composing these rocks. The absence of a primary foliation under such conditions within the banded rocks can be taken as further evidence upholding the explanation of primary foliation as a sedimentation structure because were it caused by crystallization normal to differential stress we would expect to find such a structure in the banded diorites and quartz diorites.

The theory of rhythmic differential settling advanced by Coates does not seem applicable to the primary banding found at Tilting. This theory postulates the continuous settling of two or more crystalline constituents. It seems more likely that where anorthosite bands occur then plagioclase was at one time settling by itself and where gabbroic bands occur then plagioclase and pyroxene were settling contemporaneously. The exact mechanism that would favor the settling of one mineral and not the other is imperfectly understood, yet it is felt that this must have been the case, because of the consistency of the bands.

The occurrence of poikilitic texture within some of the perknitic bands may have a significance which is as yet unknown, since such a texture often requires very special conditions of crystallization to allow large host crystals to enclose smaller ones.

Bowen has pointed out that primary banding is definitely a crystallization phenomenon only found in crystalline rocks, where crystals have had time to grow. It is for this reason that we do not find primary banding in basalts where cooling occurs quickly. The occurrence of primary foliation is best explained as a sedimentation structure. Primary lineation, however, presents a different case and in areas where such a grain orientation is encountered it is reasonable to assume convection currents or some sort of deformation during crystallization to achieve such a structure.

The banding within the Tilting area seems to be best explained on a gravitational, crystallizational, differentiational theme. The layers of different compositions being deposited at different times. The exact process causing rhythmic effects in the way of crystallization is imperfectly understood, but cooling is felt to be the most probable cause.

ASSIMILATION AND INTRUSION BRECCIAS

Within the Tilting area small islands of the diorite gabbro complex occur within the granite. The occurrence of these isolated patches, along with the occurrence of intrusion breccias which mark no contacts has given rise to the theory that the present erosional surface is very near the roof of the Fogo Batholith. The composition of these isolated patches is generally more acidic than the main mass of the diorite gabbro complex and this more acidic nature is believed to be due to partial assimilation caused by the intruding granite. Rock series occur within the granite at several places, the end members ranging from quartz diorite to alaskite type granite. Several explanations have been advanced to account for rock series, but, in the Tilting area assimilation is believed to have played a major role. The nature of intrusion breccias also show the effects of assimilation since rock types which are gradational between intruded and intruding rock are a common occurrence.

Review of Literature Concerning Assimilation:

The idea of assimilation has split geologists into two groups. There are not many geologists who will not admit a limited amount of contact assimilation. Disagreement begins mainly when the larger scale aspects of the process are in question.

Michel-Levy (1896, after Stansfield) has made the general statement that magmas may attack their containing walls and be profoundly modified. An example of granite changing to diorite at its margins is cited by him in illustration near Puy de Dome in the Central Plateau of France.

Loewinson-Lessing (1911, after Stansfield) has supposed that there are two original or primordial earth magmas (granite and gabbro) from which all others are derived by fusion or refusion, assimilation, and differentiation. Differentiation is induced by assimilation of sedimentary or igneous matter. The same author thinks that there are no primordial rocks exposed but that there has been fusion and refusion of the basement.

Sederholm (1907, after Stansfield) has described cases of injection of granitic material into ancient schists of Finland resulting in more or less assimilation of the country rock and interchange of material between it and the magma. The whole has been rendered gneissoid by movement of the pasty mass or by the effect of pressure, giving rise to a "migmatite" or composite gneiss.

Collins (1917, after Stansfield) has described a granodiorite intrusion in the Onaping Map Area of Ontario with petrographical varieties caused chiefly by assimilation. Cubic miles of Pre-Huronian basic schists have been assimilated. Collins states that magmatic assimilation has long been accepted and that quantitative conceptions are needed. He raises the question of how much assimilation has there been? According to Collins the part which has disappeared upon intrusion has actually been assimilated, changing granite to hornblende granite and diorite.

Daly (1914, after Stansfield) has supposed that there is a uniform earth magma of a basaltic nature at some depth beneath the earth's crust and that all rock types as exposed at the earth's surface have been produced by processes including assimilation and differentiation. Daly has ascribed for greater effectiveness of the processes of assimilation than any other author. The granite batholiths are for him the products of assimilation of siliceous material by basaltic magma. The nepheline syenites for him have been produced as a result of assimilation of limestone by magmas already far advanced along the way of development from the original basaltic magma.

Foye (1913, after Stansfield) has supposed that nepheline syenites are due to gaseous transfer after the solution of limestone by granite.

Turner and Verhoogen (1951) state that for a completely liquid hybrid magma to form by solution (melting) of solid rock by an initially liquid magma, the latter must have originally been superheated above the temperature at which freezing would begin. Some writers such as Daly argue that magmas commonly do have considerable superheat. Others (Bowen, Shand) deny this, since the chances of differentiated magmas, which are products of fractional crystallization, becoming superheated are very small.

Bowen's (1928) experimental work has aided considerably in explaining assimilation within igneous rocks. One of the main problems (a problem which is encountered within the Tilting Area) is to explain the assimilation of basic rocks by more acidic rocks, the former being composed of constituents which have higher melting points than those composing the latter. Bowen's explanation to this problem as cited by Turner and Verhoogen is as follows; suppose that a magma has started to crystallize and that the crystals which are forming belong to the reaction series, the usual case with igneous minerals. Then the liquid is effectively supersaturated with any preceeding member of the same reaction series (i.e. a mineral which crystallizes at a higher temperature in that series). The liquid is, therefore, incapable of converting such a member into the liquid state. If crystals of this higher temperature member are added to the magma, equilibrium tends to become established once more by a process of reaction (ionic exchange between crystals and liquid) in the case of which the foreign phase is converted to crystals of that phase with which the liquid is saturated. Take the case of labradorite crystals coming into contact with a granitic melt from which oligoclase is already crystallizing. The plagioclase constitute a reaction series which becomes increasingly sodic toward the low-temperature end. The labradorite crystals therefore cannot dissolve or melt. Instead, a complex reaction occurs in which the liquid, the suspended crystals of oligoclase, and the foreign crystals of labradorite all participate. The labradorite is thereby converted to oligoclase, the phase that can exist in equilibrium with the liquid. If the reaction occurs without loss of heat (adiabatically), then the oligoclase crystals originally present become slightly more calcic as reaction proceeds.

Assimilation Within the Tilting Area.

Intrusion breccias which are fairly widespread within the Tilting area show the effects of assimilation. The breccias consist of basic to intermediate included rocks surrounded by more acidic rocks which may range from granite to quartz diorite. The inclusions are invariably rounded. This immediately points to assimilation by the intruding more acidic rocks, thus rounding the corners and jagged edges of the inclusions. The inclusions generally show a sharp contact against the enclosing rock but may also occur as relicts being almost completely changed to the composition of the intruding rock. Where original rock types can be seen a comparison can be drawn among the originally intruded basic rocks, included fragments of these basic rocks, original intruding acidic rocks, and the acidic rocks which are found enclosing the inclusions. In all cases the intermediate to basic inclusions are more acidic than the original parent rock, while the enclosing acidic rock shows an impoverishment of quartz and potash feldspar when compared with the originally intruding acidic rock. This shows that the process of assimilation is acting in such a way as to form one statistically homogeneous rock type which will be gradational between the original intruded and intruding rock.

The intrusion breccia along the shore of Wild Cove, at location A-7, provides a good example of the effects brought about by assimilation. The original rocks involved in the brecciation are hornblende gabbro and, alaskite type granite, the inclusions being quartz diorite and are enclosed by granodiorite.

The mineral composition of the original hornblende-gabbro expressed as percentages is as follows; plagioclase feldspar 30 percent, hornblende 30 percent, pyroxene 20 percent, chlorite 10 percent, biotite 5 percent, with accessory pyrite, magnetite, apatite, zircon, and quartz. The pyroxene and hornblende often show reaction rims of chlorite which is very widespread throughout the rock. The plagioclase which generally shows albite twinning has a compositon of ($Ab_{40}An_{60}$). Accessory zircon enclosed in biotite shows pleochroic halos.

The hornblende-gabbro occurring as inclusions within the intrusion breccia has the following mineral composition; plagioclase feldspar 30 percent, hornblende 20 percent, biotite 10 percent, pyroxene 10 percent, potash feldspar 10 percent, quartz 10 percent, with accessory chlorite, apatite, magnetite, and pyrite. The introduction of quartz and potash feldspar is readily noticed in thin section. Pyroxenes are at times surrounded by uralitic hornblende which formed through reaction. Quartz which is associated with potash feldspar is easily seen in hand specimen.

The granodiorite which surrounds the inclusions is much richer in hornblende, with an accompanying impoverishment of quartz and potash feldspar, than the original alaskite type granite. The mineral composition of the rock is as follows; potash feldspar 25 percent, plagioclase feldspar 25 percent, hornblende and biotite 20 percent, quartz 20 percent, with accessory chlorite, magnetite, pyrite, and sphene. Feldspars weather a light orange which gives the rock a granitic appearance. Finally, the original granite has the following composition, potash feldspar 40 percent, quartz 40 percent, plagioclase feldspar 10 percent, biotite 5 percent, with accessory hornblende, pyrite, and sphene. Myrmekitic and perthitic intergrowths are a common occurrence. Potash feldspar is at times covered with a white scaly alteration product.

The texture and grain size of all rocks involved are approximately the same, the grain size ranges from 1 mm. to 4 mm. and an equigranular, allotriomorphic texture is predominent. Similar breccias occur near Olivers Cove Head and in several isolated patches throughout the area.

Grout (1932) includes 'abnormal mineral associations,' such as those shown by quartz gabbros, as direct evidence of assimilation. The occurrence, then, of quartz rich basic rocks within the Tilting Area may also be an aspect of this process. Such abnormal mineral associations are mostly found near the younger granite and are, therefore, taken as evidence of assimilation of basic rocks by more acidic magma.

Assimilation can also be advanced as an hypothesis to explain rock series within the granite. Such series are found near Olivers Cove Head and in several other places within the granite.

Economic Geology

No economic mineral deposits occur within the Tilting Map area. An electro-magnetic survey was carried out near the settlement of Tilting during the field season of 1953 by the Newfoundland and Labrador Corporation but this did not lead to any further development within the area. Any anomalies recorded at the time were probably due to the presence of dissiminated magnetite throughout dense basic rocks.

Summary of Conclusions

The diorite gabbro complex, containing many varied rock types ranging from granodiorite to lherzolite and harzburgite, has been intruded by the Fogo granite batholith. This intrusion has produced extensive intrusion breccias in some places, while in other places, the contacts are gradational.

Intrusion breccias, which define no contacts, also occur within the granite and the occurrence of such features can be explained by assuming that the present erosional surface is very near the roof of the Fogo granite batholith.

Marked primary banding, accompanied by a syngenetic foliation, is a very prominent structure within the diorite gabbro complex. It is felt that this banding was produced by rhythmic crystallization differentiation, and that the accompanying foliation is a sedimentation structure, comparable to that of ellipsoidal particles settling on a horizontal floor.

Rock series occurring within the Tilting area, both in the granite and diorite gabbro complex, can often be explained by the process of assimilation. The nature of intrusion breccias within the area points to a certain amount of assimilation and the occurrence of quartz rich intermediate to basic rocks (abnormal mineral associations), usually near the granite mass, also point to that process.

No economic mineral deposits occur within the area.

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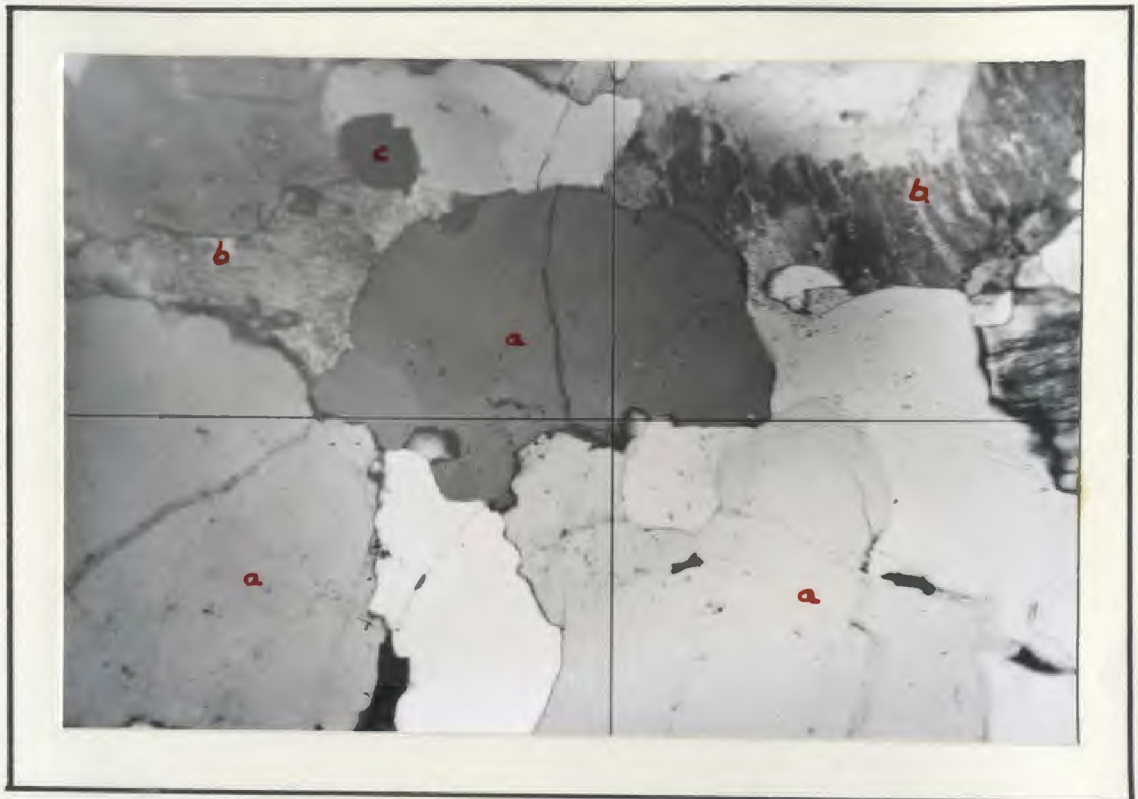


Fig. 1 Alaskite type granite. Specimen taken within location A-7. Photomicrograph shows quartz (a), potash feldspar (b) with some magnetite (c). X 65 (approx.) crossed Nicols.

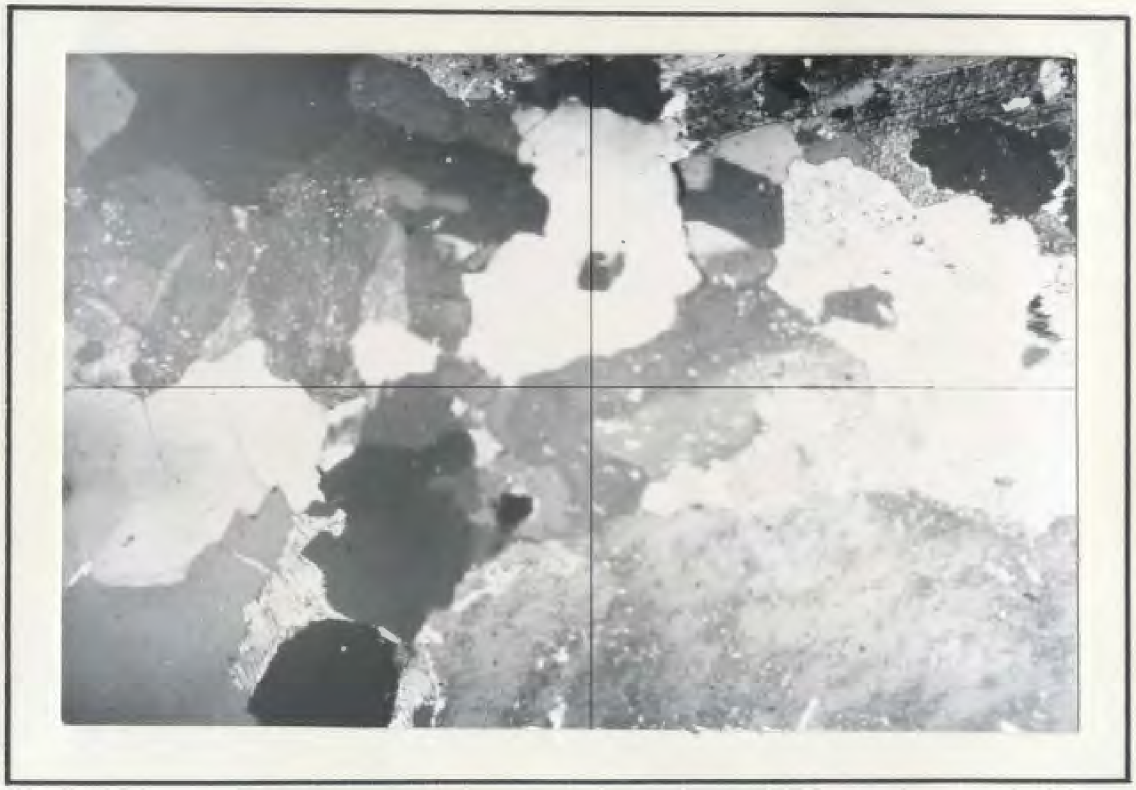


Fig. 2 Normal Fogo granite taken within location G-5. This type of granite usually contains approximately 20 percent dark minerals x 65 (approx.) . Crossed nicols.

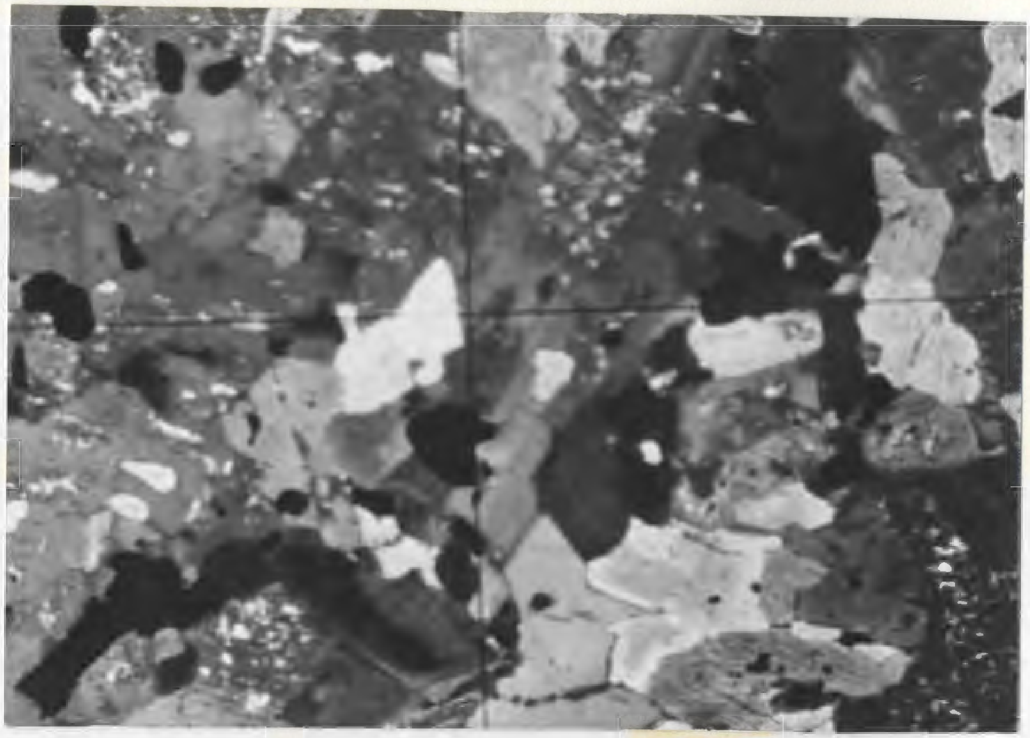


Fig. 3 Granodiorite taken from within location K-7. This rock is regionally inseparable from granite. The proportion of dark mineral generally exceeds 20 percent. X100 (approx.). Crossed nicols.

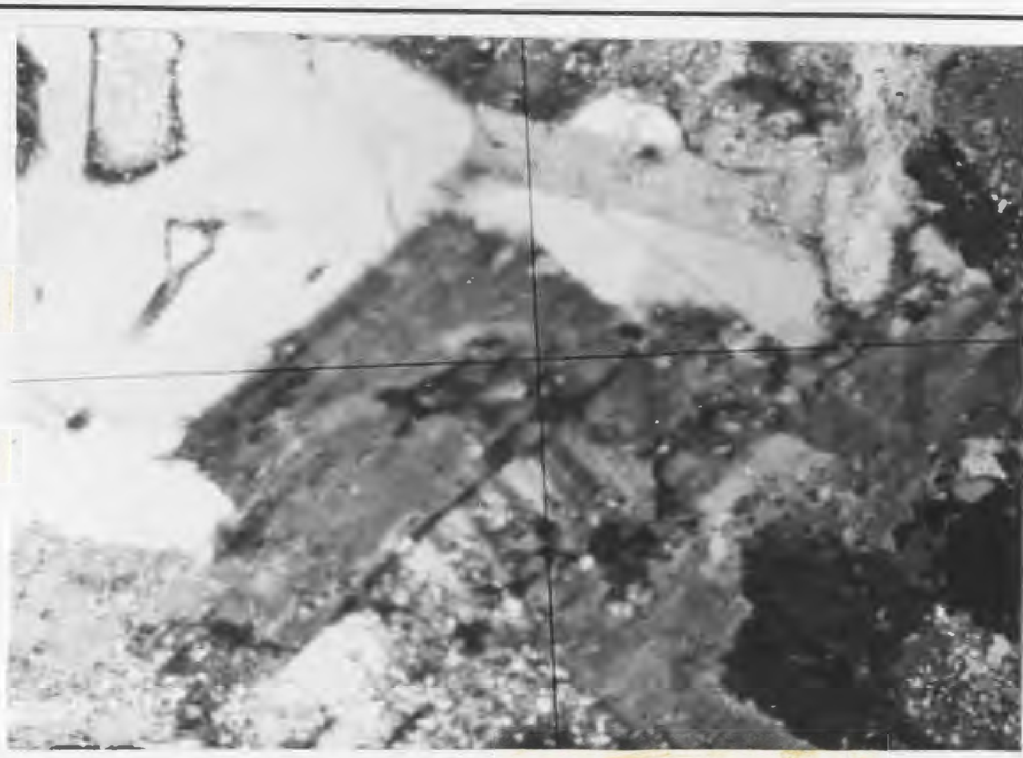


Fig. 4 Quartz diorite from location L-13. This rock is often gradational with more acidic types. Alterations are common. X 100 (approx.). Crossed nicols.

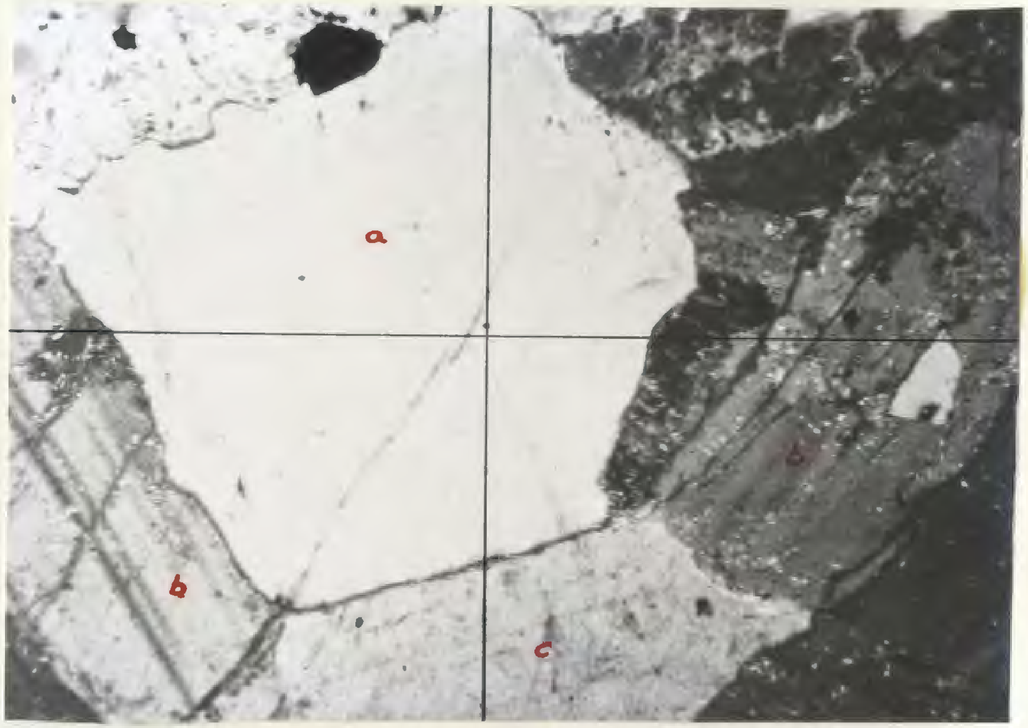


Fig. 5. Quartz crystal (a) within diorite of the diorite gabbro complex. Crystal is surrounded by feldspar (b) and hornblende (c). Sample taken within location G-6. X 100 (approx.) . Crossed nicols.

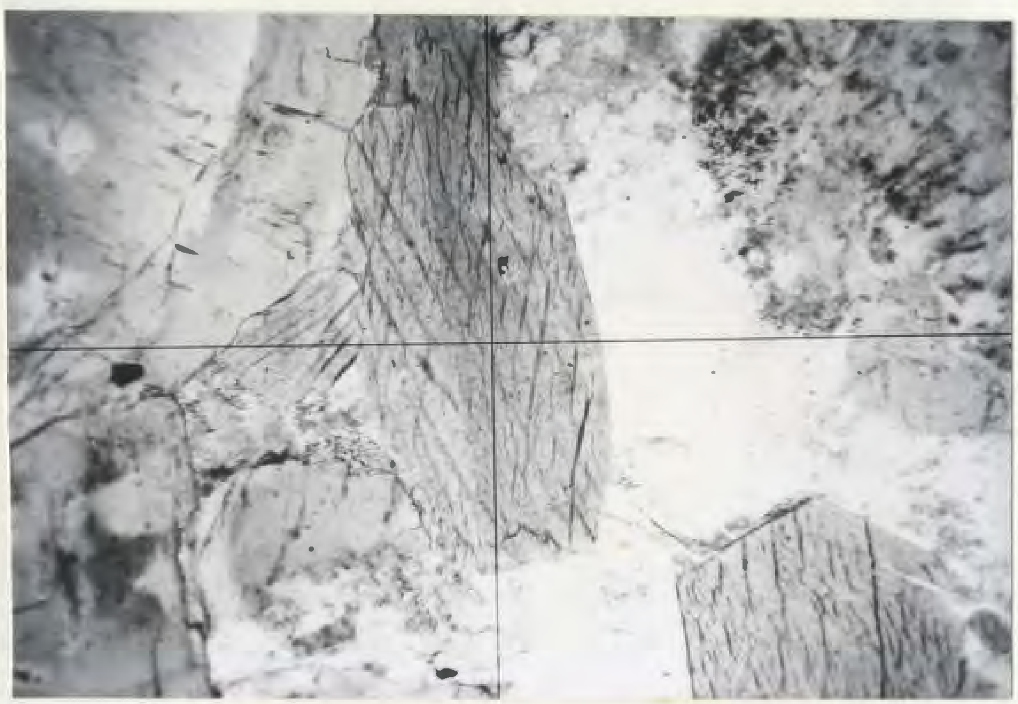


Fig. 6 Hornblende crystals as seen in quartz diorite taken within location J-8 and occurring within banded basic rocks. X 65 (approx.). Polarized light.

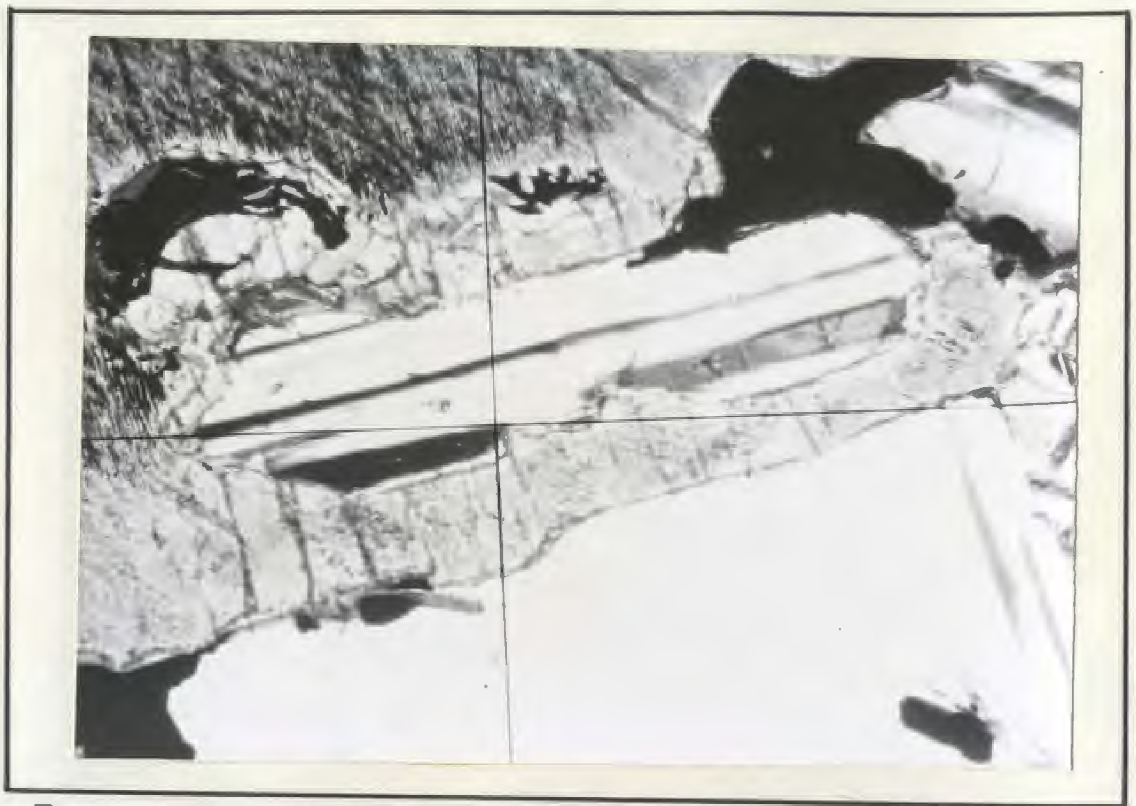


Fig. 7 Gabbroic anorthosite containing up to 60 percent plagioclase. Specimen taken at location G-10. X 100 (approx.). Crossed nicols.

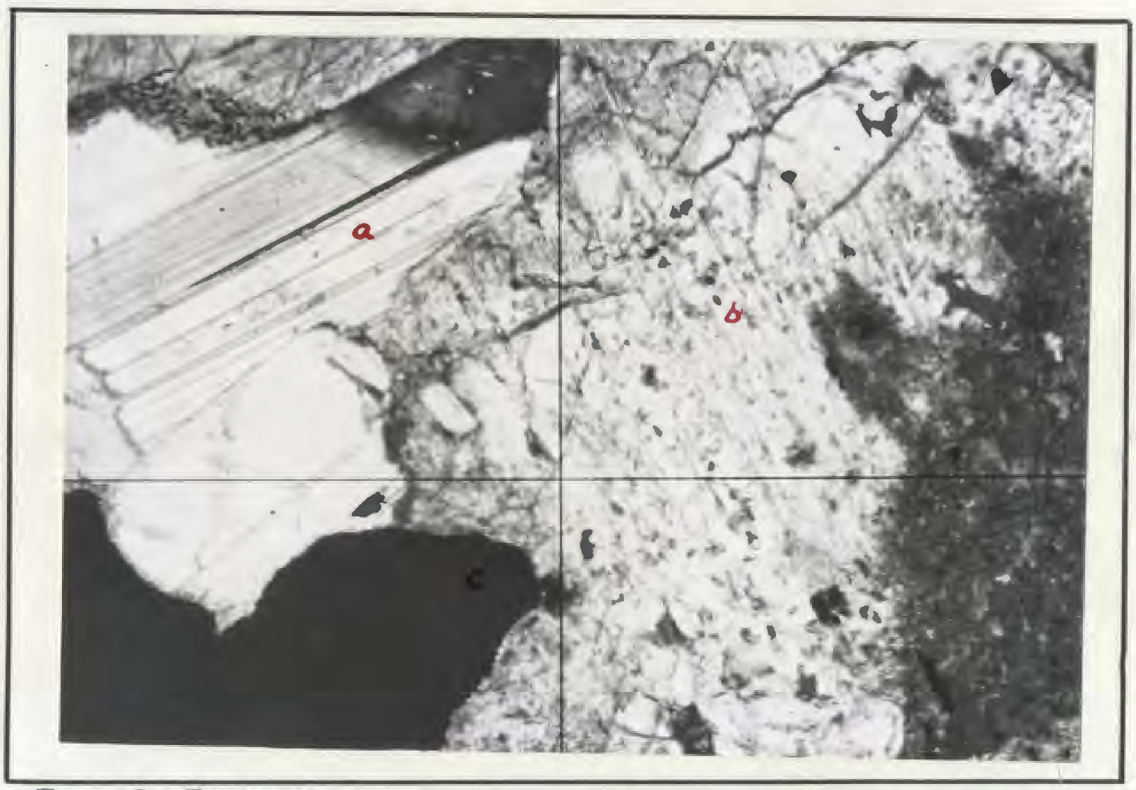


Fig. 8 Typical gabbro of diorite gabbro complex taken at location G-6. Photomicrograph shows plagioclase (a), pyroxened (b), and magnetite (c). X 100 (approx.). Crossed nicols.

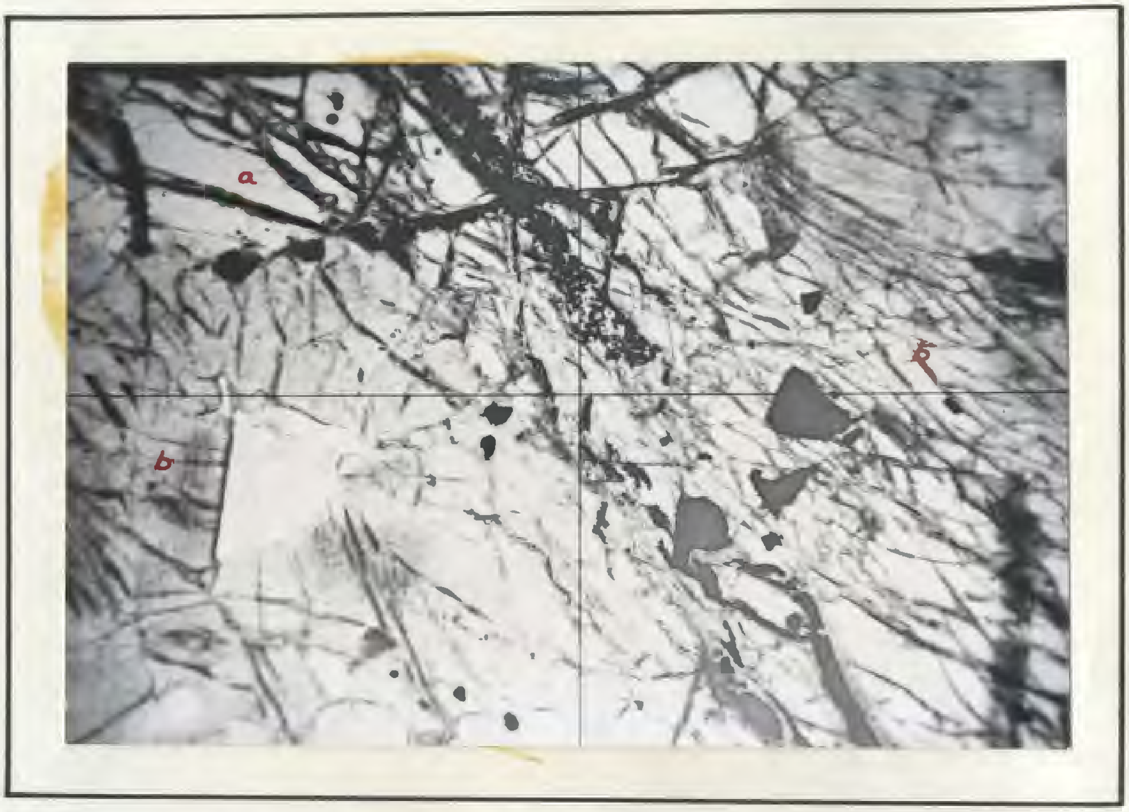


Fig. 9 Lherzolite taken within location E-8. Photomicrograph shows olivine (a), clino-pyroxene (b), and magnetite which fills cracks in olivine. X 65 (approx.). Crossed nicols.

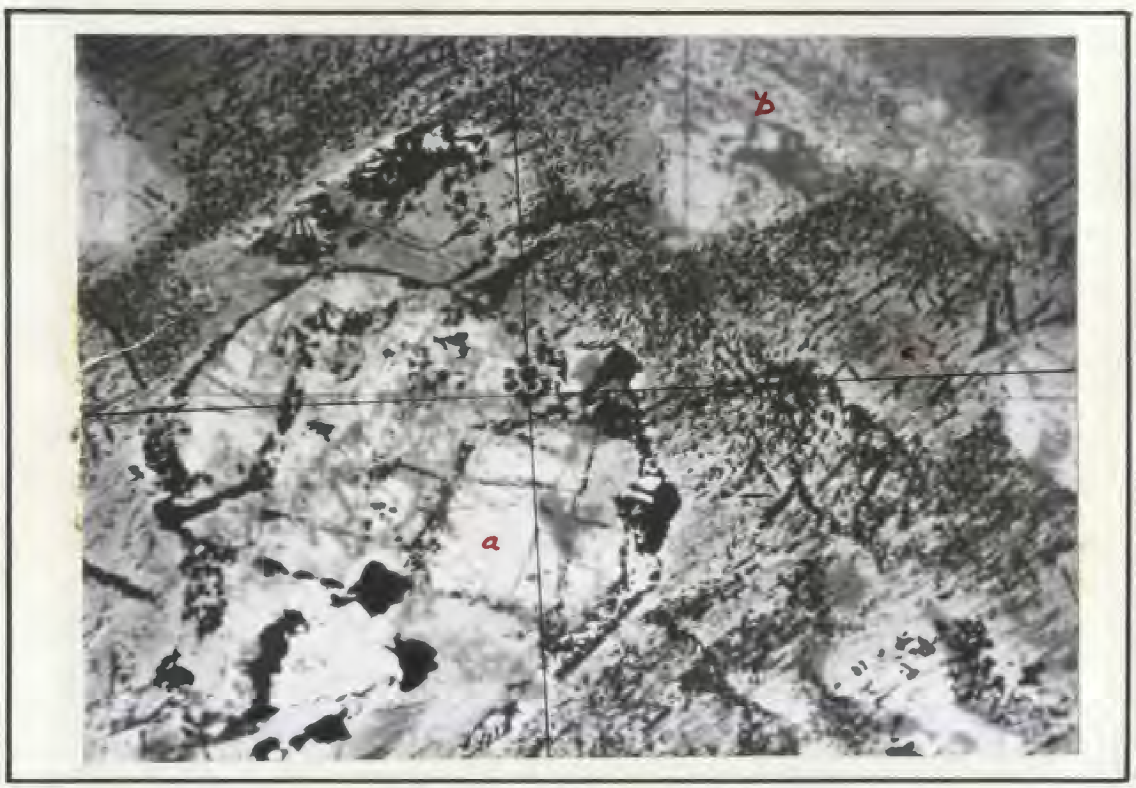


Fig. 10 Olivine crystal (a) within perknite taken at location J-12. Photomicrograph also shows pyroxene (b) enclosed by hornblende (c). Hornblende contains many small magnetite inclusions. X 100 (approx.). Crossed nicols.

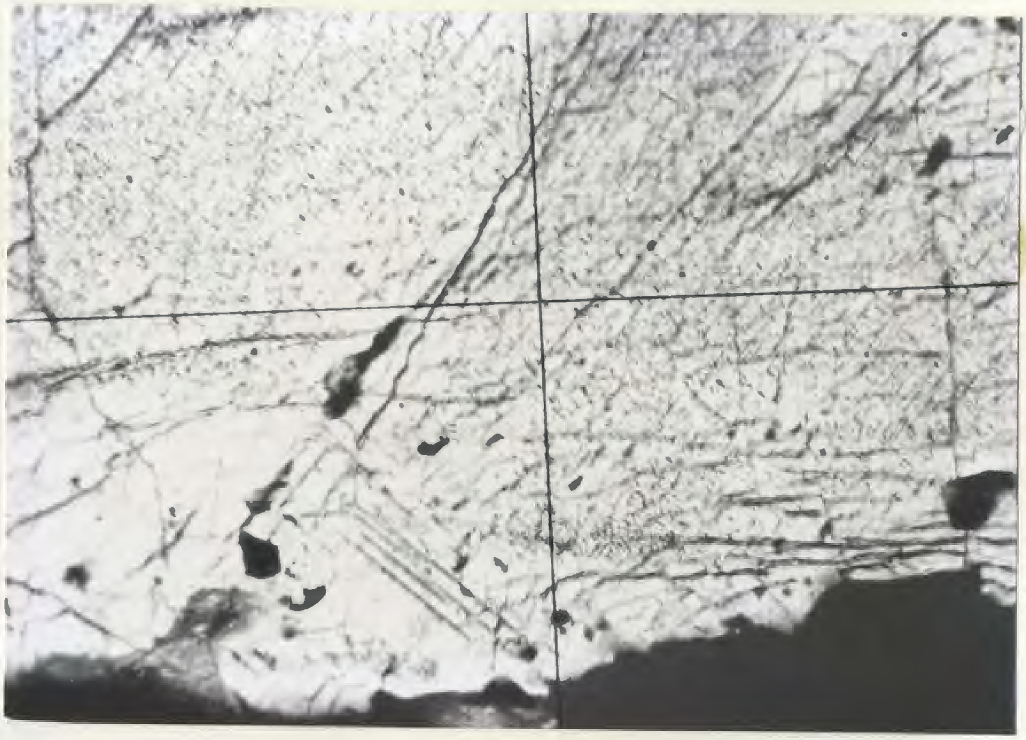


Fig. 11 Grating structure formed by trains of magnetite inclusions within augite. Specimen taken at location G-6. X 100 (approx.). Crossed nicols.

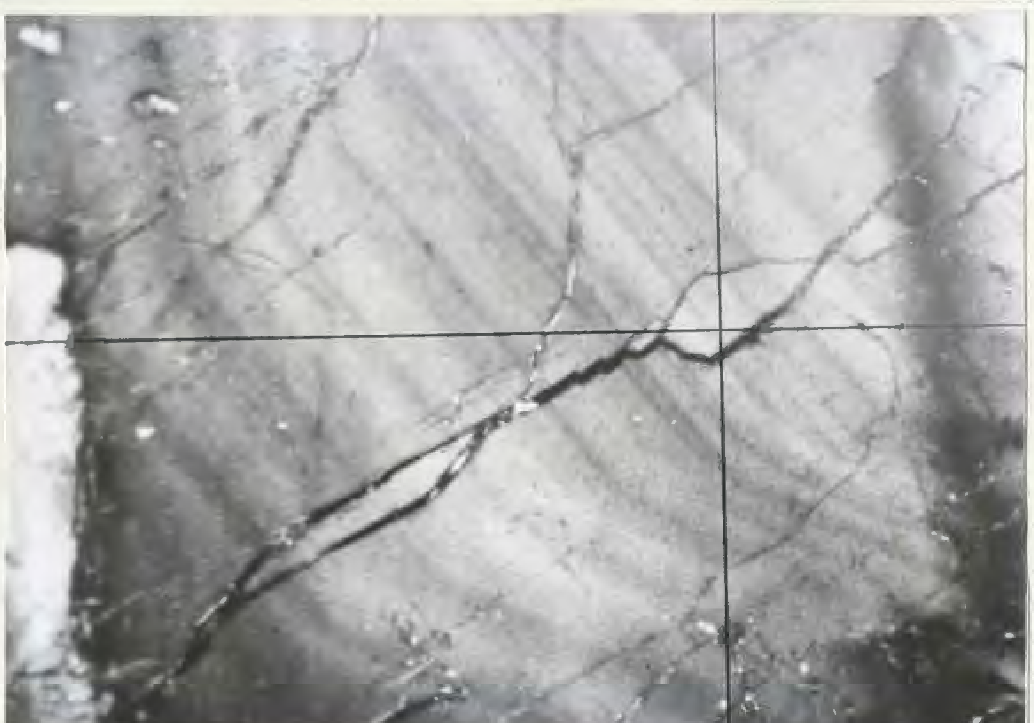


Fig. 12 Zoned plagioclase fleldspar. Specimen taken at location E-8. X 100 (approx.). Crossed nicols.

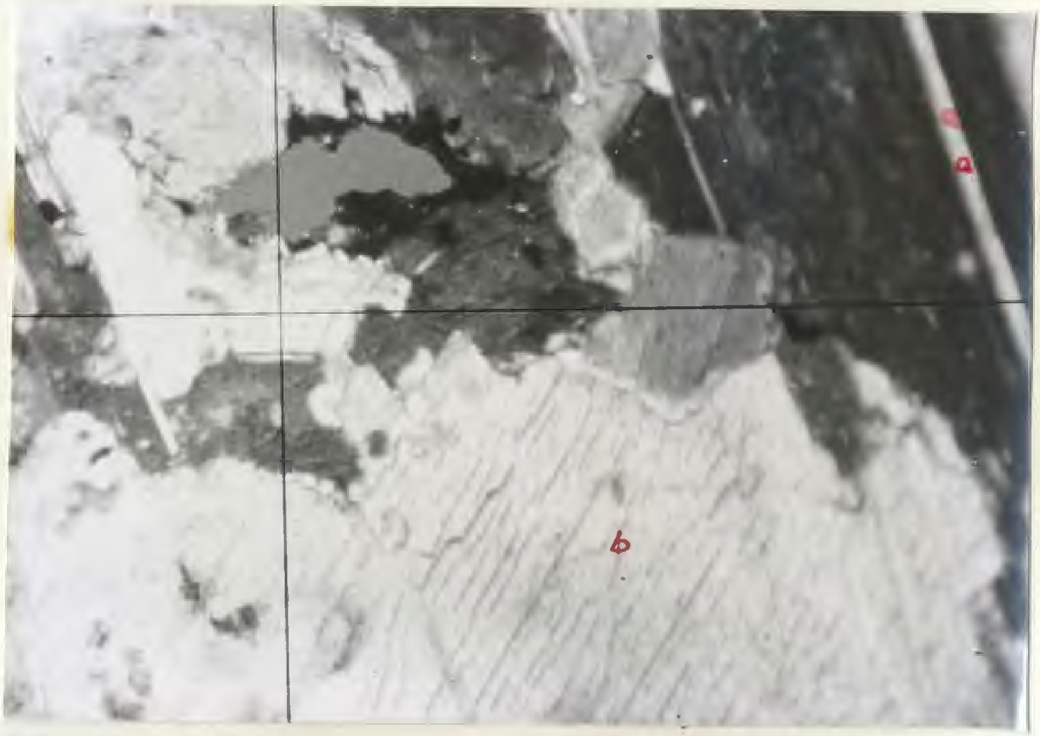


Fig. 13 Hornblende crystals showing twinning (a) and cleavage (b). Specimen taken at location J-8. X 100 (approx.) crossed nicols.

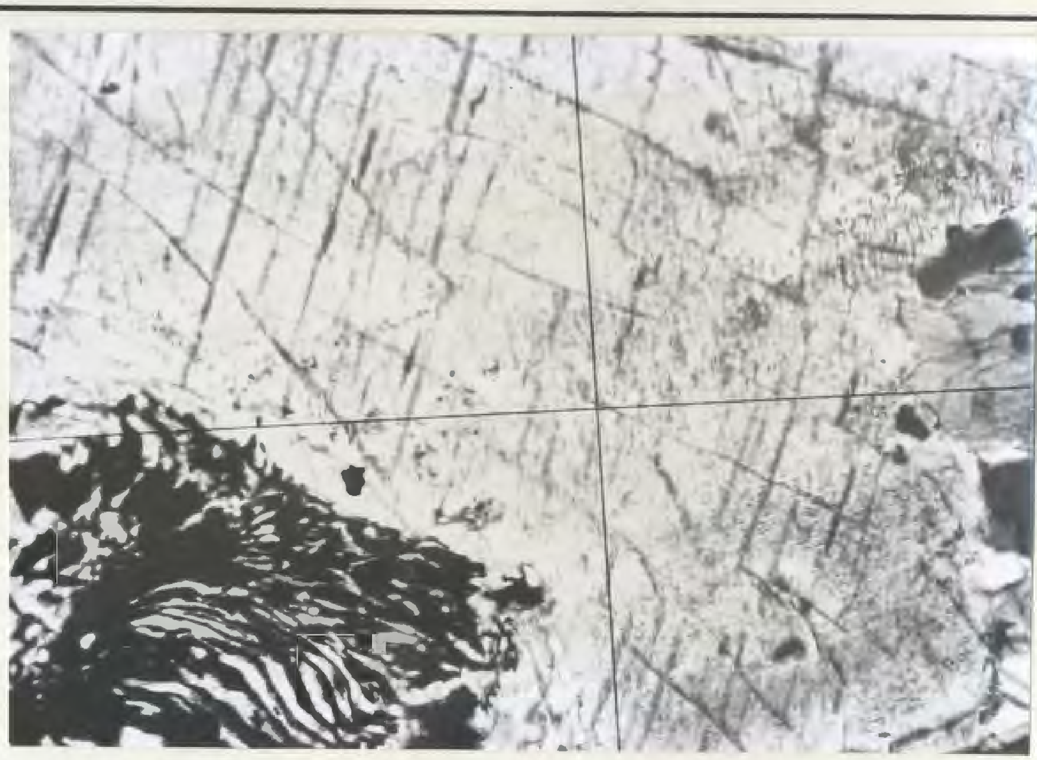


Fig. 14 Working magnetite and pyroxene crystal contained within specimen taken at location. X 100 (approx.) crossed nicols.

Fig. 15 Poikilitic texture in perknite. Sample taken at location J-12. Photomicrograph shows oikocrysts of hornblende enclosing chadocrysts of pyroxene. Hornblende also contains trains of magnetite inclusions. X 100 (approx.). Crossed nicols.

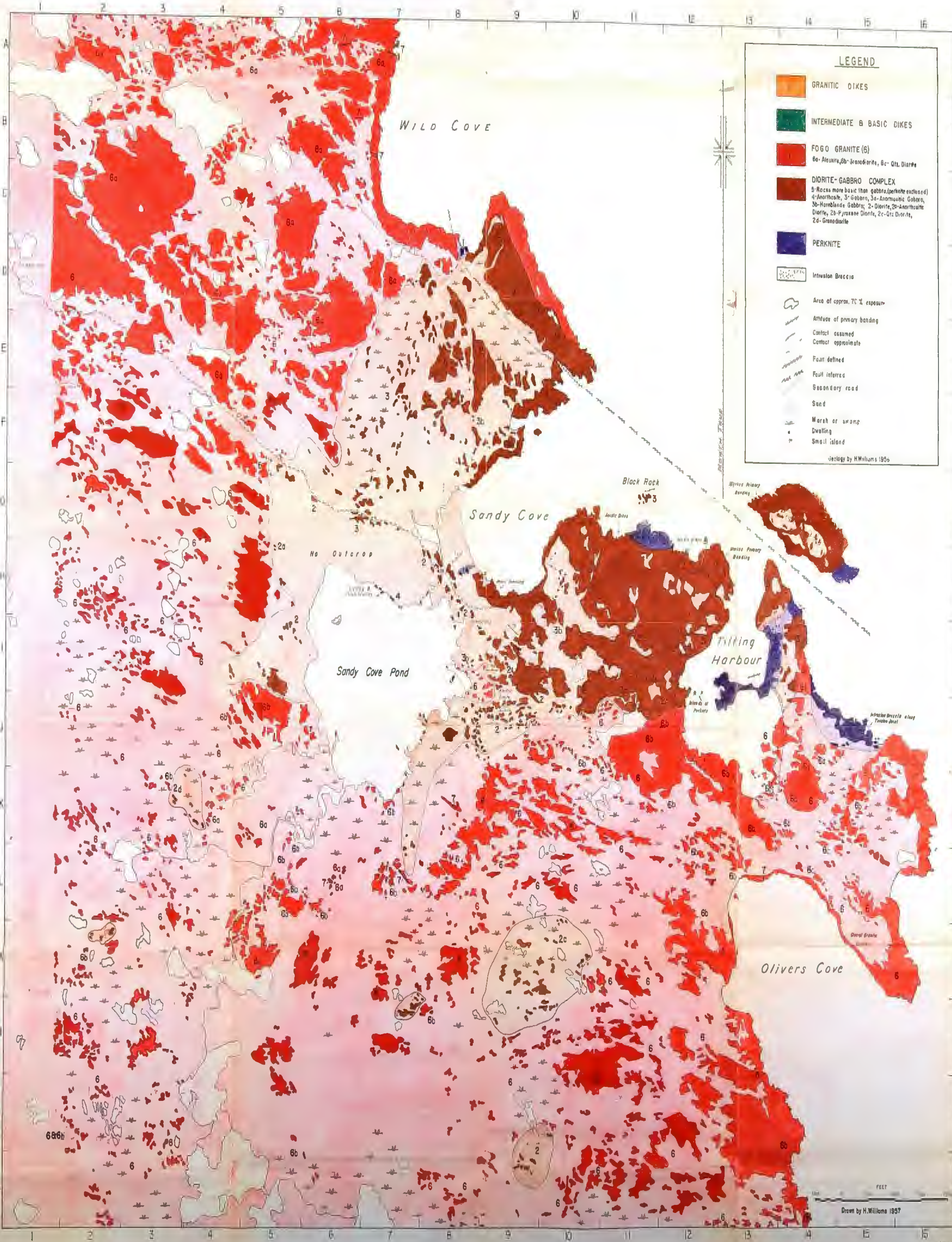
Fig. 16 Intrusion breccias formed along tension joint within perknite, east of Tilting Harbour.

Fig. 17 Banded basic rocks near northwest tip of Pigeon Island. Irregular white rocks in lower left corner are granitic dykelets.

Fig. 18 Banded basic rocks. Some contacts are sharp while others are rough and gradational.

Fig. 19 View of the settlement of Tilting looking toward the southeast.

Fig. 20 Banded basic rocks near northwest tip of Pigeon Island.



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