STRUCTURAL AND METAMORPHIC HISTORY OF THE GNEISSES OF THE PORT AUX BASQUES REGION, NEWFOUNDLAND

PETER A. BROWN

STRUCTURAL AND METAMORPHIC HISTORY
OF THE GNEISSES OF THE PORT AUX BASQUES REGION, NEWFOUNDLAND

by

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Abstract

Three geological subdivisions are recognized in the Port aux Basques area, the Cape Ray Complex, the Port aux Basques Complex and the Windsor Point Group. The first two are separated by, and the third overlies, the Cape Ray Fault. The Cape Ray Complex is thought to be the oldest division and comprises a gneissic basement intruded by two ages of granite. The gneissic basement, the Long Range Gneiss, is a somewhat homogeneous leucogneiss with basic pods, and has been intensely retrogressed. The early Cape Ray Granite is megacrystic and contains two tectonite fabrics. The later Red Rocks Granite is undeformed.

The Port aux Basques Complex comprises a series of banded gneisses intruded by the Port aux Basques Granite. These gneisses are complexly deformed and metamorphosed. The second recognised phase is the most intense and is responsible for the dominant composite fabric and gneissic banding observed in the rocks. In general the metamorphism and deformation increase in intensity from west to east as shown by the progressive development of garnet, garnet-staurolite-kyanite, kyanite-garnet, and sillimanite-garnet zones and the development of the migmatite terrain in the Margaree-Foxroost area. The second phase of deformation produced recumbent isoclinal folds with axial planes trending northwest-southeast. The third phase produced upright asymmetric folds trending northeast-southwest. The fourth phase resulted in the crenulation of pre-existing fabrics and open monoclinal folds. The Port aux Basques Granite was intruded after the first and before the second phase of deformation.

The Windsor Point Group comprises a series of metasedimentary and metavolcanic rocks which overlie the Cape Ray Fault and have suffered three phases of deformation which are related to movements on the fault. These deformations also overprint the fabrics in the Port aux Basques and Cape Ray Complexes.

The Cape Ray Fault extends for 80 km inland and is of fundamental importance in the structure of the area in that it separates two gneissic complexes of differing age, the older of which was relatively unaffected during the deformation and metamorphism of the younger.

Acknowledgements

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CHAPTER I: INTRODUCTION

Location and Access

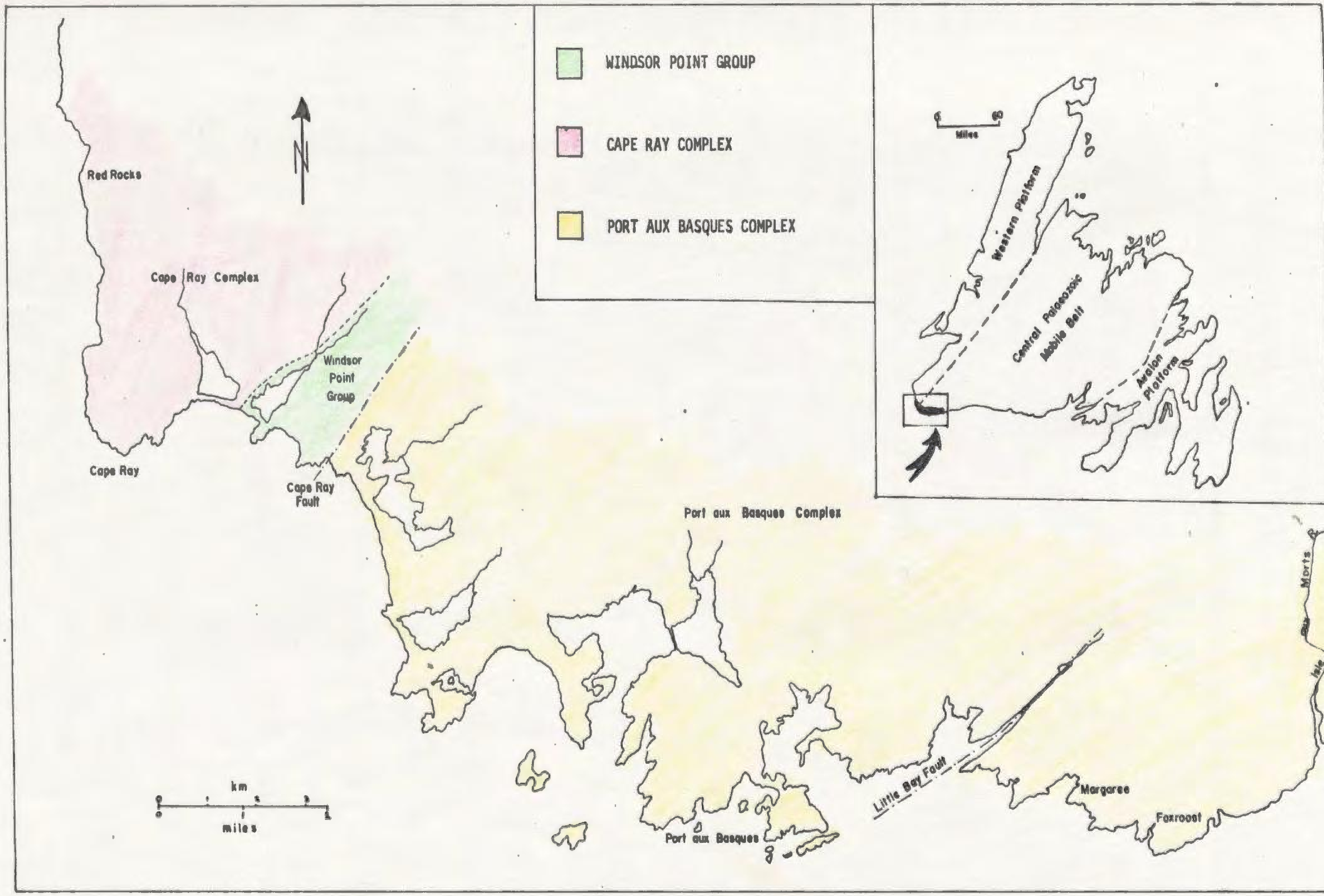
The study area is located around the town of Port aux Basques in southwestern Newfoundland and comprises approximately 80 square kilometers between the Isle aux Morts River and Red Rocks (Fig. I). The Trans-Canada Highway runs one to two km inland from the coast between Red Rocks and Port aux Basques and terminates at Port aux Basques. A subsidiary road runs eastward from Port aux Basques to Rose Blanche approximately one to two km inland from the coast. Dirt roads to Cape Ray and Foxroost further facilitate access. The main Canadian National Railways line runs east from Port aux Basques between the coast and the Trans-Canada Highway. The main settlement in the area is Channel - Port aux Basques, the C.N. terminal. Margaree, Foxroost and Cape Ray are small fishing settlements.

Physiography and Climate

Exposure in the map area is good, especially along the coast east of Port aux Basques. Sand beaches at Cape Ray, Big Barachois and between Point Enragée and Granby Point interrupt the section west of Port aux Basques. Inland the exposure is better in the east than the west. To the west the bedrock is overlain by till and waterlogged peat deposits and the valleys are densely forested. To the east, trees are sparse and bedrock crops out through a thin veneer of peat. These outcrops are generally in the form of roches moutonnées and indicate a N.N.E. to S.S.W. movement of ice. Glacial striae are not uncommon and confirm the direction of ice movement.

Rain, fog, and high winds characterize the climate in this part of Newfoundland.

FIGURE I: PORT AUX BASQUES AREA -- GENERAL GEOLOGY



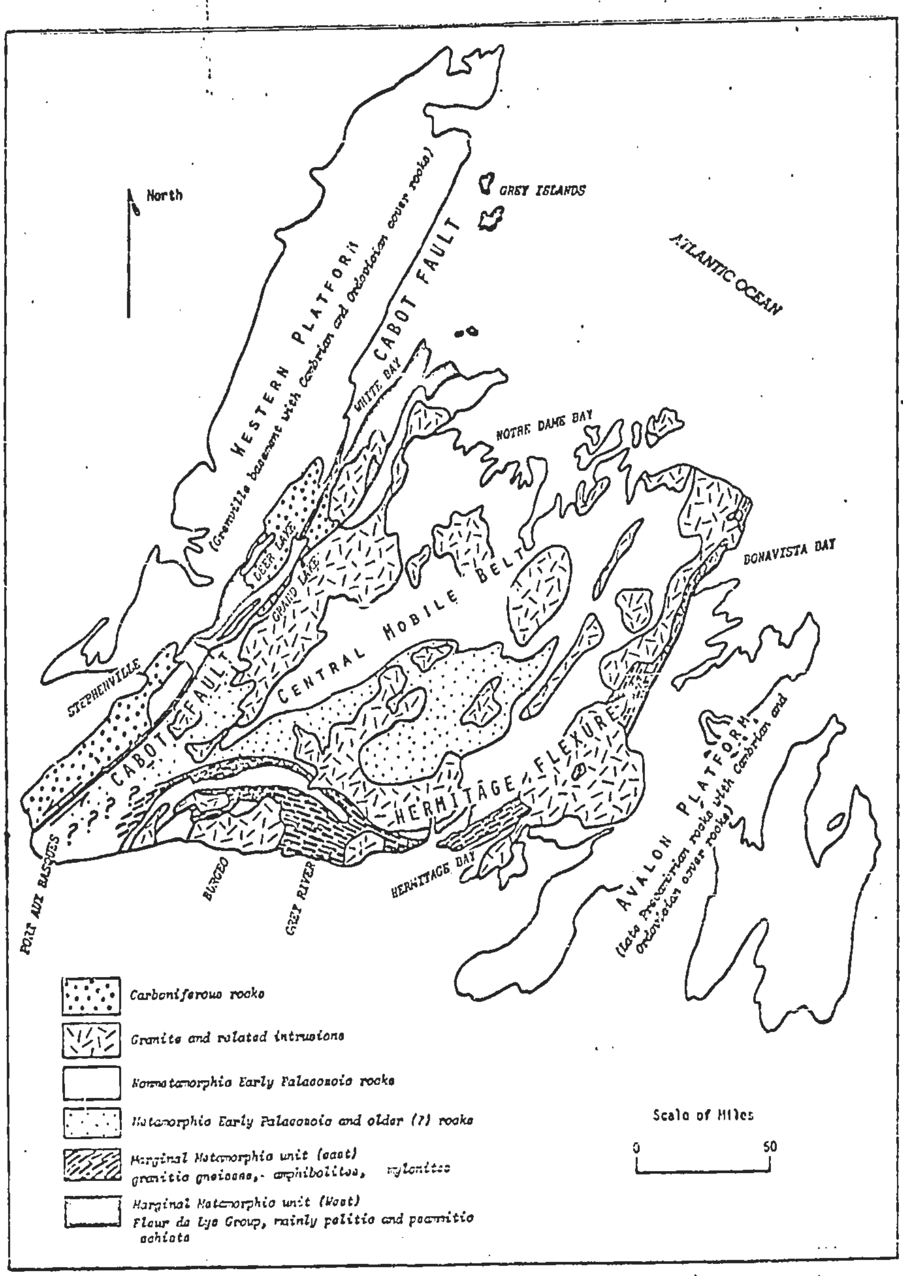
Geological Setting and Previous Work

Newfoundland is subdivided broadly into three distinct geologic divisions, the Western Platform, the Central Palaeozoic Mobile Belt, and the Avalon Platform (Williams, 1964a). The Central Mobile Belt is bounded in the West against the Western Platform, by the Cabot Fault, and is also thought to be fault bounded against the Avalon Platform in the east (Fig. II).

The eastern margin of the Central Mobile Belt consists of granitic gneisses, metasediments, amphibolites and mylonites. These rocks run in a belt from Bonavista Bay in the north to Hermitage Bay in the south, and Williams et al. (1970) suggest that they further extend along the south coast towards Port aux Basques, defining what is referred to (Williams, et al., op. cit.) as the Hermitage Flexure. Thus the Central Mobile Belt which is 200 km wide on the north coast of Newfoundland is only about 65 km wide in the Port aux Basques region. This thinning of the Belt is attributed to open folding around the Hermitage Flexure followed by westward truncation by left-lateral displacement along the Cabot Fault.

However, correlation between the Port aux Basques area and the rest of the Central Mobile Belt is somewhat tenuous as the geology of this region is not well known. Murray and Howley (1881) recognised the continuation of the Precambrian rocks of the Long Range in the Cape Ray area. Phair (1948) regarded the Long Range igneous and metamorphic complex as being Palaeozoic in age and correlated the marbles which are interbedded with the gneisses and schists with those in the Humber Gorge. Cooper (1954) mapped the area around La Poile Bay, east of the present map area, and indicated that the oldest gneisses of that area, the Keepings

FIGURE II



GENERAL GEOLOGY AND MAJOR STRUCTURAL SUBDIVISIONS

(After Williams, H., Kennedy, M. J., and Neale, E. R. W., 1970)

Gneiss, are older than recognisable metasedimentary and volcanic rocks, some of which contained Devonian fossils. The Keepings Gneiss is probably the along strike continuation of the gneisses east of Cape Ray. Power (1955) mapped a small area close to Isle aux Morts and Gale (1965) carried out an economic survey of the pegmatites between Isle aux Morts and Rose Blanche. However, it was not until the work of Gillis (1965) that a regional map of the area from Cape Ray to Rose Blanche was produced. Gillis divided the gneisses of the area into three broad belts separated by the Cape Ray and the Bay d'Est faults. West of the Cape Ray fault he recognised a complex of gneisses and schists intruded by granitic, mafic and ultramafic phases which he correlated with the Precambrian rocks of the Long Range and the Indian Head Complex near Stephenville (Riley, 1962). No age was assigned to the gneisses east of the Cape Ray and west of the Bay d'Est fault but Gillis suggested a correlation with the Keepings Gneiss of La Poile.

Pegmatites near Rose Blanche (Gillis, 1965) and Channel-Port aux Basques (Neale, 1963) yield K-Ar ages of 400 ± 20 m.y. and 415 ± 20 m.y. respectively. Similar K-Ar age determinations on biotite and muscovite of interlayered quartz monzonite on the La Poile river yielded ages of 346 ± 20 m.y. and 344 ± 20 m.y. (Gillis, 1967).

The present study resulted in the area being subdivided into three broad divisions, the Cape Ray Complex, the Port aux Basques Complex and the Windsor Point Group. The Cape Ray Complex occurs west of the Cape Ray fault and comprises a series of gneisses intruded by granites. These are correlated with the Long Range Gneisses. The Port aux Basques Complex lies to the east of the Cape Ray fault and comprises a banded series of gneisses and schists intruded by the Port aux Basques Granite. Lack of geological data to the north and west of the area makes correlation with other gneisses in the Central Mobile Belt somewhat tenuous. The Windsor Point Group are a series of metasedimentary and volcanic rocks that occur within Cape Ray fault zone. These have been little deformed and are the youngest rocks in the area.

If a Devonian age of deformation and metamorphism of the Port aux Basques Gneiss is accepted, as suggested by the K-Ar ages, then these events must have been very intense in the Port aux Basques area and consisted of at least four phases of intense deformation and metamorphism. However, this correlation is thought to be untenable since the Devonian age dates were obtained from pegmatites which were intruded into an already deformed gneiss complex and were themselves subsequently deformed.

METHODS OF PRESENT STUDY

The area was mapped, using aerial photographs, on a scale of 1:20,000 and locally in the vicinity of Port aux Basques on a scale of approximately 1:10,000. Throughout the principles of small scale structural mapping (Wilson, 1961) were applied. Three types of tectonite fabric were recognised, i.e. L, L-S, and S tectonites (Flinn, 1965). An L tectonite is one in which the fabric element is characterised by an axial direction rather than a planar surface. An S tectonite is one in which the dominant structure is a schistosity plane or surface. An L-S tectonite contains elements of both these types. The fabric associated with any one phase of deformation may vary across a section from an L to L-S to S tectonite due to variation in the nature of the deformation ellipsoid (Flinn, 1962). Recognition and interpretation of overprinting and transposition of these elementary fabric types in successive deformations resulting in a composite fabric (Whitten, 1966; Rast, 1965) forms an essential part of the present study.

Orientation data for the major planar and linear fabric elements are presented stereographically and on the geological map.

The petrographic microscope was the main tool used in the laboratory and mineral identification and composition (where in a solid solution series) was made using standard identification techniques. Identification and interpretation of intergrain relationships is based on the principles developed by Harris & Rast (1960), Voll (1960), Kretz (1960), Vernon (1968), Spry (1969) and Stauffer (1970).

CHAPTER II: WINDSOR POINT GROUP

The Windsor Point Group is a series of metasedimentary and volcanic rocks which crop out in a 1.5 km wide belt just south of Cape Ray. They strike northeast-southwest and dip steeply to the southeast, and consist of ignimbrites, tuffs, conglomerates, shales and rhyolites. To the northwest the ignimbrites unconformably overlie the Long Range Gneiss. To the southeast they lie in fault contact with the Port aux Basques gneisses. Their northeastern extent along strike was not delineated.

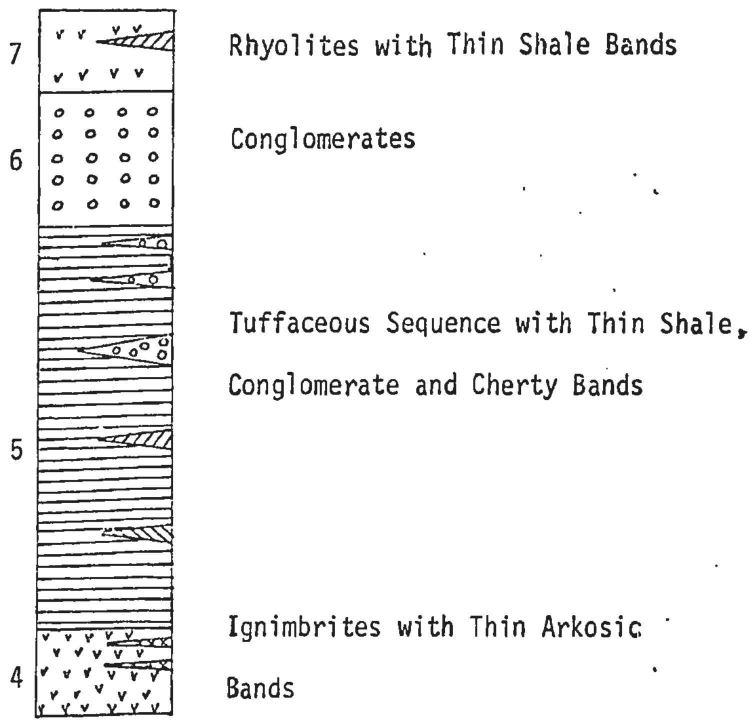
The general stratigraphic sequence becomes younger from northwest to southeast (Fig. III). Ignimbrites with arkosic bands up to 1 m thick unconformably overlie the Cape Ray Complex. (Although the contact is not actually exposed, the highly irregular outcrop pattern implies an unconformity.) These pass up into a tuffaceous sequence with occasional cherty bands. The contact between these two units was not observed. Bands of conglomerates up to 2 m thick occur in the southeastern portion of the tuffaceous unit. These become more numerous upwards until the rock is essentially conglomeratic. To the southeast the conglomerates pass abruptly into rhyolites. These are separated from the Port aux Basques Complex by the Cape Ray fault.

Deformation increases in intensity towards the Cape Ray fault and related planar structures are parallel to the trend of the fault. Two distinct episodes of penetrative deformation can be recognized. Minor faults and kink bands cut these penetrative structures. The kink bands are normal (Dewey, 1965) and strike north-northeast or east-southeast.

Ignimbrite Sequence

At their base the ignimbrites are black, fine-grained, highly welded and almost shard free. Phenocrysts of quartz and k-feldspar are

Figure III



General Stratigraphy of the Windsor Point Group
(Numbers refer to Legend on Large Map)

abundant. This rock type passes eastwards into a grey, fragment rich rock. The fragments are around 1-2 cm in length and are generally flattened and display a flow banded texture.

Further east the rock becomes agglomeratic and haematite rich, giving it a reddish pink aspect. The fragments are up to 30 cms in diameter and are derived from the Cape Ray Complex. Bands of coarse arkose, up to 1 m thick, occur in this part of the sequence.

One penetrative cleavage is present in the fine-grained material, but is not apparent in the coarser bands.

In thin section the ignimbrite is fine grained and glassy with a prominent flow banding developed. Sub-euhedral phenocrysts of quartz and k-feldspar are common. The flow banding augens these. The volcanic fragments are predominantly glassy with abundant small quartz phenocrysts. These are all flattened but whether the flattening is due to primary flow or to the superimposed deformation could not be determined. There is probably an element of both mechanisms.

Tuffaceous Sequence

The tuffaceous sequence is comprised of fine grained green tuffs with thin, black pelitic and brown cherty bands. Occasional bands of conglomerate occur in the eastern part of the section.

In the west the rocks are fine grained green tuffs with two sub-parallel penetrative cleavages. Mica has grown on both these cleavages, giving the rock a phyllitic aspect. Cross bedding found in one thin cherty band indicates right way up, i.e. succession youngs eastwards.

Elongated quartz and feldspar pods and lenses become noticeable in the central part of the sequence. These increase in number and length to the east and all plunge steeply to the northeast. The result is a 2-3 mm wide tectonic banding comprised of quartzo-feldspathic rich and epidote rich bands.

In thin section the rock is seen to be extremely fine grained. Individual grains being generally less than 0.1 mm across. The green bands are composed essentially of epidote set in a fine grained quartz rich matrix. In the light bands the fine quartzitic material predominates. No definite composition could be ascribed to these light bands and pods due to their fine grained nature.

Conglomeratic Sequence:

The conglomeratic sequence occurs to the east of the tuffaceous unit and consists of conglomerate bands up to 8 m thick interbedded with fine tuffaceous material. The lower contact with the tuffaceous sequence is conformable and gradational.

The composition of the pebbles is highly variable with volcanic, granitic and gneissic varieties occurring. The granitic pebbles closely resemble the Cape Ray Granite and the gneissic pebbles are similar to the Long Range Gneiss. The percentage of volcanic pebbles decreases towards the Cape Ray fault. No pebbles resembling the Port aux Basques gneisses were observed. The pebble diameter varies from 1 cm to 40 cms, and all are well rounded and water worn. The original shape is difficult to determine since most of them have been deformed, although some still retain a rounded aspect.

The matrix is fine grained, green tuffaceous material. Near the Cape Ray fault this becomes banded into quartzo-feldspathic and epidote rich layers up to 3 mm thick. This banding forms augen around the pebbles. Where the banding is not developed a penetrative cleavage in the matrix forms augen around the pebbles.

Close to the tuff-conglomerate contact a 50 cms wide conglomerate bed is openly folded (Fig. IV). It also closes on the limbs of the fold, indicating the original discontinuous nature of the conglomerate bands as no tectonite fabric goes round the fold. An axial planar fabric is associated with the fold.

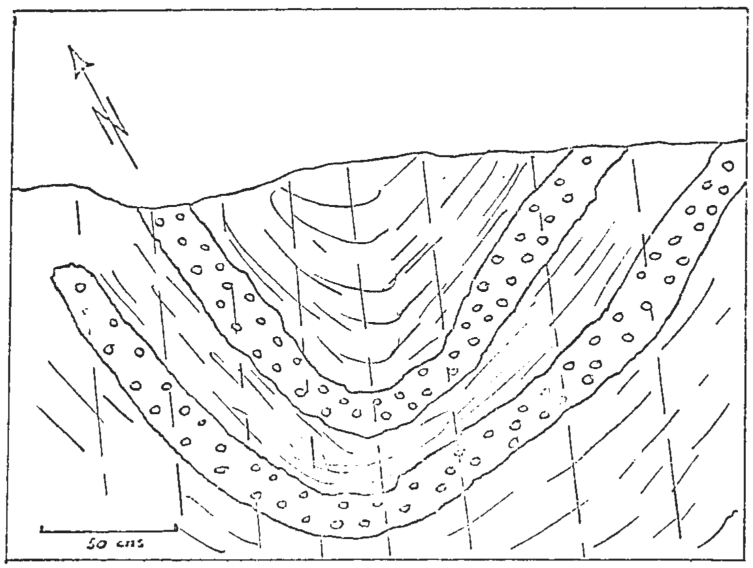
One well-rounded pebble of igneous origin was sectioned. It is a fine-grained equigranular rock consisting of epidote, quartz and magnetite. No feldspars were observed. No conclusion as to the original composition could be arrived at.

Rhyolitic Sequence

These rocks occur between the conglomerates and the Cape Ray fault. They pinch out northwards bringing the conglomerates into juxtaposition with the fault at the Trans-Canada Highway. The contact relationships with the conglomerate were not observed.

In field aspect it is a finely banded, pinkish, fine-grained rock. The bands are 2 to 5 mm wide and are alternating quartzo-feldspathic and micaceous segregations. Quartz and feldspar crystals are contained within augen of this banding.

Figure IV



F_5 Fold near the Tuff-Conglomerate Contact in the Windsor Point Group

Muscovite and chlorite in the micaceous bands define a schistosity. Subsequent deformation has isoclinally folded this fabric and produced an axial planar fabric, which is defined by muscovite and chlorite. The fabrics are subparallel on the later fold limbs.

Minor shale bands up to 15 cms wide occur within this unit. They are continuous and contain the same tectonite fabrics as the rhyolite although no related mineral growth was observed.

In thin section the rhyolite has a fine grained crystalline quartz-feldspar groundmass containing a fabric defined by mica and chlorite. The fabric is strongly developed and has been refolded. This folding is accompanied by an axial planar fabric which bears a strain slip relationship to the first fabric. The original fabric often forms augen around phenocrysts of quartz and feldspar. The feldspar is orthoclase in composition.

CHAPTER III: CAPE RAY COMPLEX

The Cape Ray Complex crops out west of the Cape Ray Fault and consists of the Long Range Gneiss, the Cape Ray Granite and the Red Rocks Granite. It is overlain by the Windsor Point Group. The Long Range Gneiss, the oldest rock type in the Complex, is a leucocratic gneiss with sparse basic pods, and is intruded by the Cape Ray and Red Rocks Granites. The Cape Ray Granite is megacrystic, contains two pervasive tectonic fabrics, and is cut by aplite dykes and shear zones. The Red Rocks Granite is equigranular and is cut by aplite dykes and intense shear zones but does not contain a pervasive tectonic fabric.

Long Range Gneiss

The Long Range Gneiss crops out in thin strips north and south of the Cape Ray Granite and at Twin Hills. The southern strip is bounded by an intrusive contact with the Cape Ray Granite to the north and is unconformably overlain by ignimbrites to the south. The northern strip is bounded by intrusive contacts with the Red Rocks and Cape Ray granites.

The gneiss is coarse grained and has a green aspect in the field. At least two tectonic fabrics were noted, both of which are intensely chloritized. Stretched quartz and feldspar crystals, up to 1 cm in length are augened by both fabrics. Quartz is more abundant than feldspar and often has a bluish colour.

Chloritized amphibolite pods and basic dykes are scattered throughout the gneisses. The pods often occur in swarms and have their long axis alligned parallel to the later fabric. Recognisable dykes are less common and are up to 9 m wide. In general they have a northeasterly trend. Most are light green in colour, fine grained and contain at least one tectonic fabric.

Petrography: The mineralogy of the leucocratic gneiss is quartz, feldspar, chlorite, epidote, and sericite with accessory magnetite and allanite.

There are two fabrics present in the rock. The earlier one is defined by an interbanding of chlorite, quartz and feldspar and appears to be composite in nature. This has been deformed and reorientated by the later deformation. The later of the two fabrics is defined by a preferred orientation of chlorite crystals.

Quartz occurs as porphyroblasts augened by the early composite fabric and also as intergrowths with chlorite defining this fabric. In the former occurrence the quartz crystals are strained, partly polygonised and have sutured grain boundaries. However, when intergrown with chlorite they are unstrained and show straight grain boundaries parallel to $(\bar{0}\bar{0}\bar{1})$ of chlorite.

The feldspar (An_{28}) occurs as porphyroblasts rather than as an intergrowth with chlorite. Twinning is well developed on the albite and pericline laws. Most of the twin individuals are wedge shaped. Saussuritisation is extensive and the composition planes are commonly outlined by epidote and sericite. Many crystals are however completely saussuritised. Epidote is also present as small rounded crystals associated with the composite fabric.

Magnetite occurs as small laths which are orientated parallel to the later of the two tectonite fabrics. Allanite is rare and occurs as small crystals (less than 0.1 mm) within the composite fabric.

Cape Ray Granite

The Cape Ray Granite is composed of large pink potash feldspar phenocrysts set in a quartz-chlorite matrix. The phenocrysts are up to 4 cms in length and show well developed Carlsbad twins. Their distribution throughout the body is generally somewhat even, although phenocryst rich pods up to 40 cms in diameter do occur. Occasionally the long axes of the feldspars are crudely aligned. This alignment is at an angle to the tectonite fabric.

The quartz-biotite-chlorite matrix defines a fine tectonic banding which forms augen around the large phenocrysts. The abundance of chlorite gives the rock a green aspect. The fabric is present over the entire outcrop area but is variably developed. Towards the centre of the granite the matrix tends to be a grey, fine-grained aggregate of quartz and feldspar.

Basic pods are present throughout the body. These are elongate, with their long axis less than 10 cms, and are aligned parallel to the tectonite fabric. The main constituents are epidote and chlorite. The pods tend to occur in swarms, the strike of which cross cuts the schistosity. They are therefore thought to represent early basic dykes rather than xenoliths (c.f. Watterson, 1965).

One porphyritic dyke with phenocrysts of potash feldspar was observed. These phenocrysts are less well developed than in the body of the granite. The dyke does not contain the tectonite fabric in the granite but is cut by the later shear zones. Rare aplite dykes, 30 cms to 3 metres in width, show the same age relationships as the porphyritic dyke. No pegmatites were seen.

Petrography: The mineralogy of the granite is: perthitic microcline, plagioclase (An_{30}), quartz, biotite and chlorite with accessory calcite, sphene, epidote, apatite, piemontite, hornblende, allanite and magnetite.

The matrix minerals tend to be orientated and define a tectonite fabric which augens the phenocrysts. Knotts of this matrix are augened by a later fabric defined by sericite.

The potash feldspars occur as phenocrysts up to 4 cms in length and are variably altered to epidote, sericite and calcite. They tend to be perthitic and often show diffuse microcline grid twinning. Carlsbad twins are also common. Alteration tends to be concentrated along the composition planes. Some crystals show a distinct zonation with at least seven sharply defined zones from centre to edge (Plate I). This zonation is very similar in appearance to oscillatory zoning in plagioclase.

Plagioclase (An_{30}) is in general sparsely developed throughout the body, however, locally it may constitute up to 30% of the rock. It occurs in elongate euhedral crystals, most of which are almost completely altered to epidote, sericite and calcite. Albite twinning is commonly developed and may be observed even in the highly altered crystals.

A variably developed albitic rim surrounds all the feldspars. It is more pronounced around the potash feldspars than the plagioclases. Pervasive replacement of microcline and perthite by albite has resulted in albite forming up to 50% of some of the original phenocryst. There is an increase in the width of the rim and the percentage of albite with increasing deformation.

Plagioclase inclusions within the large potash feldspar phenocrysts also have an albitic rim (Plate II). Where the rim around the potash feldspar and the rim of the plagioclase inclusion are in contact, they show different optical orientations, but no refractive index difference was discernable. The albite rims are regarded as the result of exsolution from the primary feldspars probably as a result of the greenschist facies metamorphic conditions prevalent during the development of the earlier tectonite fabric.

Quartz is present as phenocrysts up to 1 cm in length, as an interstitial mineral with respect to the feldspars, and as part of the matrix. The grain boundaries tend to be sutured and irregular. Where it occurs interstitially, quartz-feldspar boundaries are often straight. The phenocrysts are elongated, strained, and partly polygonised (Spry, 1969) where deformation is intense.

Sphene, apatite, and allanite occur as euhedral crystals scattered sporadically throughout the matrix. The larger crystals occur in augen of the fabric in the matrix. Allanite and sphene always show altered rims. Apatite is generally unaltered and occurs as acicular crystals up to 1 cm in length.

Magnetite and piemontite occur in trace amounts. The piemontite is restricted to inclusions within the feldspars. Magnetite, however, occurs both within the feldspars and as part of the matrix.

The basic inclusions are composed of essentially the same minerals as the granite, with the addition of up to 50% hornblende. The grain size, however, is generally less than 1 mm. One identifiable plagioclase with albite twinning gave a composition of An_{28}. Chloritized biotite occurs in flakes up to 1 mm across and shows Widmanstatten structure in rutile (Burke, 1965).

The texture of the granite is an igneous one which has been subsequently modified by later deformational and metamorphic events. The presence of large phenocryst rich pods, the allignment of these phenocrysts (at an angle to the fabric), their numerous sharply defined zones, and the predominance of Carlsbad twins in the potash feldspars, all indicate an igneous origin. Later deformation and metamorphism resulted in the breakdown and recrystallisation of the matrix to give two fabrics, and the alteration and partial replacement by albite of the originally igneous feldspars.

Red Rocks Granite

The Red Rocks Granite is an intrusive body which crops out in the Red Rocks region. The southern contact is intrusive into the Long Range Gneiss. The northern extent was not determined. It is, in the main, a medium- to coarse-grained potash feldspar rich granite with biotite being the major mafic mineral. The crystals are generally 2-3 mm across.

Alternating potash feldspar rich and mafic rich bands were noted at one locality. The bands are continuous for upwards of 10 metres although their thickness rarely exceeds 15 cms. Some bands have sharp contacts whilst others show a gradational change. This unit grades into the surrounding more homogeneous granite.

There is no penetrative tectonite fabric in the granite. However, shear zones up to 20 m wide are numerous and show a range in strike from northeast to southeast. Within them the granite shows a variation from a grey quartz-feldspar rock to a fine-grained quartz-feldspar rock with remnant quartz and feldspar phenocrysts to a fine-grained banded rock. The bands are 2 mm wide and are defined by alternating chloritic and quartzofeldspathic foliae.

Late stage granitic activity, as for the Cape Ray Granite, is poorly developed. Fine-grained aplite dykes are cut by the shear zones and contain a fabric related to those zones. They are up to 5 m wide. Later, unfoliated, fine-grained diorite dykes have been intruded along some of the shear zones. These are also up to 5 m wide.

Petrography: The mineralogy of the Red Rocks Granite is: perthitic microcline, quartz, plagioclase (An_{30-35}), muscovite, biotite, epidote with accessory sphene, magnetite, penninite, allanite, zoisite, apatite, piemontite and zircon.

The feldspars are the main constituents. Perthitic microcline occurs in large euhedral phenocrysts up to 1 cm in length. Many of the crystals show good Carlsbad twinning. The microcline grid twinning is generally sharp and appears to effect the perthite lamellae. Zonation similar to that observed in the potash feldspars of the Cape Ray Granite is present in many crystals. Individual crystals generally contain two or three zones, the zone boundaries being defined by inclusions of sericite and plagioclase. Several crystals, however, show seven or more sharply defined zones (Plate III). Slight refractive index differences between zones indicates that there is an albite enrichment from the centre outwards. This trend may be reversed at the edges.

Plagioclase is present as euhedral, altered phenocrysts up to 1 cm in length, and as inclusions in the potash feldspars. They are altered to sericite, epidote and calcite. Where albite twinning is still discernable, a composition of An_{30-35} was determined.

A thin unaltered albitic rim is present at potash feldspar-plagioclase grain boundaries. These rims are poorly developed compared to these around the feldspars in the Cape Ray Granite. Plagioclase inclusions in microcline show the best developed rims.

Quartz is almost as abundant as the feldspars and occurs interstitially with respect to them. The grains have sutured boundaries, are strained, and are partly polygonised. Small round crystals are also present as inclusions within the feldspars.

One crystal of myrmekite was observed. The plagioclase, which is altered, is surrounded by an unaltered albitic rim. The quartz intergrowth, which shows a wide radial distribution, is present in both rim and crystal. The crystal is completely surrounded by microcline.

Muscovite occurs both as an interstitial mineral and as inclusions within the feldspars. The latter occurrence probably results from alteration of the host. Biotite has a similar occurrence but is less abundant. Piemontite forms an intergrowth with muscovite within altered plagioclase crystals. Epidote is present throughout the rock and is best developed within altered plagioclase.

Magnetite, sphene and apatite occur as inclusions in plagioclase and at feldspar-quartz and feldspar-feldspar grain boundaries. Two crystals of allanite were observed, both included in microcline. Zoisite, showing blue birefringence was observed in one altered plagioclase. Penninite occurs as an alteration of biotite.

The shear zones are composed of a fine-grained aggregate of quartz, feldspar, sericite, epidote, calcite, biotite and chloritised biotite. They contain a well developed tectonite fabric defined by sericite. This fabric augens pods of a fine-grained intergrowth of muscovite, chlorite and magnetite containing an oblique fabric. The shear zones are thus a product of a composite deformational pattern. Occasional rounded porphyroclastic quartz, potash feldspar and plagioclase crystals occur in augen of the main tectonite fabric.

The green bands in the banded shear zones are composed of felted chlorite and sericite. The white bands are composed of a fine-grained aggregate of quartz and calcite. Apatite and zircon occur in augen of the fabric defining the banding.

The sericite bands are deformed by late, cross-cutting kink bands. They are not developed in the quartz-calcite bands. They are normal kink bands (Dewey, 1965) and have irregular or bifurcating kink planes (Plate IV).

The texture of the Red Rocks Granite is typically igneous with the feldspars crystallising after the accessories but prior to quartz. Modification by deformation and metamorphism is slight, except in the shear zones where the granite is broken down to a fine-grained banded rock.

CHAPTER IV: PORT AUX BASQUES COMPLEX

The Port aux Basques Complex consists of the Port aux Basques Gneisses and the Port aux Basques Granite. The Port aux Basques Gneisses are a banded series of leucocratic and melanocratic units of variable composition and thickness. The banding is generally in the order of 50 cms thick but a range from 2 cms to 5 metres was observed. The leucocratic units range from massive to highly schistose, depending upon the percentage mica present. Sillimanite, kyanite, staurolite and garnet are developed in these bands. The melanocratic units are generally fine-grained hornblende schists or amphibolites with a well developed L or L-S tectonite fabric. Coarse amphibolite pods do, however, occur as boudins within the gneissic banding. Rare epidosite bands consisting essentially of epidote with minor plagioclase are also present.

The gneisses are intruded by the Port aux Basques granite and by pegmatite, aplite and diorite dykes. The granite occurs in folded sheets which are conformable with the gneissic banding. The pegmatites are in part conformable with the banding but often show a cross cutting relationship. The aplite and diorite dykes cross cut the gneisses, are unfolded, and do not contain a tectonite fabric.

Late faulting, firstly on a north-south trend, and later on a northeast-southwest trend, has affected the whole complex.

Port aux Basques Gneisses

Leucocratic bands:

Within the area studied there are essentially three types of leucocratic bands:

(1) Massive quartz-feldspar rich bands (less than 10% mica).

(2) Schistose bands (greater than 10% mica).

(3) Granitic bands.

(1) Massive Quartz-Feldspar Rich Bands

In field aspect these bands are either white, grey or pinkish. A granular rather than schistose texture is dominant. They are generally fine-grained with the grain size rarely exceeding 1 mm. Quartz and feldspar crystals are usually equidimensional.

Mica is poorly developed and has two distinct modes of occurrence. Where the rock is sensibly micaceous some of the crystals are orientated such that they define a schistosity. The more micaceous the rock the better defined is the schistosity. In finer-grained bands the micas are confined to schistosity planes and define a subsidiary fine foliation on a 2-3 mm scale. This fine foliation is often crenulated. These finely foliated and schistose bands generally occur separately. Occasionally they occur together in the same band and the foliation and schistosity are seen to be parallel. Muscovite is the dominant mica although black and pale brown biotite is sometimes present. Micaceous pods up to 2 cms in length are occasionally observed. These are thought to represent retrogressed sillimanite pods. Thin section work verified this.

Garnets occur somewhat sporadically in these bands. They are usually less than 1 mm across although some specimens are up to 3 mm in diameter. There appears to be a crude relationship between the presence and composition of mica and the growth and composition of garnet. Garnets are generally not observed where mica is scarce. Where muscovite is the only mica present the garnets tend to be less than 1 mm in diameter and pink in colour. An increase in biotite content is accompanied by slightly larger and darker coloured garnets. Where the schistose and finely foliated bands are present together the garnets are generally restricted to the interface between the two.

Petrography: The mineralogy of these bands is: quartz, plagioclase, potash feldspar, muscovite, biotite $\pm$ garnet $\pm$ calcite $\pm$ magnetite $\pm$ apatite $\pm$ zircon $\pm$ sillimanite.

They contain either one composite fabric or two distinct fabrics. The composite fabric is defined by an isoclinally folded mica schistosity. This type of fabric was noted close to shear and fault zones. Where the rock contains two distinct fabrics these are defined by single flakes of muscovite or biotite or both. On occasions the later of the two fabrics is axial planar to folds of the earlier one. Generally they intersect at an angle of 20° to 25°. The later fabric may also show a strain-slip type of relationship to the earlier one.

The rock is composed essentially of quartz and feldspar defining a granular texture. Quartz is the dominant mineral and shows well developed triple point junctions (Spry, 1969). Quartz-feldspar boundaries are however somewhat rounded. Quartz-mica boundaries are straight. All the quartz crystals show diffuse strain shadows.

The feldspars are in general little altered and untwinned. Plagioclase is more abundant than potash feldspar. The plagioclase crystals that are twinned appear to show a large variation in composition, even within one thin section, i.e. An_{38} to An_{68}. Twinning on both albite and pericline laws is developed.

Where garnets are present they are not noticeably porphyroblastic with respect to the quartz and feldspar. Some have a ragged outline whilst others are rounded. The smaller crystals (less than 0.5 mm) occur at triple point junctions and along grain boundaries. These do not contain inclusions. The larger garnets contain inclusions of quartz, biotite and magnetite which are confined to the central portion of the host crystals and do not form recognizable trails. The quartz inclusions are much smaller than the quartz crystals in the matrix. Where the schistosity is folded the garnets in the fold limbs are unaltered whilst those close to the fold hinges are fractured.

The smaller garnets would thus appear to have been formed during or after the final recrystallisation of the matrix. The larger garnets grew, at least the central portions, before the final recrystallisation took place. An upper time limit for this growth is defined, in this rock type, by the folding of the dominant schistosity and production of a later axial planar schistosity.

Magnetite occurs as inclusions, as anhedral crystals at grain boundaries and as an intergrowth with biotite. In the first occurrence the crystals are small and rounded and are present in feldspar, quartz and garnet. When it occurs at grain boundaries the crystals are acicular with straight edges and ragged ends. In the third occurrence the crystals are either straight edged against biotite or have no distinct form.

Apatite and zircon occur as small rounded crystals throughout the rock. They are present as inclusions in the essential minerals, at grain boundaries and at triple point junctions. When included in biotite the zircons are surrounded by pleochroic halos.

In later shear zones and close to the Cape Ray Fault the groundmass is broken down along discreet planes and a fracture cleavage is developed. This imparts a banded aspect to the rock. There are essentially two types of texture: (a) quartz-feldspar with straight grain boundaries and triple point junctions. The crystals are generally in the order of 0.3 mm across. Calcite commonly occurs at the grain boundaries; (b) Quartz and feldspar with sutured boundaries. These crystals are less than 0.1 mm across. The coarser crystals generally occur in wider bands than the fine crystals. The latter are up to 0-3 mm wide. The schistosity associated with this breakdown is defined by muscovite.

At the margins of the shear zones the granular polygonal texture of the rock is preserved. Biotite is altered to chlorite and the garnets are fractured and chloritized.

(2) Schistose Bands

The schistose bands have a highly variable aspect in the field depending upon the percentage and composition of the mica present. This variability plus the occurrence of garnet, staurolite, kyanite and sillimanite allows a subdivision of this band type into three categories:

(a) Muscovite-biotite schist.

(b) Muscovite-biotite-garnet schist.

(c) Muscovite-biotite-garnet ± kyanite ± staurolite ± sillimanite schist.

(a) Muscovite-biotite schist:

These bands have a silvery to silvery-black aspect in the field. Individual bands vary in width from 5 cms to 5 metres. In general however they are of the order of 1 m wide. They are variably schistose depending upon the percentage mica present, and vary from almost massive quartzo-feldspathic bands to an essentially micaceous rock. Biotite, generally, predominates over muscovite.

The mica has two modes of occurrence, as separate flakes defining a schistosity and as aggregates defining a fine banding 2-3 mm wide. The latter is the more widely developed of the two and is commonly isoclinally folded, with thickening at the hinges and attenuation on the limbs.

Petrography: The mineralogy of the bands is: muscovite, biotite, quartz, plagioclase (An_{25-35}) with accessory magnetite, apatite, epidote, zircon and allanite. Sillimanite was observed in one thin section.

The rock always contains two fabrics defined by mica. The earlier, dominant one, is generally a 1-3 mm wide banding with well developed mica. These bands are folded and crenulated. The later fabric is a schistosity which cross cuts the fine banding at angles up to 40°, and bears a strain slip relationship to it.

Quartz and feldspar are the dominant non-micaceous minerals. The quartz crystals tend to be elongated parallel to the fine banding. They have sutured boundaries, show strain shadows and are partly polygonised. Quartz-feldspar and quartz-biotite boundaries are more regular.

The feldspar is plagioclase with a compositional range of An_{25-35}. No potash feldspar was noted. Twinning is variably developed on the albite and pericline laws. Many of the twin individuals are wedge shaped and some are slightly bent. These are assumed to be deformational in origin (Vance, 1961). Incipient alteration to sericite is commonly developed along the composition planes. A diffuse reverse zonation is present in many crystals.

Feldspar-feldspar boundaries tend to be linear or slightly curved. Occasionally they are irregular. Quartz inclusions are generally round or ovoid but commonly have at least one straight boundary. These straight edges are often related to the twin planes in the host feldspar. When quartz crystals are present at feldspar-feldspar boundaries they are either rounded or appear to grow along the boundary (Plate V). Feldspar-biotite boundaries are straight and stepped. The steps being at right angles to the (001) plane of biotite. This gives these boundaries a ragged aspect.

Magnetite occurs as small laths and blebs associated with the biotite schistosity. The laths are elongated parallel to the schistosity and generally show straight grain boundaries with the biotite. The blebs are present at triple point junctions and grain boundaries of quartz and feldspar. These are anhedral but occasionally show straight grain boundaries with quartz.

Epidote occurs as fresh, yellow pleochroic elongated crystals included in biotite and occasionally at feldspar grain boundaries. In the former occurrence its long axis is parallel to (001) in biotite. In the latter its orientation seems to be dependent upon the grain boundary orientation. The crystal boundaries are ragged and have a step like nature. Slight alteration of feldspar takes place at epidote-feldspar boundaries.

Apatite and zircon occur as small rounded crystals at grain boundaries and as inclusions in feldspar and biotite. The former occurrence is more common for apatite and the latter for zircon. Pleochroic halos result from zircon inclusions in biotite. Where acicular crystals of apatite occur they are parallel to the fine banding.

Allanite is a rare accessory and occurs as inclusions in biotite surrounded by pleochroic halos. The grain boundaries at low angles to (001) in biotite tend to be straight and regular. Those at high angles are ragged and result in allanite-biotite intergrowth.

Sillimanite was found in a 5 mm long fissure. It is fibrous in nature and appears to be altering and partly replacing the biotite of the fine banding.

Retrogressive metamorphic effects were noted close to shear and fault zones. Biotite is extensively chloritised and plagioclase is altered to sericite. Magnetite dust is widespread. A widely spaced fracture cleavage similar to that in the retrogressed quartzo-feldspathic bands is widely developed and cuts across the fine banding and the biotite schistosity.

(b) Muscovite-biotite-garnet schist:

These bands have a highly variable aspect in the field depending upon the composition of the predominant mica, the development of the mica and the percentage mica in the rock. The main fabric is a fine banding on a 2-3 mm scale which is isoclinally folded. Crenulation of this fabric is commonly observed.

Knots of quartz, and quartz and feldspar are common, and are always augened by the main fabric. Generally they are less than 2 cms long and have no observable internal structure. Some, however, do appear to be remnants of isoclinal fold closures.

The occurrence of garnet tends to be rather irregular. Where mica is relatively poorly developed the garnets are pinkish in colour and less than 1 mm in diameter. Increasing biotite content is accompanied by an increase in size and a darkening of the garnets. Highly schistose biotite rich bands contain the largest crystals, some of which are up to 1.5 cms in diameter.

The general occurrence of garnet in this rock type increases from the Cape Ray Fault towards Port aux Basques, with a maximum in size and occurrence in the Grand Bay area. Although they remain numerous, there is a general decrease in abundance from Port aux Basques towards Isle aux Morts.

Petrography: The mineralogy is: biotite, muscovite, quartz, plagioclase (An_{25-32}), chlorite, garnet $\pm$ sillimanite with accessory magnetite, epidote, sphene, apatite and zircon.

The rock contains a fine banding 2-3 mm wide defined by biotite and muscovite, biotite being the dominant mica. This fabric has been folded and crenulated and close to these fold hinges a later axial planar schistosity is developed. On the fold limb the two fabrics are indistinguishable and vermicular growth of mica, quartz, and feldspar results.

Quartz and feldspar occur in distinct bands, 2-3 mm wide, and also as an intergrowth with the micaceous minerals. In the former case the texture and grain boundary relationships are similar to those described for the muscovite-biotite schist. In the latter case the grain boundaries with (001) planes of biotite, muscovite and penninite are straight, although stepped, and parallel to the (001) plane. Those at high angles to this plane are ragged. Plagioclase has a composition range An_{25-32} and is generally sericitised.

Garnets occur as subhedral porphyroblasts. Inclusions of quartz, biotite and magnetite are common and are generally restricted to the central part of the crystal, the outer rims being clear. Occasionally they form straight or curved inclusion trails. The crystal size of the inclusions is much smaller than the size of the corresponding mineral in the matrix. Where the fine banding is folded the garnets, especially those close to the fold hinges, are altered at their edges to chlorite and sericite, and where a strain slip fabric is developed the garnets are partly augened by, and in part cross cut the fabric.

Thin garnet-quartz bands, up to 15 cms wide, occur within these schists. The garnets comprise approximately 40% of the bands and are located at triple point junctions and grain boundaries of quartz. They are generally less than 0.5 mm in diameter and are light pink in colour. The lack of inclusions, the freshness and their location with respect to the polygonal quartz suggests that these garnets developed at a late stage in the metamorphic history of the gneisses.

Sillimanite is present as single crystals and fibrous masses within plagioclase crystals. When the host crystals are closely associated with the fine banding the sillimanite needles are orientated parallel to it. Within the larger porphyroblasts the needles are orientated subparallel to, or at high angles to the feldspar grain boundaries. Radiating aggregates are common at garnet-feldspar boundaries.

Magnetite occurs in laths associated with the mica defining the fine banding and in intergrowth with it. It is also present as a mantle around muscovite, as blebs in chloritised biotite, and as inclusions in garnets. In the last two occurrences the crystals are commonly anhedral. However, in the first three, the growth appears to be controlled by the (001) plane in mica.

Sphene occurs with the biotite defining the fine banding and is intergrown with this mineral as long stringers parallel to the (001) plane. It is also present, as is zircon, as small inclusions in quartz, feldspar and biotite. Epidote occurs as fresh, small, rounded inclusions in plagioclase and biotite. Apatite is present as acicular crystals up to 2 mm long within the quartzofeldspathic bands.

(c) Muscovite-biotite-garnet ± sillimanite ± kyanite ± staurolite schists:

These schists differ from the previous group in that they contain kyanite or staurolite, or both, in addition to garnet. The rock is generally highly schistose with a well developed fine banding. The fine bands are 2-3 mm wide and are tightly folded. Quartz and feldspar knotts are common and are augened by the fine banding.

Staurolite occurs as large, brown, elongate crystals augened by the fine banding. Individual crystals are up to 3 cms in length and show no preferred orientation on the schistosity plane. Twinning is rare, only one interpenetrant twin being observed. Small quartz inclusions are common.

Kyanite is more abundant than staurolite and occurs in colourless, light blue, dark blue, and light green crystals. The colourless crystals are less than 1 cm in length and occur on the foliation planes which define the fine banding. They show no preferred orientation within the plane. The light and dark blue varieties can be up to 10 cms in length and 3 cms wide, and often contain inclusions of garnet. The largest crystals are found in the pressure shadows of large quartz pods. Smaller ones occur as knots which are generally augened by the fine banding. Pods, composed entirely of kyanite, are occasionally observed. Green kyanite has a more restricted occurrence, and appears to be associated with biotite-rich schists. The crystals are less than 1 cm long, and like the colourless variety, show no preferred orientation within the foliation plane.

Garnets are numerous, and always occur with the staurolite and kyanite. In general, they are less than 5 mm in diameter, and light to dark red in colour. The darker colour is associated with an increase in the biotite content of the schists. The larger ones generally contain inclusions.

Petrography: The mineralogy of these bands is: biotite, muscovite, quartz, plagioclase, garnet ± kyanite ± sillimanite ± staurolite with accessory magnetite, zircon, sphene, allanite and apatite.

The fabric and quartz and feldspar and mica occurrences are as described for the muscovite-biotite-garnet schists. The fine banding is, however, generally better developed. Quartz tends to be highly strained and alteration of plagioclase to sericite is common. Plagioclase has a composition range An_{30-32} and occasionally shows diffuse reverse and oscillatory zonation.

Kyanite has two distinct modes of occurrence, as porphyroblasts which are augened by the fine banding and as acicular crystals which in part help define the fine banding. The porphyroblasts are either euhedral and almost inclusion free or else show a dendritic type of growth. When euhedral they occasionally show twinning on (001), and are often partly recrystallised to give smaller crystals with a different orientation to that of the parent. Inclusions are generally restricted to small rounded quartz and feldspar crystals, garnets are, however, also present (Plate VI).

The acicular crystals help define, with biotite and muscovite, the fine banding. Where this fabric is folded the kyanite is also folded. The folded crystals show little straining, even at the fold hinges, indicating polygonisation after the deformation. Some of these crystals are stubby and are augened by the fine banding. This form of kyanite tends to be dendritic with many quartz, feldspar and occasionally staurolite and magnetite inclusions. The crystal size of the inclusions is much smaller than that of the corresponding minerals in the groundmass. The kyanite boundaries are always defined by a rim of white mica.

Sillimanite is present as single crystals and fibrous aggregates in plagioclase and porphyroblastic muscovite crystals, the latter being the more common host. Occasionally the sillimanite occurs as felted masses which are parallel to the fine banding, and have been folded with the banding. The mica porphyroblasts are later than some of the kyanite crystals since they contain inclusions of that mineral. Straining of the mica seems, on occasions, to be related to the appearance of sillimanite. Kyanite and sillimanite often occur together and show either straight or highly irregular boundaries. In the former case the two minerals are co-existing whilst in the latter the sillimanite is replacing the kyanite.

Staurolite occurs as porphyroblasts which are augened by the fine banding, as inclusions within kyanite, quartz and plagioclase, and at quartz-feldspar grain boundaries. The first occurrence is by far the most common. These crystals generally contain abundant inclusions of quartz with minor feldspar, magnetite and garnet, which often define straight or curved trails. The rims of the staurolite crystals are sometimes inclusion free. A reaction rim of white mica, similar to that around kyanite, is always present. In the second and third modes of occurrence staurolite is present as small anhedral crystals often associated with the large porphyroblasts. In general they show curvilinear grain boundaries with rounded corners. Occasionally they contain small rounded quartz inclusions which are much smaller than the quartz crystals in the present groundmass.

Garnets are numerous and occur as porphyroblasts, as inclusions in kyanite, staurolite, quartz, feldspar and mica, and at grain boundaries within the quartzo-feldspathic areas. The first occurrence is the most common. The crystals are up to 5 mm in diameter, are euhedral to subhedral in outline, generally contain inclusions, and are partly augened by the fine banding. The inclusions are more common in the larger crystals and tend to be restricted to the central portion. Quartz is the most common included mineral but plagioclase, magnetite and biotite are also present. Often they define straight and curved trails. The crystal size of the inclusions is much smaller than that of the corresponding mineral in the groundmass.

Garnet grain boundaries with mica tend to be straight or curvilinear, especially those parallel to (001) in mica. Garnet-quartz and garnet-feldspar boundaries are more irregular. Garnet-garnet boundaries are straight. Subsequent deformation has broken and partly chloritized many of the crystals.

Garnets included within kyanite, staurolite, mica, quartz and feldspar are generally smaller than those occurring as porphyroblasts. However, those within kyanite and staurolite may be up to 2.5 mm across and contain inclusions. Those occurring in mica, quartz and feldspar are less than 0.5 mm in diameter, contain no inclusions, and have a rounded outline. At grain boundaries the garnets are also less than 0.5 mm across and rounded. They do, however, show straight grain boundaries against mica.

The occurrence of accessory minerals is similar to that previously described.

Retrogressive metamorphism is sparsely developed and is restricted to breakdown and chloritisation of garnets and chloritisation of biotite. Breakdown of sillimanite results in large porphyroblastic muscovite crystals.

(3) Granitic Bands

These bands occur in the eastern part of the map area around Margaree and Foxroost and give the gneiss a migmatite aspect. They are coarse quartz and feldspar rich rocks with a well-developed fabric defined by biotite. This fabric gives the rocks a banded aspect, individual bands being up to 1 cm wide. Subsequent deformation has isoclinally folded this banding and produced an associated axial planar schistosity defined by biotite. Pink porphyroblasts of K feldspar are augened by both fabrics, and constitute up to 20% of the rock.

Veins of quartz and feldspar, up to 2 cms wide, are common. Generally they are conformable with the banding in the rock but occasionally cross cut it. Biotite selvages often rim these leucocratic fractions. Garnets are poorly developed and are generally less than 2 mm in diameter. They tend to occur along the schistosity planes and in the biotite selvages. They are also present, however, within the quartz and feldspar rich bands.

Petrography: The mineralogy of these bands is: biotite, quartz, perthitic microcline, plagioclase An_{25}, with accessory magnetite, sphene, allanite, apatite, and zircon.

The rock contains a fine banding defined by biotite. It is irregular due to the coarse and porphyroblastic nature of the essential minerals. Subsequent deformation has sub-isoclinally folded this fabric and produced a poorly defined axial planar fabric. This latter fabric is generally recognized by the partial breakdown of the quartz and feldspar and the development of a mortar texture (Spry, 1969).

Quartz and feldspar are the essential minerals and constitute up to 80% of the rock. Quartz comprises 20% to 40% of the rock and has an interstitial habit with respect to the feldspars. Most crystals show well developed strain shadows and have sutured grain boundaries. Quartz-feldspar boundaries are regularly curved. Rounded, ovoid, and dumbbell shaped quartz inclusions are common in both microcline and plagioclase. When included in plagioclase a vermicular intergrowth sometimes results.

Perthitic microcline in the dominant feldspar and constitutes up to 40% of the rock. It occurs as porphyroblasts up to 5 mm across and as small crystals associated with the mortar texture. String and sheet perthite are the two varieties present, many crystals, however, are not visibly perthitic. The perthite lamellae are generally restricted to the central portion of the crystals and are surrounded by a variably developed lamellae free rim. Microcline grid twinning is well developed and may be either sharp or diffuse.

Plagioclase is less abundant than microcline and has a composition An_{25}. Twinning is variably developed. Few crystals show sharp well defined twins on the albite law, most are hazy and wedge-shaped and are probably deformational in origin (Vance, 1961). A diffuse zonation is patchily developed and appears on occasions to be reverse but generally no systematic pattern is apparent. Alteration to sericite is less well developed in those crystals showing wedge-shaped twins than in crystals whose twinning is either poorly developed or absent.

Myrmekite is quite common at microcline-plagioclase grain boundaries, the microcline often completely surrounding the myrmekite. However, many plagioclase-microcline boundaries are non-myrmekitic. The quartz rods are always at high angles to the plagioclase-microcline interface. This sometimes gives rise to a leaf-like structure (Plate VII). There is a slight but significant coarsening of the quartz rods from the edge to the centre of the plagioclase hosts. This is usually a gradational change but in one instance there is a very sharp boundary between the coarse and fine sectors (Plate VIII). The myrmekite-microcline boundary is somewhat irregular and ragged suggesting that it is not in equilibrium.

Although occasional magnetite porphyroblasts are present the occurrence of the accessory minerals is generally as described for the other leucocratic band types.

Melanocratic Bands:

There are essentially three types of melanocratic bands present in the gneiss complex:

(1) Hornblende schist ($\leq$70% Hornblende).

(2) Fine-grained Amphibolites.

(3) Coarse-grained Amphibolites.

(1) Hornblende Schist

Hornblende schists occur in bands up to 1 m thick, which are conformable with the overall gneissic banding. They contain less than 70% hornblende (Cannon, 1963). Bands of this type are more common in the eastern than western part of the area.

The hornblende occurs as single acicular crystals set in a quartz-feldspar or biotite rich groundmass. In the former case the rock has a spotted aspect. An L or sometimes an L-S tectonite fabric is defined by the hornblende. Where an L-S fabric is defined the rock shows a fine banding. These bands, defined by mafic and felsic elements, are less than 5 mm wide and are parallel to the larger scale gneissic banding.

Petrography: The mineralogy is: quartz, plagioclase, biotite, and hornblende with accessory epidote, sphene, allanite, apatite and magnetite.

The rock always contains a 1-2 mm wide banding of mafic and felsic minerals. When hornblende is the dominant mafic mineral the fabric is generally of the L type, but may also be L-S. Where biotite is present the fabric is always of the L-S type. Subsequent deformation has produced a schistosity, where biotite is present, which cross cuts the fine banding.

The groundmass is composed essentially of quartz and feldspar, the latter mineral being dominant. Quartz occurs as elongated crystals parallel to the fine banding, and as porphyroblastic crystals intergrown with plagioclase and hornblende. In both cases the crystals are strained. Polygonisation is, however, more pronounced in the former occurrence. Quartz-quartz boundaries are irregular and sutured. Quartz-feldspar boundaries are, however, curvilinear and more regular. Inclusions of biotite laths and small rounded plagioclase crystals are not uncommon. The biotite laths are orientated parallel to the fine banding.

Plagioclase (An_{28-30}) shows variably developed twinning on the albite, pericline and Carlsbad laws. The first of these is by far the best developed. Many of the twin planes are wedge shaped and have been bent by subsequent deformation. Crystals showing well developed wedge-shaped twins are generally less altered to sericite than those which are untwinned or twinned on the Carlsbad law. Diffuse reverse and oscillatory zoning is present in several crystals. In the latter case the core and the rim are anorthite rich.

Inclusions of biotite, quartz and hornblende are common in the feldspars. The biotite occurs as laths which are orientated parallel to the fine banding. Quartz is present as small rounded or ovoid crystals which are much smaller than those in the groundmass. These occasionally have straight edges parallel to twin planes in the host plagioclase. Hornblende occurs as anhedral disseminated laths and appears to be replacing the plagioclase.

Hornblende occurs as porphyroblasts, as small anhedral crystals at quartz-feldspar grain boundaries and apparently replacing plagioclase. The porphyroblasts, in part, occur in augen of the fine banding and have their C axis alligned parallel to the bands. Many of them have a dendritic habit and include crystals of quartz, plagioclase and biotite which are of equivalent dimensions to the respective minerals in the groundmass. Some, however, are euhedral and either contain no inclusions or else very small rounded quartz and feldspar crystals, and are intergrown with the biotite defining the fine banding.

The small anhedral crystals are generally associated with the dendritic crystals and may represent an early stage of growth of the porphyroblastic crystals. These do not contain inclusions.

Epidote occurs as small anhedral crystals at plagioclase-biotite grain boundaries and as rims around allanite. It is not present where plagioclase is being replaced by hornblende. Allanite is present as inclusions in biotite and plagioclase and at quartz-feldspar grain boundaries. Sphene and magnetite occur as small anhedral crystals associated with biotite. Zircon is common as small rounded inclusions in biotite with associated pleochroic halos. Apatite is rare and occurs as rounded crystals at quartz-feldspar grain boundaries.

(2) Fine-grained Amphibolites

These rocks are the most common mafic element in the gneiss complex, within the area studied. They are fine grained, green, dark green, or black rocks and occur in bands which vary from 1 cm to 10 metres in width. The major leucocratic mineral is feldspar and this imparts a mottled or fine banded aspect to the rock. The width of these fine bands rarely exceeds 2 mm except at the hinges of isoclinal folds.

Within the amphibolite bands an internal finer banding is defined by variations in the relative proportions of hornblende and plagioclase. These bands have sharp boundaries and occur on a 3 cm to 50 cm scale depending on the thickness of the amphibolite. In general the thicker the amphibolite band the thicker is the internal banding. The fine banding is conformable to the compositional bands which are conformable with the amphibolite bands which are in turn conformable with the large scale gneissic banding.

The hornblende crystals are generally acicular and up to 1 cm in length. Where a fine banding is developed they define an L-S fabric. Otherwise they define an L fabric. Where the amphibolite bands are folded the hornblendes are folded around the folds.

Granets are commonly present at the contact of the amphibolitic and quartzo-feldspathic or schistose bands, but may also be present within the amphibolite bands. They are dark red in colour, rarely exceed 3 mm in diameter, and generally appear to be augened by the fine banding.

Petrography: The mineralogy is: hornblende, quartz, plagioclase (An_{25-75}), biotite $\pm$ garnet with accessory magnetite, epidote, apatite and sphene.

The rock sometimes contains a fine banding on a 1-2 mm scale defined by hornblende or biotite, or both. Subsequent deformation has folded this banding and, where biotite is present, has produced a schistosity axial planar to these folds.

The groundmass is composed essentially of quartz and feldspar. Quartz occurs in strained elongated crystals orientated parallel to the banding. Quartz-quartz boundaries are sutured due to the later deformation. Where hornblende constitutes over 70% of the rock, quartz occurs as equant, polygonised, unstrained grains.

The feldspar is plagioclase with a composition range An_{25-75}. The crystals are generally untwinned, variably altered to sericite, and show a zonation. Twinning, where observed, is on the albite and pericline laws and the twins are generally wedge shaped. Alteration to sericite is most pronounced along twin planes and at grain boundaries. Zonation is generally normal but oscillatory and reverse types are also present. The precise compositional variation was, however, not determined. Feldspar-feldspar and feldspar-quartz boundaries tend to be curvilinear. Where the groundmass has been extensively recrystallised these boundaries meet at well defined triple point junctions.

Hornblende constitutes up to 80% of the rock and occurs as subhedral crystals showing dark green to yellow brown pleochroism. In general the C axis of the crystals are aligned and help define the fine banding. The larger porphyroblastic crystals have either a dendritic type of growth or are subhedral and often contain numerous small rounded quartz and feldspar inclusions. The latter are also, on occasions, twinned. The smaller crystals, however, do not show twinning and seldom contain inclusions. Hornblende-hornblende boundaries are straight and often meet at triple point junctions. Hornblende-quartz and hornblende-feldspar boundaries are generally curved.

Biotite occurs as acicular poikiloblastic crystals which form an intergrowth with hornblende. They are associated with the fabric defining the banding and also define the axial planar fabric associated with the folding of the banding. In both occurrences the pleochroic scheme is light to dark brown.

Garnets occur as porphyroblasts up to 1 cm in diameter. They are generally augened by the fine banding in the rock. Inclusions of quartz, feldspar, biotite and magnetite are common and occasionally define curved trails. The crystal size of these inclusions is much smaller than the size of the corresponding mineral outside the garnet. Some garnets show a well developed inclusion free rim.

Magnetite is a common accessory and generally occurs as an intergrowth with biotite and hornblende. It is also present as inclusions in all the essential minerals. Epidote occurs as rounded grains at feldspar grain boundaries and also as rims around allanite. Occasionally it occurs as large clear porphyroblastic crystals with inclusions of hornblende, feldspar and quartz, but in general it is poorly developed.

Apatite occurs as rounded crystals at feldspar and quartz grain boundaries and as inclusions in the essential minerals. Sphene has a similar occurrence but occurs in aggregates as well as single crystals. Allanite is generally included in biotite or hornblende and has a rim of epidote.

(3) Coarse-grained Amphibolites

These are coarse-grained hornblende rich rocks which occur as pods and lenses up to 20 m long within the gneissic banding. There is an increase in size and frequency of these pods from west to east. Hornblende constitutes over 95% of the rock and individual crystals are up to 2 cms in length.

The edges of the pods are schistose and banded in conformity with the gneissic banding. The centres, however, are coarsely crystalline and the crystals have no preferred orientation. Where these pods are flattened in the plane of the gneissic banding they are distinguished from the fine-grained amphibolites by their coarse and highly schistose nature.

Petrography: The mineralogy of these bands is: hornblende and plagioclase.

The rock consists essentially of hornblende occurring in euhedral crystals showing straight grain boundaries and triple point junctions. Many crystals are twinned and slightly recrystallised.

The plagioclase occurs interstitially with respect to the hornblende and forms less than 5% of the rock. The composition was not determined since pervasive alteration to sericite and muscovite has taken place.

Epidosite Bands:

These bands are found only on the northern shore of Little Bay. They are up to 2 m in width and are conformable to, and folded with, the gneissic banding. Their light pistachio green colour distinguishes them from the amphibolites. Cross-cutting quartz-plagioclase veins typically show a red reaction rim.

Petrography: The mineralogy of these bands is: epidote, plagioclase, calcite, magnetite and haematite.

Epidote occurs as euhedral crystals up to 5 mm in diameter and constitutes up to 90% of the rock. Epidote-epidote and epidote-plagioclase grain boundaries are straight or curvilinear and often meet at triple point junctions, giving the rock a granular polygonal texture. Parallelism of grain boundaries defines the only tectonite fabric observed in this rock. The plagioclase occurs interstitially with respect to the epidote and is highly saussuritised.

Calcite and magnetite occur as anhedral interstitial crystals. The former mineral is restricted to the epidosite whilst the latter occurs in the cross-cutting veins. The veins are pegmatitic. The plagioclase in them has a composition An_{38} and is saussuritised at the contact with the epidosite. Grain boundaries and fissures are filled with haematite which imparts a pinkish aspect to the rock.

Port aux Basques Granite

The Port aux Basques Granite crops out in the gneissic terrain to the east of Port aux Basques. It occurs in sheets up to 80 m thick which are conformable with the gneissic banding. No contact metamorphic effects were noted. On the fresh surface it has a pink aspect but weathers white. The texture varies from equigranular to porphyroblastic with microcline porphyroblasts up to 2 cms in length. In general it is easily distinguished from the gneiss by its pink colour and coarse texture. However, around Foxroost the gneiss becomes appreciably migmatitic with increasing proportion of the granitic bands and it becomes difficult to distinguish between the leucocratic gneiss phase and the granite.

The rock contains one well defined fabric. Where this is strongly developed the granite resembles an augen gneiss. The augen is composed of pink feldspar and quartz. When the fabric is poorly developed the granite tends to be equigranular. The quartz and feldspar crystals are here in the order of 1 mm. A gradation between these two extremes may be observed over the area. Subsequent deformation has folded this fabric into tight and open folds, depending upon the structural position. An axial planar fabric is associated with this folding and is defined by muscovite.

Petrography: The mineralogy of the Port aux Basques Granite is: quartz, plagioclase, potash feldspar, biotite, zircon, sphene, apatite ± allanite ± muscovite ± garnet ± ferrohastingsite ± epidote.

Modal Analyses (excluding the specimen containing garnet)

	1242	1342	1343	1346	1348
Quartz	35%	38%	27%	31%	39%
Potash feldspar	39%	37%	38%	32%	24%
Plagioclase	15%	20%	28%	28%	31%
Mica	3%	4%	2%	5%	4%
Epidote	t	t	t	t	--
Sphene	t	t	1%	1%	t
Ferrohastingsite	6%	t	2%	--	--
Allanite	t	t	1%	--	--
Apatite	t	t	t	t	t
Zircon	t	t	t	t	t

The rock is composed essentially of quartz and feldspar, and has a mortar texture (Spry, 1969) which is variably developed depending upon the structural position. An S tectonite fabric is generally present and is defined by alligned mica flakes. The breakdown and recrystallisation to give the mortar texture effects the schistosity and is thus the later of the two events.

Orthoclase, perthitic orthoclase, microcline, and perthitic microcline are described together since they bear an intimate relationship to one another. These feldspars constitute up to 39% of the rock and form large porphyroblasts. They are, however, also present as much smaller crystals in the recrystallised zones. Where the mortar texture is well developed the microcline, perthitic microcline pair dominate at the expense of the pair orthoclase-perthitic orthoclase.

There are two phases of string perthite formation, an early fine phase and a later coarser phase. These intersect at angles ranging from 41^{0} to 58^{0}. Most crystals, however, contain the early or the later phase, not both. If the crystal shows microcline grid twinning the early phase is parallel to one of the twin disections. The later coarse phase shows no relationship to the twin composition planes, although the lamellae often bisect the angle between the twin planes. One large crystal containing both exsolution phases shows that the early fine phase is restricted to the central portion of the crystal, whilst the later coarse phase occurs over the entire crystal (Plate IX).

Microcline occurs both as large crystals and as small ones in the recrystallised zones associated with the mortar texture. Twinning is best developed where the mortar texture is strongest. Inclusions of quartz and plagioclase are often partly surrounded by diffuse twins whilst the rest of the crystal is untwinned. The plagioclase inclusions are often twinned on the albite law. One large perthitic microcline crystal shows a remnant Carlsbad twin.

Plagioclase (An_{25-30}) constitutes up to 30% of the rock and occurs as porphyroblasts and as small crystals within the recrystallised zones defining the mortar texture. There is no compositional difference between the two occurrences within the same thin section. The twinning is on the albite law only. Some crystals are perfectly twinned with straight, well defined composition planes. In them the twin individuals are wedge-shaped and often poorly defined. These wedge shaped twins are most common within the recrystallised zones and are thought to be deformational in origin. Reverse zonation was observed at the rims of several large crystals but in general this phenomena is not present.

Quartz occurs as strained crystals with slightly sutured boundaries, and constitutes up to 39% of the rock. The large crystals are up to 6 mm long and 1 mm wide and partially polygonised. The crystals in the recrystallised zones are somewhat equant and up to 1 mm in diameter. Small rounded, unstrained crystals are common as inclusions in potash feldspar.

Myrmekite is widespread throughout the granite and appears, in general, to be associated with microcline. The intergrowth occurs both in twinned and untwinned plagioclase. The shape of the quartz rods is highly variable. This, however, may be due to the variable orientation of the crystals within the section. Those that show a 'longitudinal' section invariably have a radial aspect with respect to the microcline-plagioclase boundary. Rods well within the plagioclase appear to have a random orientation. Where the plagioclase crystals is almost enclosed by the microcline the radial quartz rods outline a fold type of structure. Inclusions of plagioclase in microcline show poor, if any, development of myrmekite.

The presence, and abundance, of myrmekite is related to the development of microcline. Where microcline is common, myrmekite is well developed. The structure itself is variably developed, even within one thin section. Some plagioclase crystals show a somewhat even distribution of quartz rods, in them the rods appear to be coarsest at the plagioclase-microcline boundary, whilst in still others, the reverse of this is the case. There would appear to be no relation between the abundance of quartz and the size of the plagioclase enclosing it.

Muscovite and biotite occur throughout the granite and constitute up to 5% of the rock. They are the major minerals defining the fabric. In general biotite is the more abundant of the two. There are three distinct modes of occurrence, at feldspar-feldspar and feldspar-quartz grain boundaries, as inclusions within feldspars and in the recrystallised zones.

In the first case the crystals have straight boundaries and ragged ends. In general they are acicular and parallel to the grain boundaries. Some, however, are at right angles to the grain boundaries and these tend to be more equant.

The inclusions in feldspar have a variable outline and orientation. Some are small and rounded whilst others are up to 1 mm in length and euhedral. Many of them, especially the smaller ones, may be related to the breakdown of feldspar. The larger biotites, however, would appear to be inclusions.

Within the recrystallised zones the micas have recrystallised to give biotite-muscovite-magnetite and muscovite-quartz intergrowths. The crystals have a more fibrous nature than in the two former occurrences and tend to be orientated parallel to the length of the recrystallized zones.

In general the micas are little altered. However, at one locality, close to a late fault, biotite is altered to penninite. The muscovite appears to be unaffected by this retrogressive phase of metamorphism.

Accessory minerals form up to 5% of the rock. They are subhedral in form and are associated with each other and with the biotite defining the schistosity. Sphene, zircon and apatite also occur as rounded inclusions within feldspars.

Ferrohastingsite is found in trace amounts in the southern part of the granite. In the northern part it may, however, constitute up to 6% of the rock. Where abundant it is associated with biotite and helps define the tectonite fabric.

Garnet is present in the southern part of the granite. The crystals are subhedral, contain no inclusions and do not appear to be associated with the schistosity.

Pegmatite dykes and quartz veins and pods are associated with the intrusions of the granite. The pegmatites occur close to the granite sheets whereas the quartz veins and pods are best developed to the west of the sheets in the Grand Bay area. This type of occurrence is similar to that described by Brown (1971) in the Loch Coire migmatites, Scotland. He suggests that the sequence granite body ⟶ granite sheets ⟶ pegmatites ⟶ quartz veins represents movement of hydrous fluids along a pressure gradient away from the granite body.

CHAPTER V: DYKES

The dykes described in this section are those which cross cut the gneissic banding. They may or may not contain a tectonite fabric.

There are two major types, and several ages of dykes that intrude the Port aux Basques and Cape Ray Complexes. The two distinct compositions are dioritic and granitic. The diorite dykes are all fine grained and are more common in the Cape Ray than in the Port aux Basques Complex. The granitic dykes are either fine grained aplite, medium grained granite, or coarse grained pegmatite, and are found over the entire area.

Diorite Dykes

The diorite dykes are fine grained, light green, or speckled grey and green, and are generally less than 5 m wide. The only occurrence in the Port aux Basques Complex is 40 metres east of Foxroost, and it is undeformed. They are, however, quite common in the Cape Ray Complex and are affected by the shear zones related to the Cape Ray Fault.

Petrography: The main minerals present are: plagioclase An_{30-40}, hornblende, chlorite, epidote, zoisite, calcite, sericite, sphene, magnetite and apatite.

The bulk of the rock consists of interlocking plagioclase laths which are generally less than 1 mm but may be as much as 3 mm long. All are twinned on the albite law and many show pericline and Carlsbad twinning also. The composition is in the range An_{30-40} but is generally close to

An_{40}. Alteration to epidote, zoisite and sericite is variable from dyke to dyke. In the east, at Foxroost the alteration seems to be predominantly to sericite. In the Cape Ray Complex the alteration products are generally epidote and zoisite, sericite being subordinate.

Hornblende occurs as laths up to 2 mm long and is pleochroic in light yellow and green. The crystals have very ragged outlines and are commonly altered to chlorite. The hornblende and plagioclase form interlocking laths and it is suggested that they crystallised together.

Sphene and ilmenite are the common accessories and are often intergrown. Generally the sphene is present as a rim around the ilmenite, which occasionally shows lamellar twinning in three directions. Apatite is somewhat scarcer but does occur in acicular crystals up to 3 mm in length.

Epidote and zoisite most often occur within plagioclase crystals but are also present at plagioclase-plagioclase grain boundaries. The former mineral also appears to be associated with the breakdown of hornblende to chlorite. Chlorite occurs as distinct laths or surrounds the hornblende crystals. When sericite is the dominant alteration product of plagioclase, calcite occurs as an interstitial mineral.

Granitic Dykes

The aplite, granite and pegmatite dykes have a similar mineralogy to that of the granite sheets i.e. predominantly potash feldspar and quartz with small but variable percentages of plagioclase, muscovite, biotite and allanite. The latter mineral is, however, more concentrated in the pegmatites.

The aplites are very fine grained, generally do not contain a tectonite fabric, tend to be planar, and cross cut the gneissic banding at high angles. Some, however, also have an allignment of mica flakes which may be an intrusive feature. One granitic dyke cross cuts the gneissic banding and contains a fabric which can be related to the D_3 fabric in the gneisses. This occurrence, at Port aux Basques, may be related to the intrusion of the Port aux Basques granite but appears to be later.

The pegmatites are coarse with potash feldspar crystals up to 10 cms across, large knots of muscovite and biotite, and long acicular crystals of tourmaline. They show a highly variable relationship to the gneiss, i.e. sometimes folded with the banding and at other times cross cutting it. Both these features may be seen in one dyke in one outcrop. However, they always contain a tectonite fabric which can be related to the D_3 fabric in the gneisses, and show differential movement between the bands during the D_3 deformation.

CHAPTER VI: METAMORPHIC HISTORY

The metamorphic history is described in terms of growth stages which are identified with reference to periods of deformation. These are referred to as MS_1, MP_1, MS_2, etc. after Sturt and Harris (1961), and represent essentially an alternating sequence of static and dynamic mineral growth episodes. While it is realized that this is essentially a continuous sequence of events, the development of preferred mineral orientation during the periods of dynamic or syntectonic growth (Flinn, 1965) provides recognisable markers in the sequence which are used for a descriptive subdivision (Fig. V).

Port aux Basques Gneisses

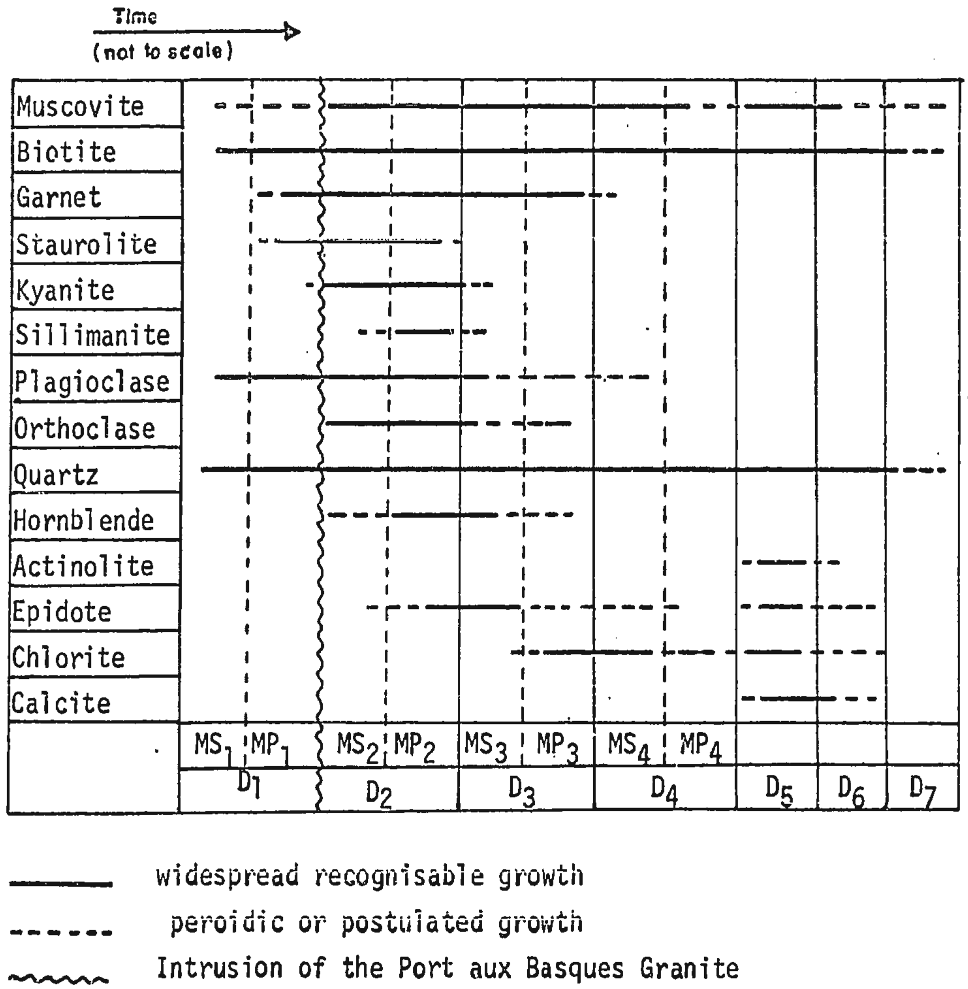
Four major episodes of deformation have been recognised in the Port aux Basques gneisses. Consequently the metamorphic history is described in eight stages MS_1 to MP_4. Although D_1 and MS_1 are here the first events recognised in the area, it is realised that they may have been preceded by earlier episodes, the effects of which are completely overprinted by the later metamorphic and deformational events.

MS_1:

These minerals are only recognisable as inclusions within the MP_1 porphyroblasts. They are rare due to the intensity of later deformation and recrystallisation but quartz, feldspar, magnetite and biotite occur and occasionally define straight inclusion trails within the MP_1 porphyroblasts (Plate X). The main evidence for this phase of deformation and metamorphism is, however, the composite nature of the D_2 fabric.

FIGURE V

The Growth History of the Metamorphic Minerals in relation to D_{1-7}.



The Port aux Basques granite was intruded into the gneisses in the late stages of, or after this phase of deformation and mineral growth and the migmatite terrain developed.

$\underline{MP_1}$:

MP_1 effects are generally strongly overprinted by MS_2 and MP_2 growth but some porphyroblasts are recognisably surrounded by augen of S_2 and others contain areas of inclusions which are either discontinuous with S_2 (Plate XI) or pre-date areas of curved inclusions trails due to MS_2 growth (Powell and Treagus, 1970).

Garnet and staurolite are the only minerals forming recognisable MP_1 porphyroblasts and inclusions within these minerals show the progressive polygonisation associated with D_1.

$\underline{MS_2}$:

The tectonic fabric developed in the MS_2 event in response to the D_2 stress system, although modified by MP_2 polygonisation and porphyroblast growth and partially transposed by MS_3 effects is the dominant fabric of the Port aux Basques gneisses. It is a composite fabric (Whitten, p. 126) formed by the total transposition and regrowth of the earlier D_1 fabric, is finely banded, and is defined in the leucocratic portion by mica and in the melanocratic portion by hornblende and biotite. The hornblende is often poikiloblastic and contains rounded inclusions of quartz and feldspar. In the west of the area the earlier quartz and feldspar (An_{20-30}) fraction recrystallised without compositional change in response to the stress. In the east, however, potash feldspar grew as a new metamorphic mineral.

Staurolite continued growth from MP_1 through MS_2 times. The quartz and feldspar inclusions within these porphyroblasts generally show curved trails which are continuous with the external schistosity (Plate XII). Garnets are also present as inclusions indicating that the growth of the two minerals was synchronous but that staurolite growth outlasted that of garnet. The garnets generally occur as porphyroblasts which occasionally show curved inclusion trails. These trails are continuous (by extrapolation) with the external schistosity.

Kyanite occurs as somewhat acicular crystals which help define, with mica, the second fabric (Plate XIII). These laths are generally poikiloblastic and contain inclusions of rounded quartz and feldspar crystals. Inclusions of garnet are occasionally observed.

MP_2:

Most of the minerals that grew in MS_2 continued growth into MP_2 times and the boundary between the two growth phases is regarded as being represented by the polygonisation of quartz and feldspar and the mimetic regrowth of micas. In the MP_2 event the highest grade mineral assemblage developed and recrystallisation was most intense but the overall pattern of the MS_2 tectonite fabric was preserved.

The continued growth of kyanite resulted in large porphyroblasts (Plate XIV), some of which are euhedral and inclusion free whilst others are sieve like. The former are generally twinned whilst the latter are untwinned. The inclusions are generally rounded quartz, feldspar, and magnetite but staurolite and garnet also occur. Quartz inclusions containing inclusions of staurolite were also observed (Plate XV). The poikiloblastic crystals generally have their long axis parallel to the second fabric whilst the inclusion free crystals often grow across this fabric. The latter type of growth is common in the hinge areas of boudined quartzo-feldspathic bands.

Garnet growth continued throughout this period but at a slower rate (Rast, 1965), resulting in the development of inclusion free rims around almost all the MS_2 crystals. Together with this,staurolite appears to have recrystallised in situ resulting in MP_2 crystals being apparently augened by the second fabric. These crystals contain large polygonal quartz and feldspar inclusions. Staurolite growth always appears to have outlasted garnet growth (Plate XVI). Kyanite-garnet growth relationships are, however, variable over the area.

Sillimanite growth, in the form of fibrolite, is the final progressive event in this stage of metamorphism. It occurs to the east of, and overlaps with, the kyanite bearing rocks in the Grand Bay area. Where the polymorphs occur together they either co-exist (Plate XVII) or the kyanite shows alteration to sillimanite (Plate XVIII). Generally the fibrolite occurs as knots which are flattened by the third deformation. It is also present, however, as inclusions in quartz and feldspar crystals.

The fibrolite pods were locally retrogressed to muscovite before the onset of the third deformation. These muscovite crystals are porphyroblastic and in part overgrow the second fabric. However, the bulk of the muscovite is probably mimetic after MS_2 crystals, as is the biotite. (They are, however, strained and folded by the third deformation.)

Epidote was present in the epidosite bands since it shows evidence of being folded by the third deformation. However, recrystallisation during and after the third deformation has almost obliterated all evidence of this early occurrence.

MS_3:

The intensity of this phase of metamorphism is highly variable across the area but generally appears to be more progressive in the east than in the west. Quartz, feldspar (An_{20-30}), mica and hornblende recrystallise, and the growth of the latter two define a tectonite fabric axial planar to F_3 folds.

Garnet nucleation and growth occurred in thin quartz bands in the Grand Bay area. The crystals are pink, less than 0.5 mm in diameter and occur at quartz and feldspar grain boundaries and as inclusions in these minerals (Plate XIX). The kyanite defining the D_2 fabric was folded during D_3. The crystals are strained and partially altered to fine white mica. Sillimanite is found in one D_3 shear zone. It is not known whether it nucleated and grew during MS_3 deformation or whether it was merely physically reorientated.

Epidote nucleated and grew with hornblende in some of the melanocratic bands. It is, however, generally not present within the leucocratic portion.

In the extreme west of the area potash feldspar grew on the limbs of isoclinal F_3 folds and recrystallised in the hinge areas.

$\underline{MP_3}$:

There was little nucleation or growth during this period of metamorphism. Quartz,feldspar, hornblende, epidote and mica partially polygonised. Kyanite, which was strained in the D_3 fold hinges polygonised (Plate XX) and porphyroblasts partially recrystallised to give smaller crystals which have a different orientation than the parent.

The polygonisation of quartz in the quartz garnet bands in the Grand Bay area was accompanied by continued nucleation and growth of garnet. In some melanocratic bands hornblende and epidote have grown. This is, however, not commonly observed.

$\underline{MS_4}$:

This phase of metamorphism is sporadically developed and is generally retrogressive. Garnet and biotite were altered to chlorite, especially at fold hinges. Quartz, feldspar and mica locally recrystallised, the latter defining a weak fabric axial planar to F_4 folds.

$\underline{MP_4}$:

There was no nucleation and growth during this phase. Quartz, feldspar and mica partially polygonised in areas of D_2 strain. The MS_4 alteration of garnet and biotite probably continued into this phase.

Later metamorphic events are restricted to narrow shear zones associated with local deformations. They have a retrogressive effect on the gneisses and resulted in their breakdown to finely intermixed quartz, feldspar, sericite, calcite, and chlorite.

Metamorphic Assemblages:

The leucocratic portions of the Port aux Basques gneisses show a zonation of metamorphic mineral assemblages with zone boundaries tending approximately N.E.-S.W. (Fig. VI). The zones are defined by the following parageneses: (assemblages)

Zone A:

Garnet-muscovite-biotite
Garnet-biotite
Garnet-muscovite
Muscovite-biotite

+ quartz + plagioclase (An_{20-30})

Zone B:

Garnet-staurolite-kyanite-muscovite-biotite
Garnet-staurolite-muscovite-biotite
Garnet-kyanite-muscovite-biotite
Garnet -muscovite-biotite
Garnet-biotite
Muscovite-biotite

+ quartz + plagioclase (An_{20-30})

Zone C:

Garnet-kyanite-muscovite-biotite
Kyanite-muscovite-biotite
Garnet-muscovite-biotite
Garnet-biotite
Muscovite-biotite

+ quartz + plagioclase (An_{20-30})

Zone D:

Garnet-sillimanite-muscovite-biotite
Sillimanite-muscovite-biotite
Garnet-muscovite-biotite
Muscovite-biotite

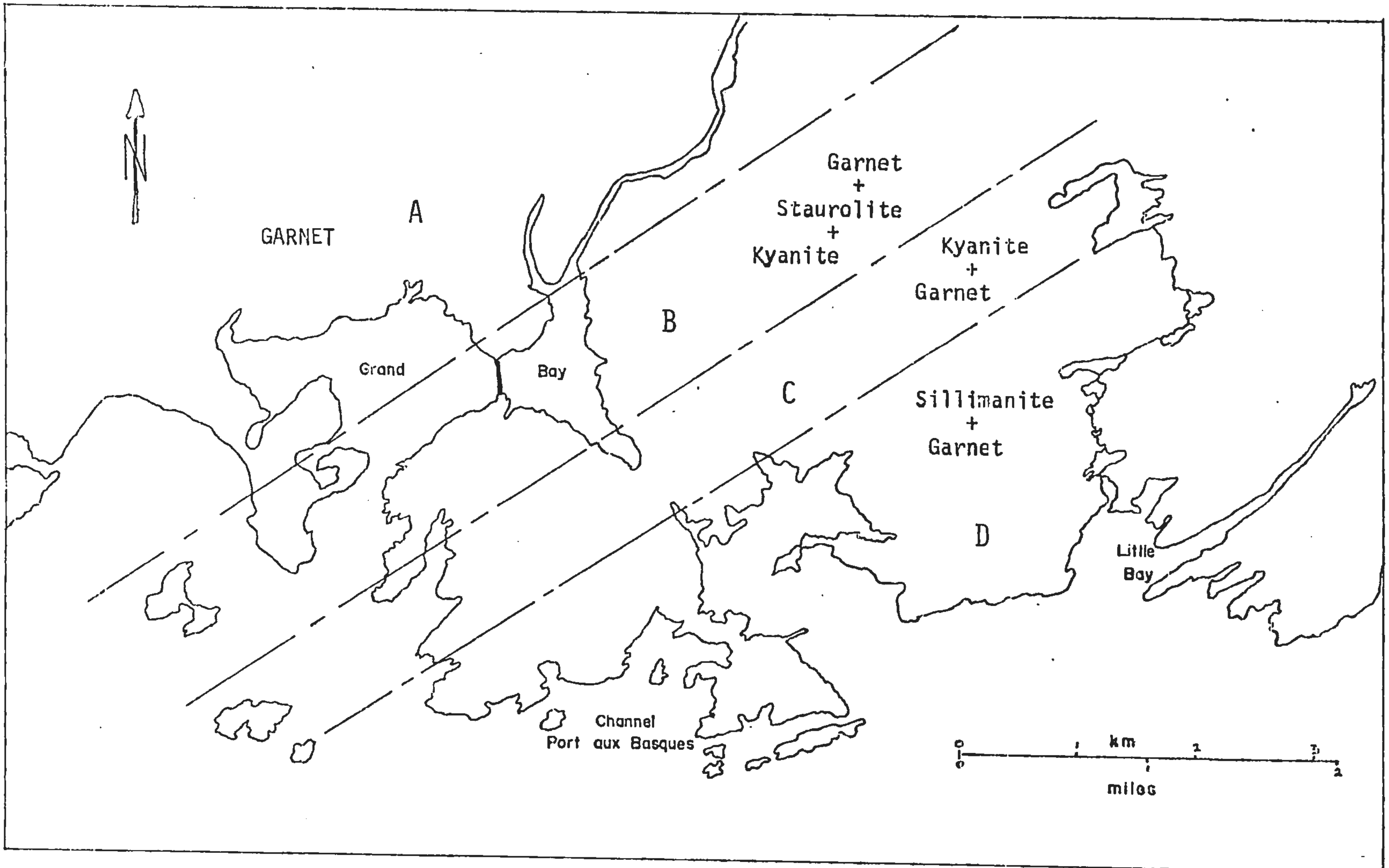
+ quartz + plagioclase (An_{20-30}) $\pm$ potash feldspar

The boundary between zones A and B is defined by the incoming of kyanite and/or staurolite. Apart from staurolite and kyanite, zone B is characterised by large garnets, some of which are over 1 cm across. The B-C zonal boundary is defined by the disappearance of staurolite. In zone C the garnets are not as large as those in zone B. The polymorphic transition between kyanite and sillimanite defines the C-D boundary. The occurrence of sillimanite apparently decreases eastwards from the boundary and it was not observed in the migmatites east of the Little Bay fault. This may reflect a compositional control rather than a change of physical conditions.

The parallel, linear nature of the zone boundaries (Fig. VI) is a result of structural control. The diagnostic minerals of the assemblages grew during or immediately after the second phase of deformation and their present trend is parallel to the strike of S_3 and is regarded as a function of D_3 folding and flattening. Overall grade decreases westwards away from the granite sheets and migmatites, and the present trend of the zones is parallel to that of the edge of the migmatite belt.

The mineral assemblages developed are characteristic of the Barrovian metamorphic sequence (Barrow, 1893, 1912; Miyashiro, 1961) and all fall within the Amphibolite Metamorphic Facies (Turner, 1968).

FIGURE VI: METAMORPHIC ZONES IN THE PORT AUX BASQUES AREA



Occurrence of Garnet:

Garnet occurs throughout the Port aux Basques gneisses. In zone A it is the diagnostic metamorphic mineral. In the other zones it occurs alone or in association with staurolite, kyanite or sillimanite. In general there is an increase in size and frequency eastwards from the Cape Ray fault with a maximum being reached in zone B. There is a sharp decrease in both parameters to the east of this zone.

The composition of the host rock appears to be the dominant control of the composition and development of garnets. When the host rock is biotite poor the garnets are generally less than 0.5 mm across and are light pink in colour. Within biotite rich bands the garnets may be up to 1.5 cms across and have a deep red colour. The margins of amphibolite bands also appears to have been a favourable location for their nucleation and growth. These occurrences suggest that the general reaction producing garnet is related to the breakdown, or compositional changes, in biotite with increasing grade.

The widespread occurrence of garnet may possibly be explained by overstepping of reactions if the reaction to give garnet is different at different grades of metamorphism (Hollister, 1969). Different ages of growth in different areas and the presence of more than one growth phase in many of the garnets makes evaluation of detailed compositional changes which might indicate changes in the grade of metamorphism (Nandi, 1968) unfeasible in this area.

Occurrence of Staurolite:

Zone B, defined by the presence of staurolite with or without kyanite, represents an intermediate zone between the garnet and kyanite zones in A and C. The staurolite is restricted to thin biotite rich bands and occurs as single porphyroblasts up to 2 cms long. No textural evidence relevant to a possible metamorphic reaction was observed but the appearance of staurolite is probably related to the breakdown of mica and possibly of garnet with increasing temperature.

In the type Barrovian metamorphic sequence the almandine zone is followed successively by staurolite and kyanite. However, in the Port aux Basques area, staurolite and kyanite appear together making these zones indistinguishable. Similar occurrences are reported in the Moinian rocks of Scotland (Francis, 1956).

It has been suggested by some authors (Deer, Howie and Zussman, 1962) that staurolite will grow only when the host rock falls within a specific chemical range. However, analyses of 34 staurolite bearing rocks (Jurrisum, 1956) showed that the SiO_2 and Al_2O_3 content ranged from 28.12% to 90.44% and 4.11% to 42.51% respectively. This would seem to indicate that although staurolite bearing rocks are rich in alumina, high alumina content in the host rock is not essential to its formation and therefore the chemical limits of the host rock are not as restrictive as has been suggested.

Ganguly (1968) demonstrated that oxygen fugacity, particularly in the upper part of the magnetite field, has very significant effects on the equilibrium relations between almandine, staurolite and kyanite.

Kyanite is found to be restricted chiefly to highly oxidised rocks whereas staurolite is mainly confined to relatively less oxidised rocks. The presence of magnetite in the staurolite bearing rocks of the Port aux Basques gneisses suggests a limited mobility of O_2 and H_2 within these assemblages (Mueller, 1961). Consequently, the partial pressure or fugacity of oxygen can vary sharply over small volumes of rock. Therefore the distribution of staurolite, almandine and kyanite may be controlled by variations in redox potential rather than in overall pressure and temperature. It is therefore concluded that the appearance of staurolite is a complex function of pressure, temperature and oxygen fugacity. In the Port aux Basques area the first appearance of staurolite accompanied by kyanite suggests that the latter effect may be important here. The appearance of staurolite is, therefore, not used as an indicator of prevailing P.T. conditions, at the time of its formation. The disappearance of staurolite may, however, reflect a general increase in the grade of metamorphism.

Occurrence of Kyanite:

Kyanite occurs in zones B and C. In zone B it occurs with staurolite and in zone C staurolite is absent. It is, however, present in much greater amounts in the former zone, and occurs as colourless, light blue, dark blue and light green porphyroblastic crystals up to 10 cms in length.

Near the A-B zone boundary kyanite occurs as large blue crystals associated with quartz pods. These pods are associated with the intrusion of the Port aux Basques granite and are probably the result of SiO_2

migration along a pressure gradient (Brown, 1971). Where they are absent kyanite occurs as single crystals on the schistosity planes. However, where the pods become pronounced, kyanite often occurs in knots on the schistosity planes. Where the pods are abundant kyanite occurs in their pressure shadows and boudin necks and as separate pods up to 15 cms in length, and is not found on the schistosity planes.

This common association of kyanite with the quartz pods would seem to imply associated movement of SiO_2 and Al_2O_3 although the large volume of the quartz pods indicates a greater mobility or greater volume of SiO_2.

The occurrence of kyanite on the schistosity planes in zone B is unlikely to be the result of a reaction involving staurolite since it often occurs in association with that mineral, i.e.

3 staurolite + 2 quartz $\rightleftharpoons$ almandine + 5 kyanite + 3 water (Francis, 1956).

This association may, however, be due to local fluctuations in the partial pressure of oxygen (Ganguly, 1968) and the staurolite breakdown reaction may become significant close to the B-C boundary, i.e. the disappearance of staurolite. The most probable reaction is, however, thought to be of the type (Francis, 1956):

paragonite + quartz $\rightleftharpoons$ albite + kyanite + water.

Occurrence of Sillimanite

Zone D, which contains sillimanite probably represents, except for the migmatites, the highest grade of metamorphism reached in the area.

The sillimanite occurs as single crystals and fibrous aggregates in plagioclase and porphyroblastic mica crystals, as a coexisting phase with kyanite, and as a phase replacing kyanite. These last two relationships are observed close to the C-D zone boundary and indicates a change in P.T. conditions from the stability field of kyanite to that of sillimanite in this area during and after the second episode of deformation.

The occurrence of sillimanite in plagioclase may indicate an exsolution origin (Watson, 1948; Sturt, 1970). The latter author shows, from examination of a considerable number of feldspar analyses, that SiO_2 and Al_2O_3 often occur in excess of stoichimetric requirements, and therefore concludes that, given the appropriate physical conditions, exsolution of Al_2O_3 and SiO_2 could occur from heterotype feldspar solid solutions. Furthermore SiO_2 would be more readily precipitated at lower temperatures forming myrmekitic quartz,and Al_2O_3 and SiO_2 would be exsolved together as sillimanite only at higher temperatures. It is suggested that for the development of the exsolved sillimanite the temperature control was subsidiary and that the dominant control is the thermal stress configuration (Sturt, 1970) allied with the total stress configuration i.e. when garnet abuts plagioclase, sillimanite is often present as an exsolved phase. Adjacent plagioclase crystals, surrounded by quartz most often do not contain sillimanite. Also, where plagioclase forms large crystals, the width of the tectonic banding, and where D_3 has appressed this banding, then sillimanite occurs as an exsolved phase.

The most common occurrence of sillimanite in the area is in association with porphyroblastic mica crystals. The sillimanite here is generally associated only with white mica and not as in other documented areas with both biotite and white mica (Chinner,1961; Guidotti, 1970; Velde et al., 1970), although it was found in one occurrence to be associated with biotite. The latter authors report sillimanite occurring as a breakdown product of white mica with an increase in the basal spacings of the mica from the kyanite to the sillimanite bearing rocks. Chemical analyses indicate that this change in all dimensions is due to a decrease in the sodium content by the exsolution of the paragonite molecule. They thus suggest that the appearance of this type of sillimanite is due to the reaction

$$\text{paragonite} + \text{quartz} \rightleftharpoons \text{albite} + \text{sillimanite}.$$

The growth of sillimanite in the Port aux Basques gneisses probably follows this type of reaction although later porphyroblastic growth of white mica suggests a reversal during the third deformation.

The presence of sillimanite in the Port aux Basques gneisses may therefore be attributed to four processes:

(1) Metamorphic reaction, i.e. paragonite + quartz $\rightleftharpoons$ sillimanite + albite. Probably the dominant process resulting in the development of knots of sillimanite.

(2) Exsolution from plagioclase. Dependent, to a great extent, on local mineralogical and physical conditions and, as such, irregularly developed throughout the zone.

(3) Breakdown of biotite. Uncommon and found at only one locality.

(4) Alteration from kyanite. Only seen locally close to the kyanite-sillimanite transition but may have gone to completion within the sillimanite zone and as such is not observed there.

Absolute Pressure and Temperature Conditions

The absolute P and T conditions varied with each of the four phases of metamorphism and also within individual phases. Little may be said about MS_1 due to the lack of data but biotite grew at an early stage and there was a general increase in P and T with time, as shown by the later growth of staurolite and garnet.

MS_2-MP_2 represents the highest grade of metamorphism reached in the area, and is associated with the intrusion of the Port aux Basques granite and the development of the migmatite terrain. The migmatites and granite sheets in the east indicate T and P conditions close to the ternary minimum of the quartz-albite-orthoclase system (Mehnert, 1968). The presence of sillimanite, kyanite, staurolite and garnet progressively westwards away from the migmatites suggests a decrease in T and P from east to west during the second phase. The complete absence of andalusite implies a pressure above that of the Al_2SiO_5 polymorphs triple point junction. The mineral zones are similar to those defined by Barrow (1892, 1912) and the PT conditions and variation across the area are thought to be similar to that represented by Turner (1968, p. 363 ; Fig. 8-5).

During and after MS_3 a gradual decrease of T and P is indicated culminating in local chloritisation, saussuritisation, and sericitisation.

Long Range Gneiss

Both fabrics observed in the Long Range Gneiss have been completely retrogressed to chlorite and sericite by late stage metamorphic and deformational events. Their metamorphic history could therefore not be determined. However, the presence of blue quartz porphyroblasts, characteristic of the Grenville gneisses, suggests a long and protracted history.

Windsor Point Group

In the metasedimentary and metavolcanic rocks of the Windsor Point Group, the growth of actinolite, epidote and mica is associated with the fifth phase of deformation. Epidote is best developed in volcanic pebbles. Limited chlorite and sericite growth is associated with the later deformational events. Minor quartz recrystallisation also occurred.

The maximum grade of metamorphism in these rocks is attained during the fifth phase of deformation and is restricted to the greenschist facies (Turner, 1968).

CHAPTER VII: STRUCTURAL HISTORY

The structural history of the area is described in terms of successive deformational episodes and their resultant fabrics, and the relationship of one fabric to another. The earliest deformation and resultant folding are referred to as D_1 and F_1 respectively. As previously mentioned D_1 may not have been the first phase of deformation, but it is the first that is recognisable in the field and in thin section. The D_3 tectonite fabric is recognised by its overprinting of the D_2 fabric and the F_3 folds by their folding of the D_2 features. These types of relationships are used to determine the relative ages of all the folds and fabrics recognised in the area.

Four regionally developed phases of deformation are recognised in the Port aux Basques gneisses, D_1, D_2, D_3 and D_4. D_4 is, however, not as widespread as the first three phases. In the Cape Ray Complex the effects of three phases of deformation can be recognised. In the metasedimentary rocks and granites of this complex these deformational episodes affected previously undeformed rocks but the gneisses show evidence of an earlier deformational history. These three phases of deformation are related to the Cape Ray fault and in the Port aux Basques gneisses east of the fault they overprint D_3 and D_4. Consequently they are referred to as D_5, D_6, and D_7.

Port aux Basques Complex

There are four discernable phases of deformation in the Port aux Basques Complex defined by folds and associated tectonite fabrics. The earliest phase is almost obliterated by the intensity of superimposed events and, in the field, can only be identified on the basis of knots of quartz and feldspar which appear to be folded around F_2 fold hinges. The existence of this period of deformation was subsequently verified in thin section. Its existence is substantiated by the composite appearance of the D_2 tectonite fabric.

The second phase of deformation (D_2) was preceded by the intrusion of the Port aux Basques granite. The configuration and style of the large scale folds is difficult to determine within the gneisses. The Port aux Basques granite, however, occurs as sheets up to 80 m thick and is folded into flat lying isoclinal folds with an amplitude up to 5 km, and which trend northwesterly. This was a very intense period of deformation and it obliterates all evidence of the earlier phase, or phases, of deformation. It was also mainly responsible for the development of the gneissic banding.

The third phase (D_3) was not as intense as the second. The major folds are characterised by numerous small parasitic folds in the hinge areas and their axial planes strike northeasterly. Most of the major folds appear to be antiformal with the intervening synforms pinched out. The axial planes of the major D_2 and D_3 folds are at right angles to one another and they have a similar order of magnitude of wavelength and amplitude resulting in a basin and dome type of outcrop pattern (Ramsay, 1967, p. 525). This is well illustrated by the map pattern of the Port aux Basques granite.

The fourth phase of deformation is observed in the Port aux Basques -Grand Bay area. It is characterised by large open monoclinal folds and, on a smaller scale by the crenulation of the earlier tectonite fabrics. An axial planar fabric is occasionally associated with these crenulations, and strikes northwesterly.

$\underline{D_1}$:

No direct and unambiguous evidence for D_1 was found in the field. However, in the Port aux Basques area there are numerous indications of this phase of deformation. Knotts of quartz and feldspar which may be remnant fold hinges are folded around recognisable second phase folds. In general, however, the second phase of deformation is so intense that no identifiable fabric was folded around F_2 and the intensity of the D_2 fabric obliterates most evidence of D_1 or earlier structures.

In thin section the D_1 fabric is seen to be defined by biotite and magnetite laths. Evidence, however, is rather sparse and no conclusion could be reached about the development or type of fabric since it is best preserved as inclusions within garnet and staurolite porphyroblasts.

$\underline{D_2}$:

The second phase of deformation was very intense and associated fabrics and structures are observed over the entire area. In general the related folds are isoclinal and were refolded during the third deformation. Their wavelength is usually less than 1 m and may be down to several centimeters and they are straight limbed irrespective of scale developed.

The area may be subdivided into regions where minor F_2 fold closures are commonly observed and others where no fold closures are apparent. The latter case is most commonly encountered but in the Port aux Basques - Grand

Bay area F_2 folds are common. Where these closures are absent it is generally not possible to separate, in the field, the second and third tectonite fabrics as they are both parallel to the gneissic banding. Occasionally, however, a cross cutting relationship is seen and here the second fabric is an S tectonite fabric defined by muscovite and biotite, the latter being the dominant mica. In this situation the second fabric is parallel to the gneissic banding whilst the third fabric cuts across it (Plate XXI).

In F_3 fold hinges where the D_3 axial planar fabric is weakly developed the D_2 fabric is well preserved. In the amphibolite and hornblende schist bands it is an L-S tectonite fabric defined by hornblende and biotite. The hornblende crystals are acicular and up to 1 cm in length and define a lineation. The biotite content is highly variable and where absent, the fabric is almost pure L tectonite. A fine 2-3 mm hornblende-plagioclase banding is also observed to be folded around F_3 folds. In the leucocratic bands the D_2 fabric is an S tectonite fabric defined by mica. When the fabric elements are closely spaced a fine 2-3 mm wide banding is developed.

The D_2 fabric is thus variable over the area from an L to L-S to S tectonite, although the latter is most commonly developed. It is therefore suggested that the D_2 deformation ellipsoid was oblate rather than prolate.

The large scale D_2 structures could not be determined in the majority of the gneisses due to the intensity of D_3 and the absence of recognisable marker horizons. However, the distinctive nature of the

Port aux Basques granite allows the mapping of major D_2 folds in the east of the area. The granite occurs as a series of sheets which were folded during the second and third deformations and define a type II interference pattern (Ramsay, 1967, p. 525). Since the D_3 folds are upright, then the second phase folds are flat lying. They have an amplitude up to 5 km, a frequency of less than 80 m and the axial plane strikes northwesterly.

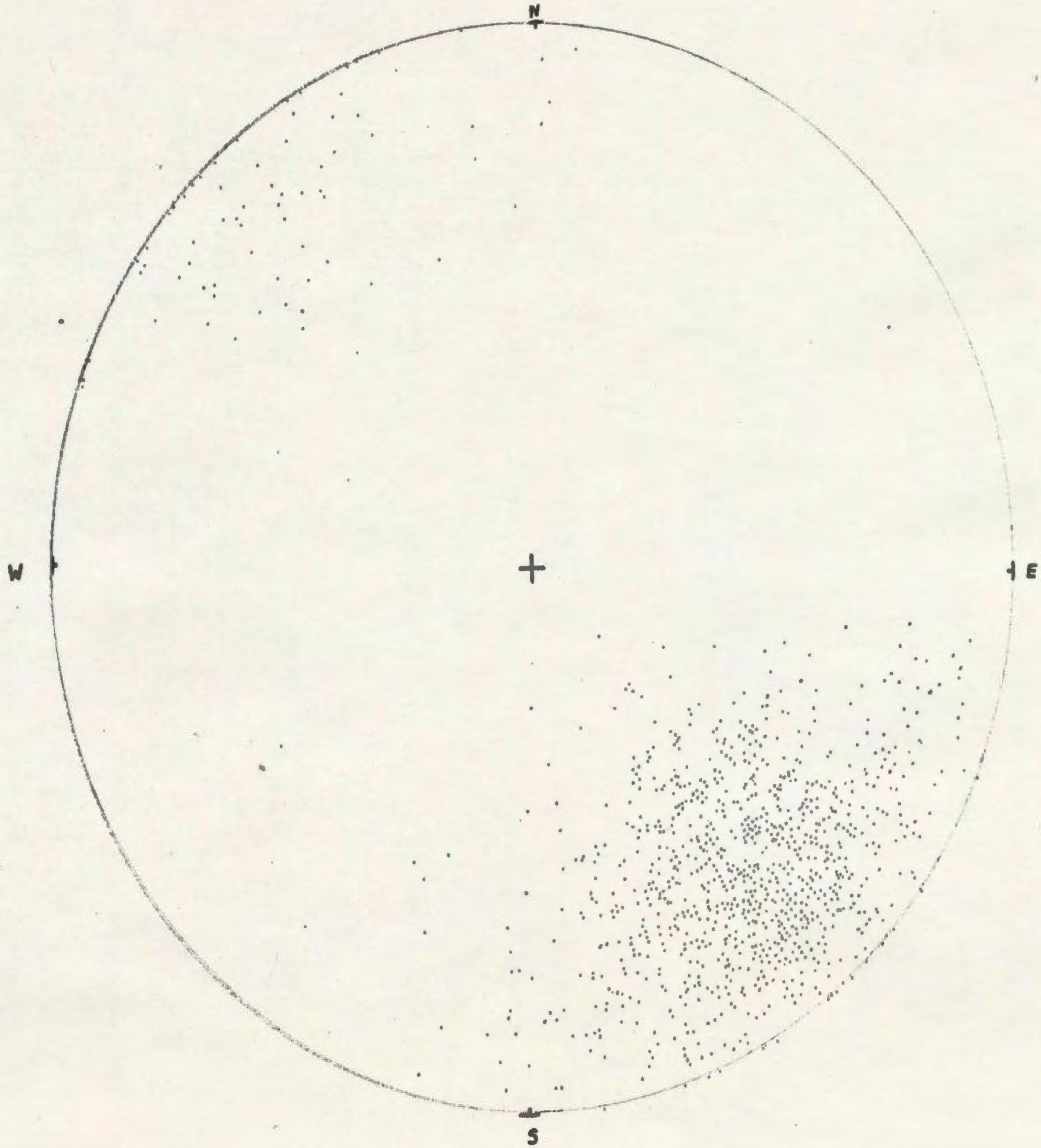
Minor D_2 structures are uncommon and are only observed close to F_3 fold hinges and were of little assistance in determining the large D_2 structures. Their absence on the limb of F_3 folds is probably due to the intensity of the later D_3 flattening.

$\underline{D_3}$:

The third phase of deformation, although less intense than the second is presently the dominant phase throughout the Port aux Basques Complex. It produced upright folds which strike northeasterly and which have a highly variable plunge (Fig. VII). This variation is thought to be due mostly to interference with the D_2 structure (Ramsay, 1967). The F_3 folds are asymmetrical and are characterised by numerous small parasitic folds close to the hinge areas. This feature is present on all scales of F_3 folding.

In a general sense the intensity of the D_3 deformation increases from west to east. In the west the F_3 folds are open and often do not have a pronounced associated axial planar fabric. When present, however, it is defined, in the leucocratic bands by muscovite and biotite and

FIGURE VII: π DIAGRAM OF S_3 SCHMIDT NET



overprints or cross cuts the D_2 fabric. In the melanocratic bands an L-S tectonite fabric is developed, defined by hornblende and biotite.

In the central part of the area, around Port aux Basques, the folds are sub-isoclinal to isoclinal, and their asymmetric nature becomes pronounced. Minor parasitic folds on these F_3 folds show that most are antiformal. These antiforms can be grouped, by their asymmetry, into larger antiforms where wavelength varies from 5 to 50 metres. These in turn are grouped into antiforms with wavelengths up to 1.5 km. The associated synforms are subordinate or are completely pinched out, especially in the larger scale structures.

The smaller two scales of structures are readily observed in the gneisses. The largest scale structure is, however, difficult to define due mainly to its large dimensions and to the difficulty of recognition of the intensely reflattened zones which represent the intervening synforms.

In the eastern part of the area the outcrop pattern of the Port aux Basques granite shows well the form of the large structure. The D_3 axial planar fabric has similar characteristics as that in the west except is more strongly developed. Where no F_3 folds are observed the D_2 and D_3 fabrics are generally parallel to the gneissic banding and cannot be differentiated. The D_3 fabric does, however, occasionally cut across the gneissic banding. In the former case, thin section work showed that the D_3 flattening had caused partial recrystallisation of the D_2 fabric elements.

To the east of Little Bay the gneisses are regularly banded and have been intensely flattened. The D_3 fabric is concordant with the banding. The F_3 folds are all isoclinal but may occasionally show the asymmetry which was marked in the Port aux Basques area. Minor, antiformal type of structures similar to those described above are readily delineated. The large scale structure could not, however, be determined, although there is no reason to suspect that it has a different form than that shown by the Port aux Basques granite. The fabrics are similar to those described above but are often poorly developed due to the migmatitic nature of the gneisses.

D_4:

The fourth phase of deformation is not as widespread and was much less intense than the previous phases. It is observed in the Port aux Basques - Grand Bay area and caused large open monoclinal folds. No fabric is associated with these folds. In some highly micaceous bands this deformation causes a crenulation of the D_3 fabric. The wavelength of these minor folds is in the order of 1-2 cms. Their axes, like the monoclines, strike northeasterly and generally dip steeply to the northeast.

The highly variable plunge of the F_3 folds may in part be due to this deformation. However, most of the tight plunge variations do not affect the axial planar fabric of the F_3 folds (Plate XXII). This variation is thus more probably due to the interference between the second and third structures.

Cape Ray Complex

Long Range Gneisses:

The structures within the Long Range Gneiss could not be determined. Two retrogressive fabrics represent at least two phases of deformation but the augened basic pods and the general homogeneity of the rock suggests previous phases which cannot now be recognised. The earlier fabric is defined by an intergrowth of chlorite, quartz, and feldspar, and was recognised at only one locality in the field. The later fabric, defined by chlorite, transposes the earlier fabric and is parallel to the main fabric in the Cape Ray Granite and to the Cape Ray Fault.

The age of these fabrics within the regional pattern could not be determined since they cannot be correlated with any deformation in the Port aux Basques Complex. They are, however, older than the tectonite fabrics in the metasedimentary and metavolcanic rocks of the Windsor Point Group which are associated with movements on the Cape Ray Fault since these latter fabrics die out towards the Long Range Gneisses.

Cape Ray Granite:

The Cape Ray granite, like the Long Range Gneisses, contains two fabrics. The earlier is defined by chlorite, biotite and quartz. The later fabric, defined by sericite, transposes the earlier one, strikes northnortheast and dips steeply to the east-southeast. It is variably developed throughout the body and appears to be more pronounced at the margins, especially the southeastern margin.

These fabrics are cut by intense shear zones which strike north-northwest to north-northeast. The zones are generally less than 1 m wide and within them the large potash feldspar phenocrysts are broken down. There may be some relation between these zones and the Cape Ray Fault since both represent zones of intense flattening.

Red Rocks Granite:

There is no penetrative tectonite fabric in the Red Rocks Granite. However, shear zones up to 20 m wide are numerous and show a range in strike from northeast to northwest, but are generally northeasterly and dip steeply to the southeast. Within these the granite is broken down to a very fine grained, grey quartz-feldspar rock which may be unfoliated or finely banded with some relic quartz and feldspar phenocrysts locally preserved. The banding where developed is 2 mm wide and is defined by alternating chloritic and quartz and feldspar rich fabric.

These zones are similar to those developed in the Cape Ray Granite. They show the same type of deformation and the same range in strike. Both of these may be related to the Cape Ray fault.

Windsor Point Group

The sedimentary and volcanic rocks of the Windsor Point Group have been deformed three times. All these deformations are thought to be related to the Cape Ray Fault since they increase in intensity towards it, and can be traced into the fault zone. To the east of the fault the effects of these deformations are seen to overprint the effects of the previously described four phases of deformation in the Port aux Basques Complex, consequently they are referred to as D_5, D_6, and D_7 respectively.

D_5:

This deformation was most intense close to the fault zone where a 2-3 mm wide tectonic banding is developed. In the conglomerates this banding forms augen around the pebbles. Away from the fault plane D_5 is represented by a penetrative cleavage which decreases in intensity with increasing distance from the fault. It can, however, still be seen in the ignimbrites over 1.5 km from the fault.

F_5 folding was only observed at one locality close to the tuff-conglomerate contact (Fig. IV). A 50 cms wide conglomerate band is folded and closes around the fold. There is, however, no fabric going round the fold, the folded closure is interpreted as being due to the original discontinuous nature of the conglomerate bands. An axial planar fabric, defined by white mica, is developed.

The tectonic banding close to the fault zone is due to intense flattening and there is no evidence of related small scale displacement. Pebbles in the conglomerate are flattened in the plane of the bedding, and shale bands within the rhyolites, which are cross cut by the banding, still form recognisable units.

D_6:

The sixth deformation is very similar to and co-axial with, but less intense than the fifth. Close to the fault zone the D_5 tectonic banding is sub-isoclinally folded by the sixth deformation and an associated axial planar fabric, defined by sericite and chlorite is well developed. No F_6 folds were observed in the ignimbrites, tuffs or conglomerates. The latter two do, however, contain a penetrative cleavage which is subparallel to and locally cross cuts the D_5 cleavage.

D_7:

The seventh deformation indicates a further decrease in intensity of deformation. It is expressed by kink bands and possibly minor faulting. Unlike the previous two phases it is not obviously more intense in the region of the Cape Ray Fault.

All observed kink bands were normal (Dewey, 1965). The kink planes strike north-northeast and east-southeast and generally dip steeply to the east. This may represent the development of conjugate sets of kink bands although sufficient data was not collected to substantiate this. The width of the kink foliae varies from 2 cms to 50 cms but they are normally in the order of 5 cms wide.

Summary

Seven phases of deformation are recognised in the area. The first four of these are defined in the Port aux Basques Complex and show a general decrease in intensity from the second to the fourth. The earliest phases, i.e. D_1 and D_2, were responsible for the production of the gneissic banding although the intensity of the second fabric makes it possible that D_1 was not the earliest deformation to affect the Port aux Basques Gneisses.

The deformations apparent in the Long Range Gneisses and Cape Ray Granite may possibly be related to the early phases of deformation in the Port aux Basques Complex but this could not be substantiated due to the lack of correlation across the Cape Ray Fault zone.

The fifth, sixth, and seventh phases are best developed in the Windsor Point Group and are represented in the Port aux Basques Complex, Long Range gneiss and Cape Ray and Red Rocks Granite by narrow zones of intense flattening.

Faults and Fractures

Cape Ray Fault:

The Cape Ray Fault is defined by a zone of intense flattening or shearing, up to 30 m wide, which strikes northeast and dips steeply southeast. It crops out on the coast 40 m east of Windsor Point. Fabrics associated with the fault are, however, observed up to 1.3 km across strike on either side of the fault. Zones of intense flattening, which are thought to be associated with the fault, are found to the east and west of the fault. Generally they are less than 20 m wide and often contain a well developed tectonite fabric.

On the eastern side, within the Port aux Basques gneisses, only two such zones were found. The first is 2 km and the second 3 km southeast of the main fault zone and both crop out on the Trans-Canada Highway. The associated fabric is a fine, less than 0.5 cms wide, tectonic banding which is not related to and overprints the gneissic banding. Their lateral extent was not determined since neither crop out on the coastal section or in the intervening ground.

The zones on the western side have already been described in the Cape Ray Granite, the Red Rocks Granite, and the Windsor Point Group.

Within the Cape Ray fault zone itself, the affected rocks have been completely broken down to a quartz-chlorite-sericite phyllite and a fine tectonic banding is developed. The banding is generally less than 5 mm in width and defined by chlorite. At the margins of the fault zone it is defined by mafic and felsic layers. Subsequent deformation has crenulated these bands.

The fault is of fundamental importance in that it separates the Long Range Gneisses which may be correlated with the Grenville gneisses of the Western Platform of Newfoundland (Williams, 1964a) from the Port aux Basques gneisses which are part of the Central Mobile Belt. It extends for at least 70 km inland and has a significant aeromagnetic and topographic expression over its length. Within the area studied the relationships between the two Complexes are not observed due to the presence of the Windsor Point Group.

Little Bay Fault:

The Little Bay Fault crops out at Little Bay and strikes generally northeast and dips steeply to the northwest. It is arcuate in form with the convex side to the southeast. The southwestern extension is probably through Channel and Channel Head. Because of the absence of marker horizons in the gneisses the amount of movement cannot be estimated.

The fault plane is defined by a breccia with angular fragments of Port aux Basques gneiss and granite. These latter may be up to 10 cm across. The matrix consists of a fine, light green, carbonate rich fraction with numerous flakes of cataclastic mica, and makes up the bulk of the rock.

Approximately 3 km inland from Little Bay the fault transects a major N-S striking fault. Although it is difficult to observe the fault planes in the gneisses, the age relationship between these two systems of faults is shown well by the lake pattern in the Margaree-Foxroost hinterland i.e. the N-S striking set are older than, and displaced by, those associated with the Little Bay fault.

Fractures:

Two sets of fractures with an accompanying dilation affect the Port aux Basques gneisses. The earlier is the dominant one and the fractures strike northwest and dip steeply to the southwest. They are commonest in the Port aux Basques - Grand Bay area. The larger ones are occasionally intruded by aplite dykes whilst the smaller ones may be quartz or tourmaline filled. Generally the fractures are brittle but they are locally ductile.

To the north and east of the Port aux Basques - Grand Bay area a decrease in the number of fractures is accompanied by an increase in the displacement of each until each becomes a minor fault with a sinistral displacement of up to 50 m. This is well illustrated by minor offsets of the Port aux Basques granite. They are generally ductile rather than brittle, especially in the Margaree-Foxroost area.

These fractures are locally offset by minor fractures, strike northeast and dip southeast. The displacement is generally less than 5 cms and they are occasionally filled with tourmaline.

CHAPTER VIII: GEOLOGICAL SUMMARY AND CONCLUSIONS

Geological Summary

The Long Range Gneiss is a somewhat homogeneous leucogneiss with basic pods. It is probably the southern extension of the Grenville Inliers of Western Newfoundland, represented by the Long Range, Indian Head, and Steel Mountain Complexes (Clifford and Baird, 1962; Williams, 1967). The Cape Ray granite was intruded into the gneisses and subsequently deformed twice. The presence of potash feldspar megacrysts throughout the body suggests slow cooling and a relatively stable environment after the intrusive event. The intrusion of the Red Rocks Granite is a much later event as evidenced by the lack of penetrative fabrics within that body.

The Port aux Basques gneisses are thought to be derived from sedimentary rocks because of:

(1) Diversity of composition of the bands, i.e. almost pure quartzite bands interbedded with pure biotite bands and epidosite bands.
(2) The presence of the epidosite bands.
(3) The abundance, and restricted band width, of kyanite and staurolite rich bands.

However, east of Little Bay fault in the Margaree-Foxroost area migmatitic effects become dominant and the primary origin of the gneisses is completely obscured. The amphibolite bands in the Port aux Basques gneisses may represent either basic lava flows or dykes whose cross-cutting relationships have been obliterated by intense superimposed deformation (c.f. Watterson, 1965).

The present features of the Port aux Basques Complex are dominantly the result of metamorphism, deformation and intrusion and, because of the absence of definite primary features the total complexity of these events is uncertain. After the first recognisable and before the second phase of deformation the Port aux Basques granite was intruded and the migmatite complex to the southeast was developed.

The second phase of deformation was very intense and resulted in the development of flat-lying, northwest trending isoclinal folds and the dominant composite fabric. Related deformation was not detected in the Cape Ray Complex. The metamorphic mineral assemblages associated with the second deformation increase in grade from west to east, with progressive zones of garnet, garnet-staurolite-kyanite, kyanite-garnet, sillimanite-garnet up to the margin of the migmatite complex after which the absence of sillimanite is probably a compositional effect.

The third phase of deformation was not as intense as the second and resulted in the development of northeast trending upright asymmetric folds of variable plunge. There is an increase in intensity of deformation from west to east. The amplitude of these folds is up to 3 km and the characteristic style is noted on all scales. The prominent fabric in the Long Range Gneiss and Cape Ray Granite is sub-parallel to the fabric produced by this deformation in the Port aux Basques gneisses. It is, therefore, possible that these may be related. The associated metamorphism was essentially a recrystallisation of pre-existing mineral assemblages rather than the nucleation of new high grade minerals. New muscovite, biotite and minor amounts of garnet were developed, and there was a little growth of potash feldspar in the migmatites. The garnet growth is usually a continuation of the growth during and after the second phase of deformation.

The fourth phase of deformation shows a further decrease in intensity and results in open monoclinal folds and crenulation of the third fabric. No new fabric was developed with the monoclinal folds but a poorly defined axial planar fabric is occasionally associated with the crenulations. The metamorphic event was generally retrogressive and garnet and biotite are locally broken down to chlorite.

Three later phases of deformation i.e. D_5, D_6 and D_7 are related to movements on the Cape Ray fault and are best developed in the previously undeformed Windsor Point Group. Within the Port aux Basques and Cape Ray Complexes these deformations are represented by narrow zones of intense flattening and phyllonitisation. In the Windsor Point Group D_5 produced a fine tectonic banding close to the fault and the associated metamorphism reached the greenschist facies i.e. growth of actinolite, epidote and mica. D_6 produced asymmetric folds and a cleavage defined by the growth of white mica. D_7 produced kinking and minor quartz recrystallisation.

The final geologic events in the area were the development of north-trending faults, followed by northeast-trending faults, and two sets of minor fractures. There is no mineralisation associated with the faults but the fractures are occasionally tourmaline filled.

The Cape Ray fault is the major fault in the area and separates the Cape Ray Complex from the Port aux Basques Complex. It can be traced for approximately 80 km inland in a northeasterly direction on the basis of its topographic and magnetic expression. Movements in the Cape Ray Fault zone caused the deformation of the Windsor Point Group although it is also possible that initial instability in this zone was responsible for the extrusion of the volcanic rocks of the Windsor Point Group. All the pebbles in the conglomerates of the Windsor Point Group can be related to lithologies west of the fault zone suggesting that the Port aux Basques Complex was depressed with respect to the Cape Ray Complex during this early instability. The Cape Ray fault is therefore of major tectonic significance in the area and may have been active throughout a considerable period of geologic time.

Regional Conclusions

Due to the lack of geological data in the adjacent areas of Central and Southern Newfoundland, correlations between the Port aux Basques and other parts of Newfoundland are somewhat tenuous.

The Port aux Basques gneisses are, however, similar to some of those in Bay d'Espoir (S. Colman-Sadd, personal communication) and as such represent the basement on which the Gander Lake metasedimentary sequence was deposited (Kennedy and McGonigal, 1972).

The Windsor Point Group, which is younger than the Port aux Basques gneisses, is lithologically similar to the La Poile Group of Cooper (1954) although the stratigraphic sequence is different in the two areas. This correlation implies a Devonian age for the Windsor Point Group.

The Long Range Gneiss is the along strike continuation of the

Grenville Inliers of western Newfoundland (Clifford and Baird, 1962; Williams, H., 1967) and is lithologically similar to them. As such it represents the basement to the Western Platform of Newfoundland.

If these correlations are acceptable then the Cape Ray Fault must be recognised as a fundamental structure in the geotectonic framework of Newfoundland cutting out, as it does, the whole of the Central Mobile Belt of the Newfoundland Appalachians, and juxtaposing the basement of the Western Platform and that of the eastern margin of the Central Mobile Belt.

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PLATE I: Potash feldspar phenocryst with well developed compositional zones, Cape Ray Granite, X4.

PLATE II: Plagioclase inclusions with albitic rim in potash feldspar, Cape Ray Granite, X12.6.

PLATE III: Potash feldspar with well developed compositional zones, Red Rocks Granite, X7.9.

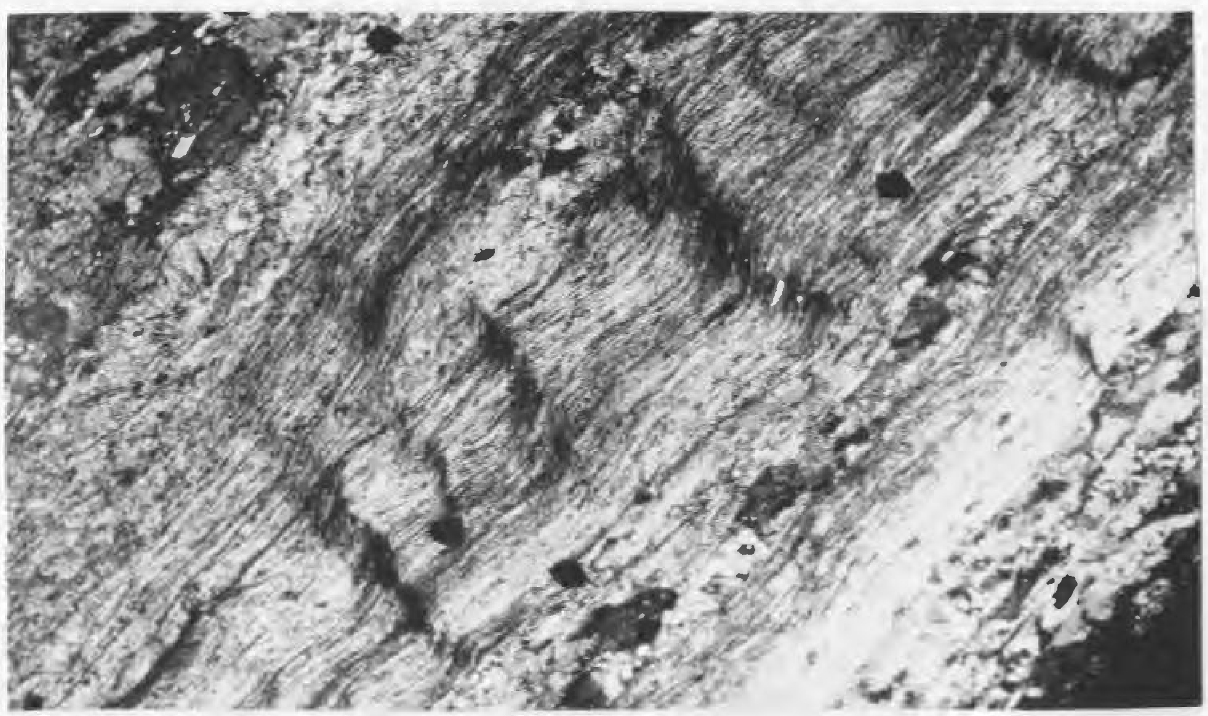


PLATE IV: Kink bands developed in the zones of intense flattening in the Red Rocks Granite, X4.

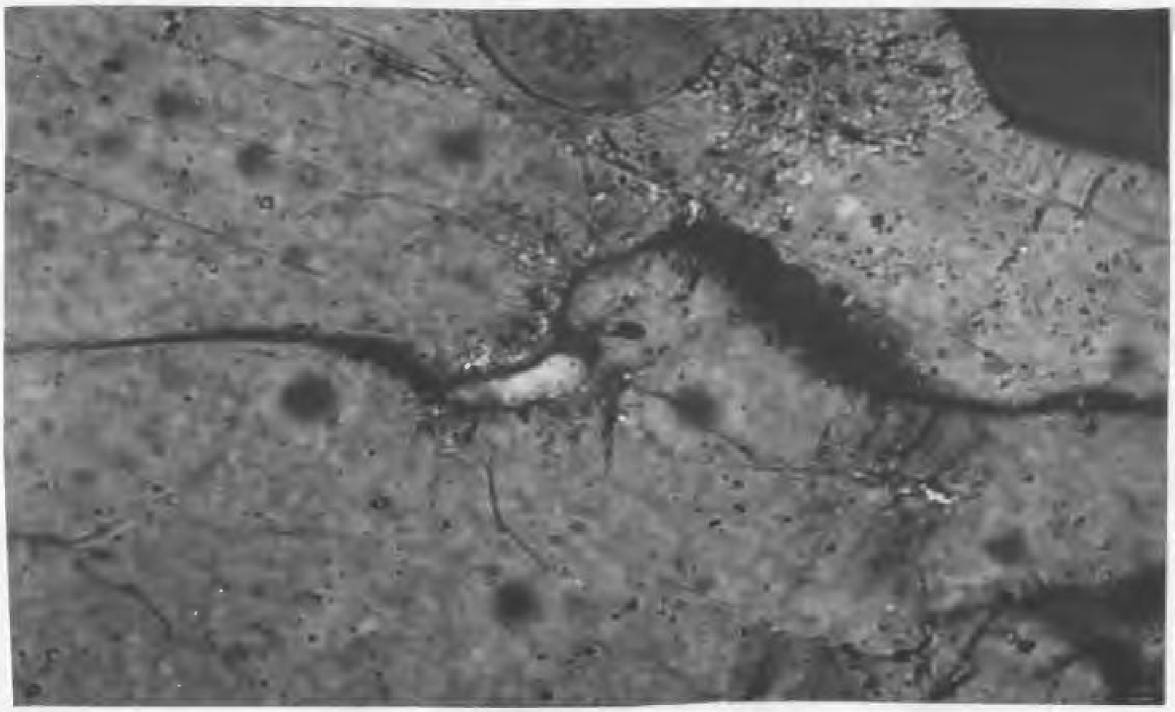


PLATE V: Rounded quartz crystal at feldspar-feldspar grain boundary, Port aux Basques Gneiss, X78.8.

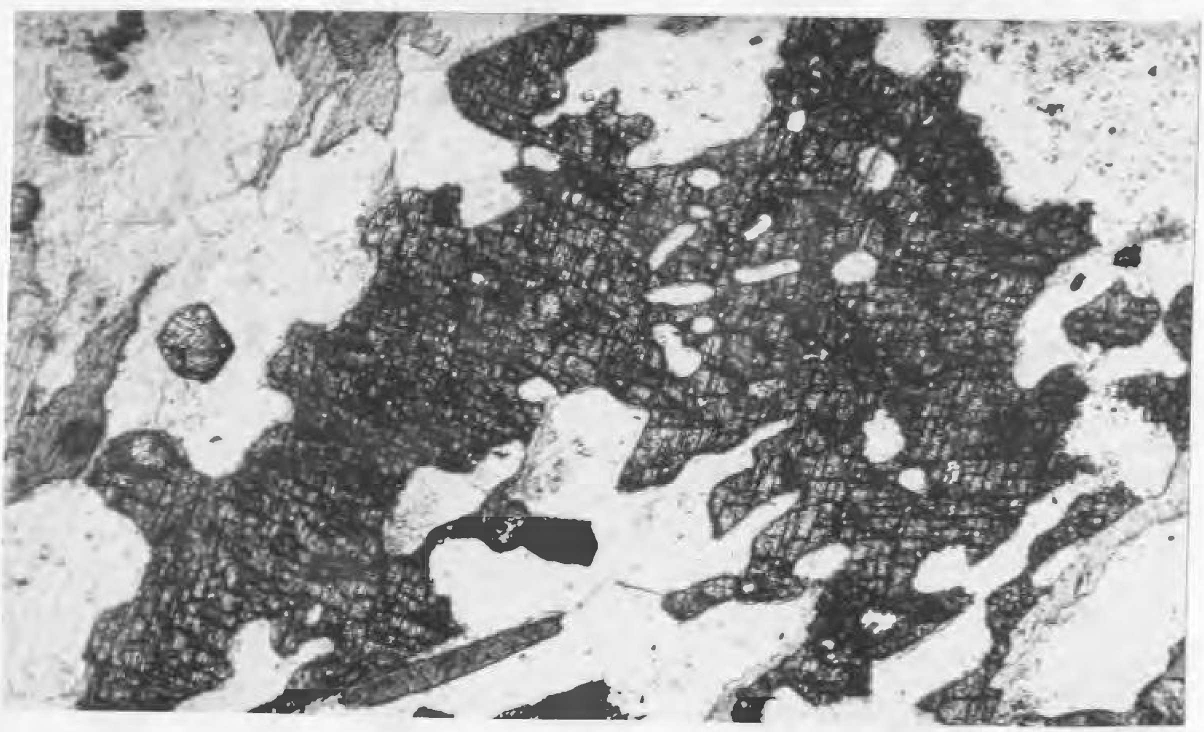


PLATE VI: Garnet inclusions in kyanite, Port aux Basques Gneiss, X19.7.

PLATE VII: Myrmekite, showing radial distribution of quartz rods with respect to the potash feldspar-plagioclase boundary, Port aux Basques Granite, X19.7.

PLATE VIII: Coarsening of quartz rods from the edge to the centre of the plagioclase host, Port aux Basques Granite, X19.7.

PLATE IX: Two phases of perthite lamellae in potash feldspar in the Port aux Basques Granite, X10.

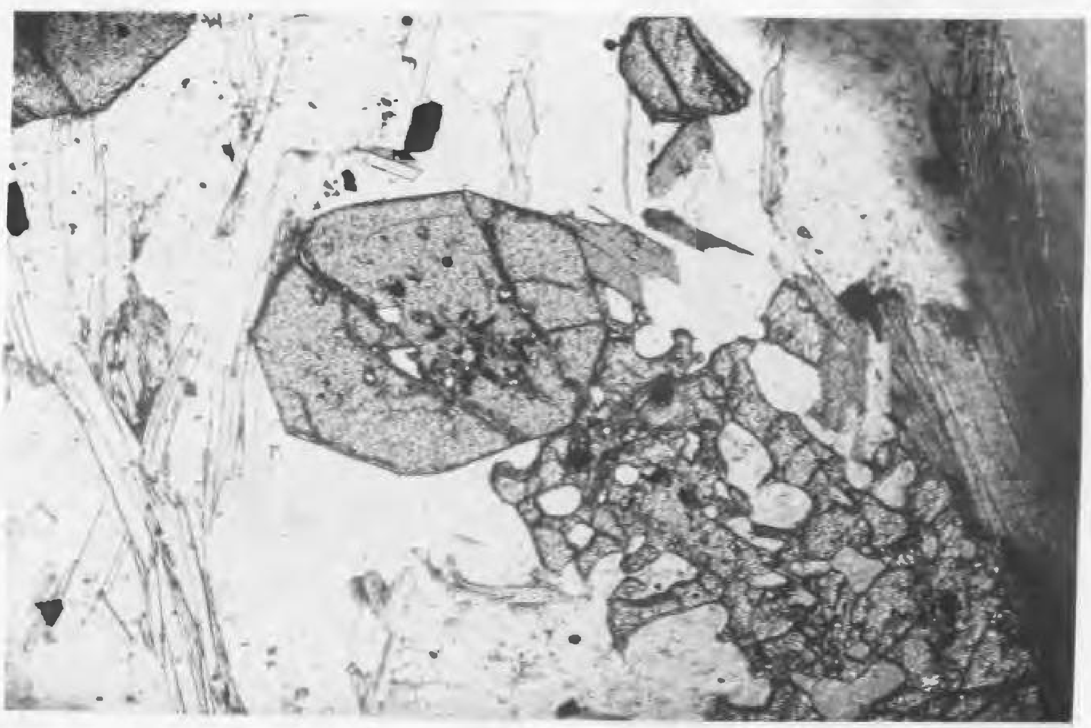


PLATE X: MS_1 inclusions in an MP_1 garnet porphyroblast, Port aux Basques Gneiss, X10.

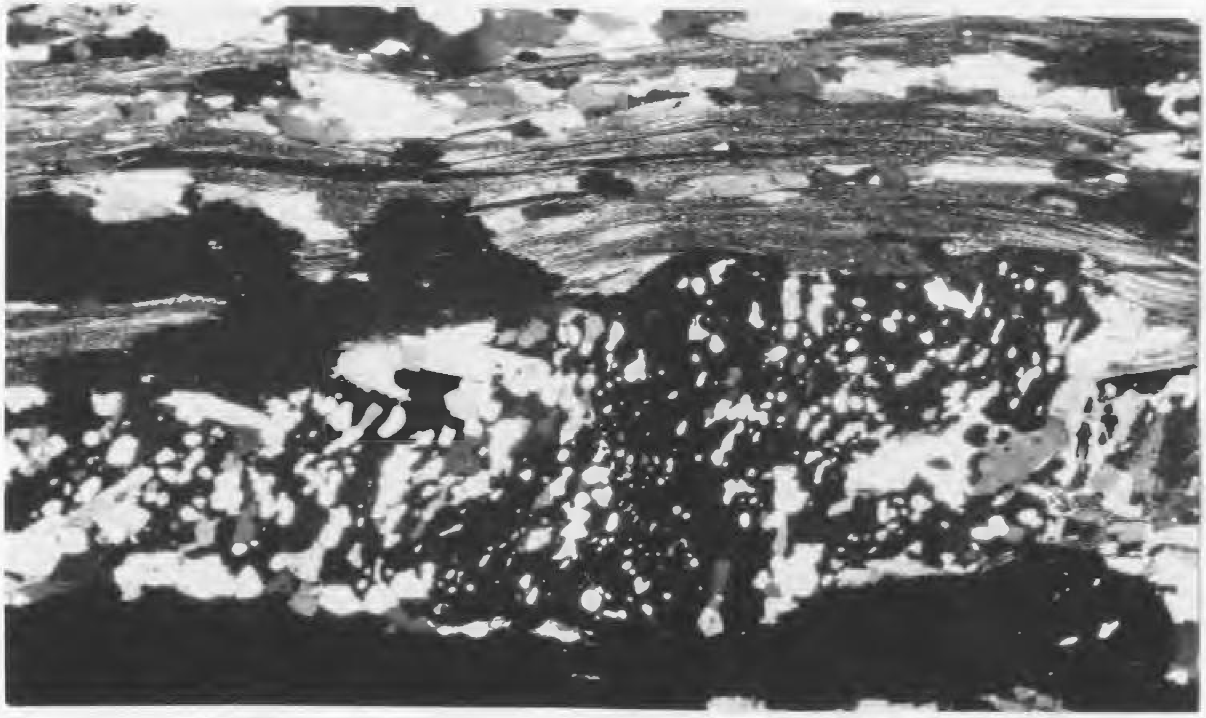


PLATE XI: MP_1 growth of staurolite and inclusion trails discontinuous with the external D_1 schistosity, Port aux Basques Gneiss, X4.

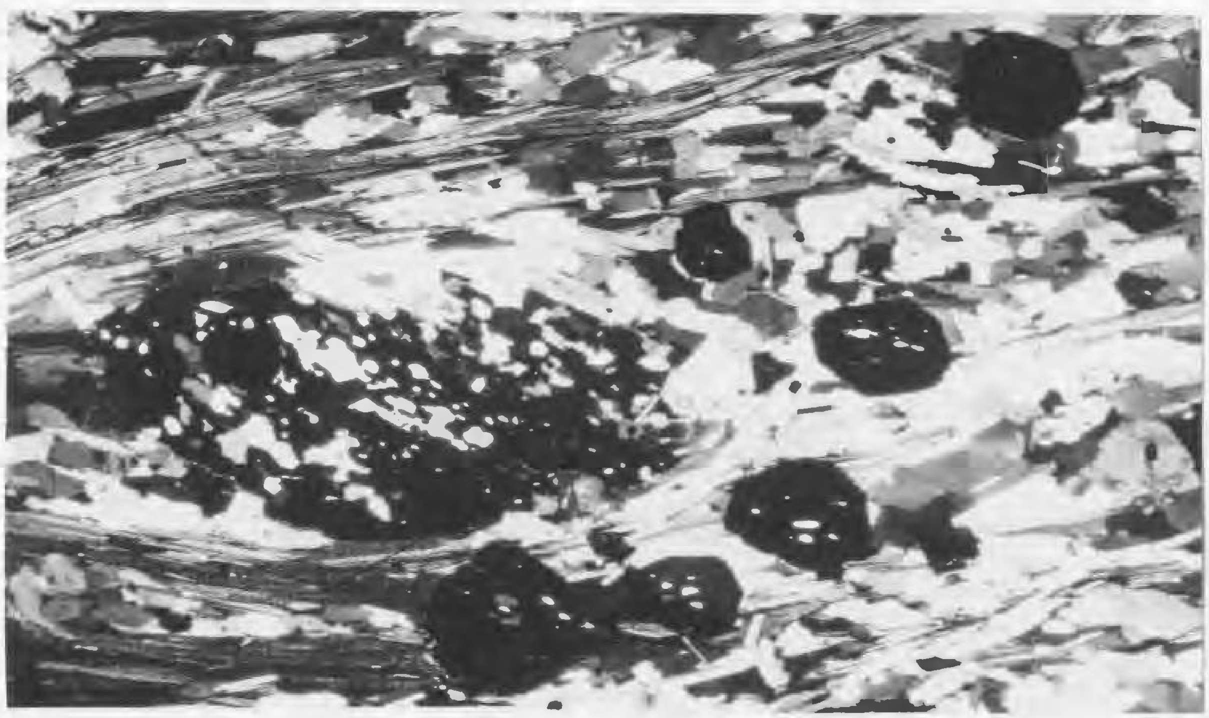


PLATE XII: MS_2 growth of staurolite with inclusion trails continuous with the external D_2 schistosity, Port aux Basques Gneiss, X4.

PLATE XIII: Acicular MS_2 kyanite crystals defining, with mica, the second fabric, Port aux Basques Gneiss, X4. This is folded by D_3.

PLATE XIV: Twinned porphyroblastic MP_2 kyanite with garnet inclusion, Port aux Basques Gneiss, X4.

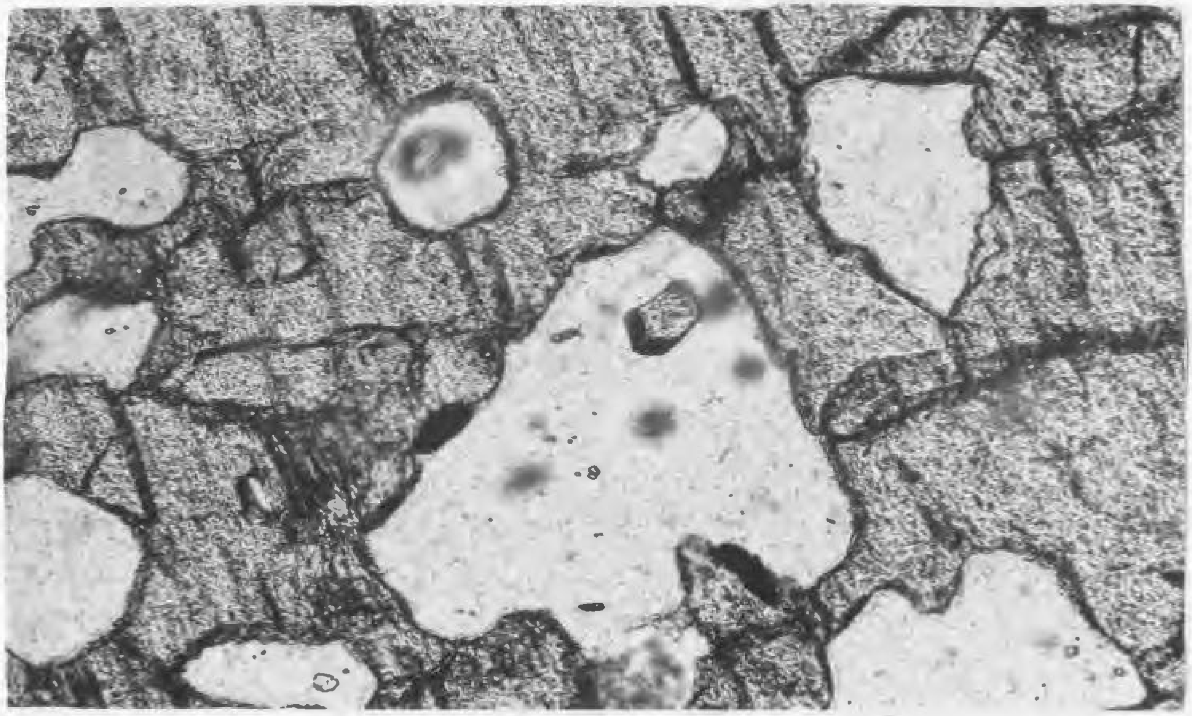


PLATE XV: Quartz inclusions in MP_2 kyanite containing inclusions of staurolite, Port aux Basques Gneiss, X40.

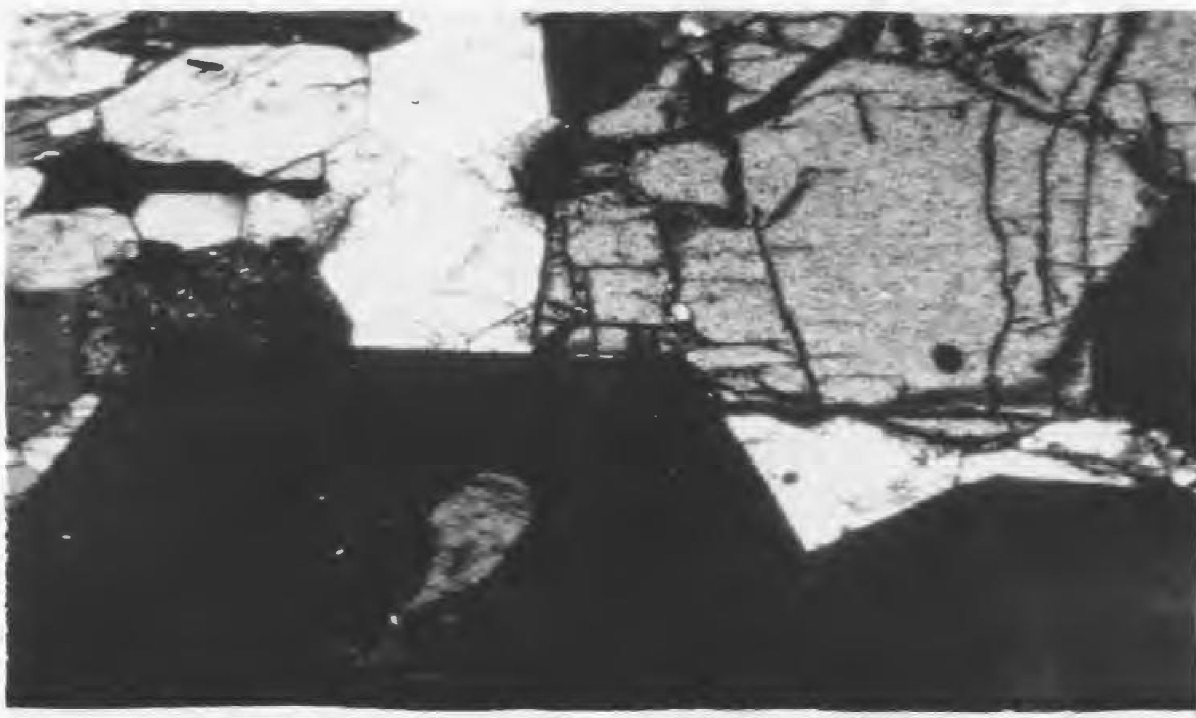


PLATE XVI: MP_2 staurolite-garnet boundary showing staurolite growth outlasted garnet growth, Port aux Basques Gneiss, X7.9.

PLATE XVII: MP_2 kyanite coexisting with sillimanite, Port aux Basques Gneiss, X12.6.

PLATE XVIII: Sillimanite replacing MS_2 kyanite, Port aux Basques Gneiss, X12.6.

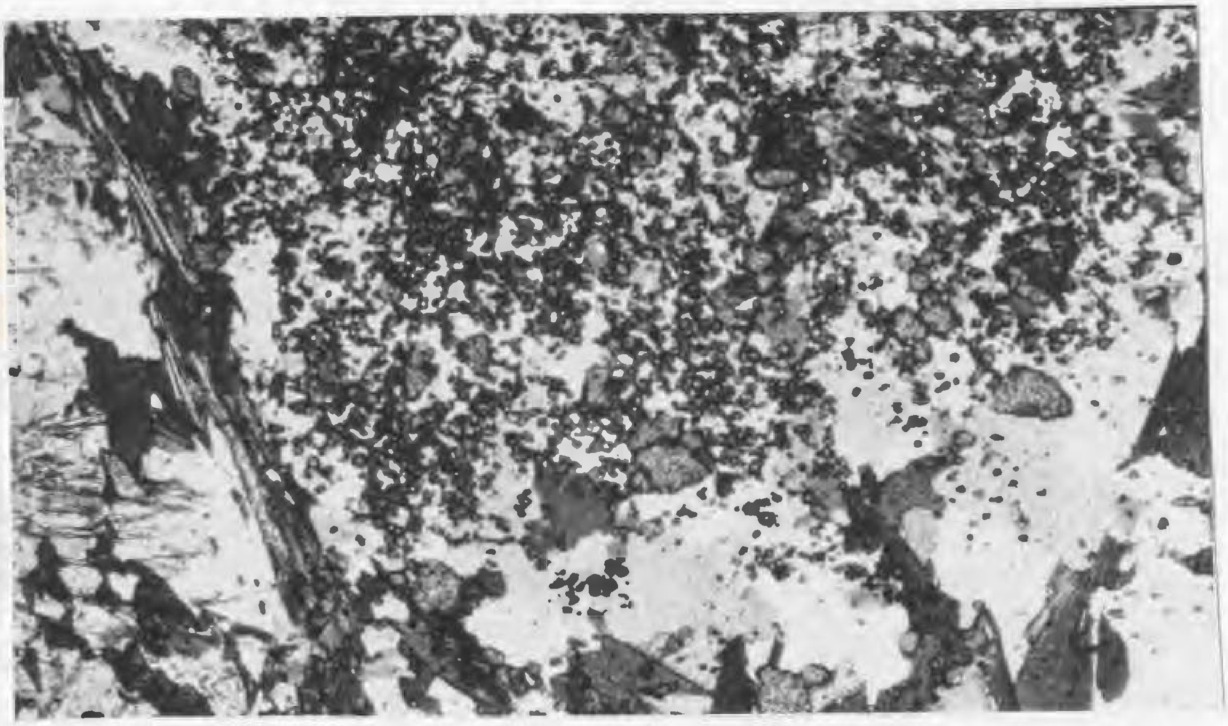


PLATE XIX: MS_3 garnet nucleation and growth in thin quartz bands, Port aux Basques Gneiss, X7.9.

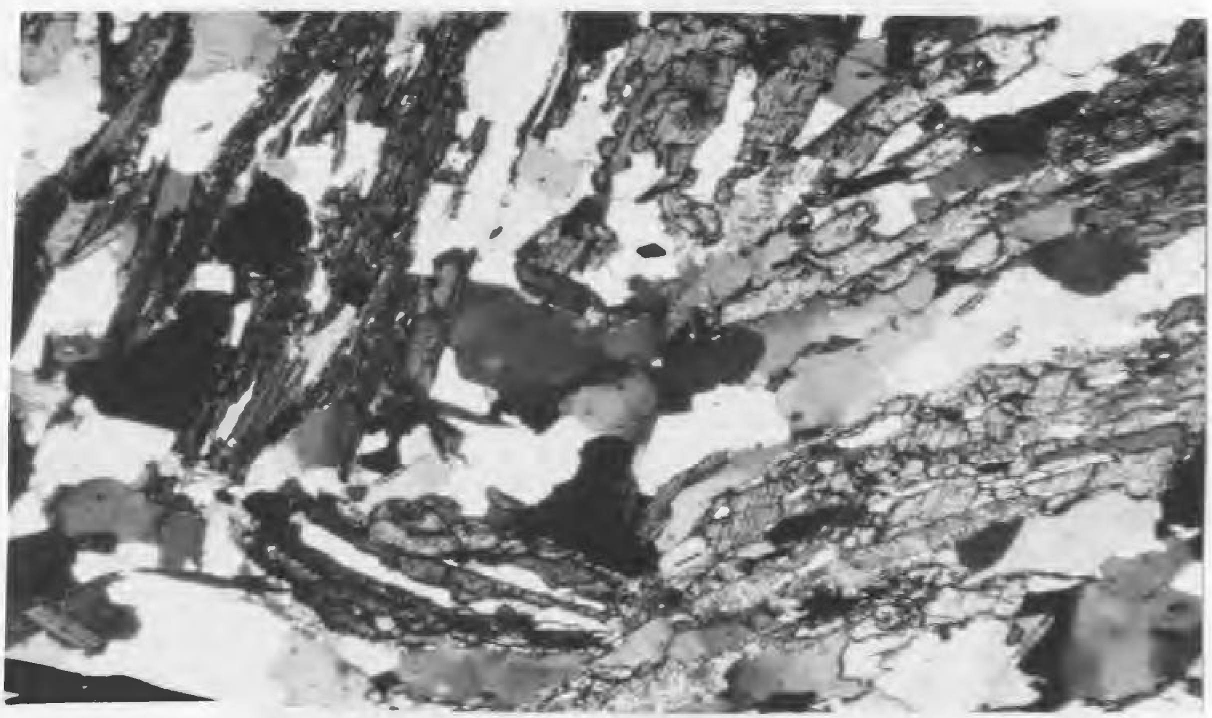
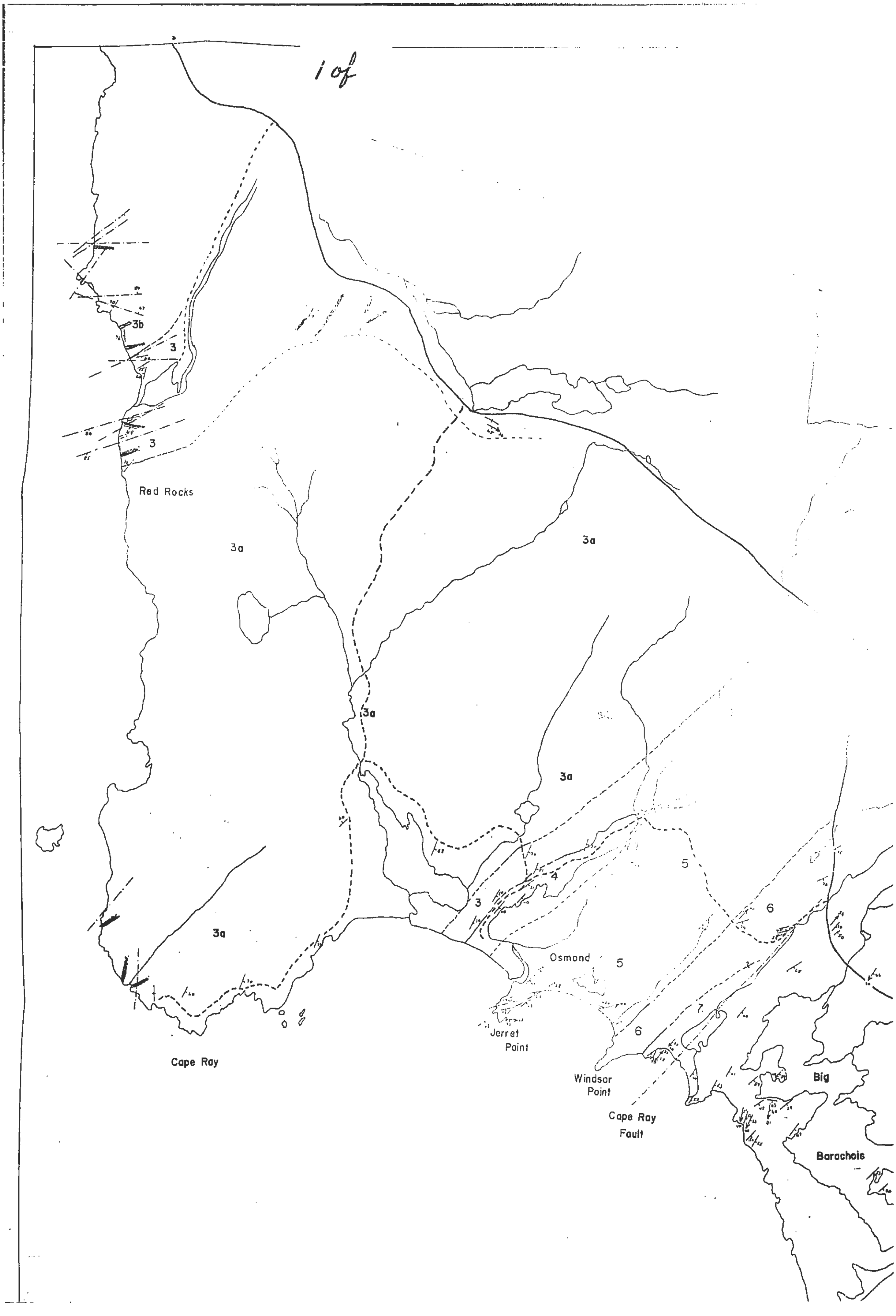


PLATE XX: Polygonised MS_2 kyanite on F_3 fold hinges, Port aux Basques Gneiss, X7.9.

PLATE XXI: D_3 fabric cross-cutting the gneissic banding. Port aux Basques Gneiss.

PLATE XXII: F_3 plunge variation. No fabric is associated with this. Port aux Basques Gneiss.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Cape Ray Fault
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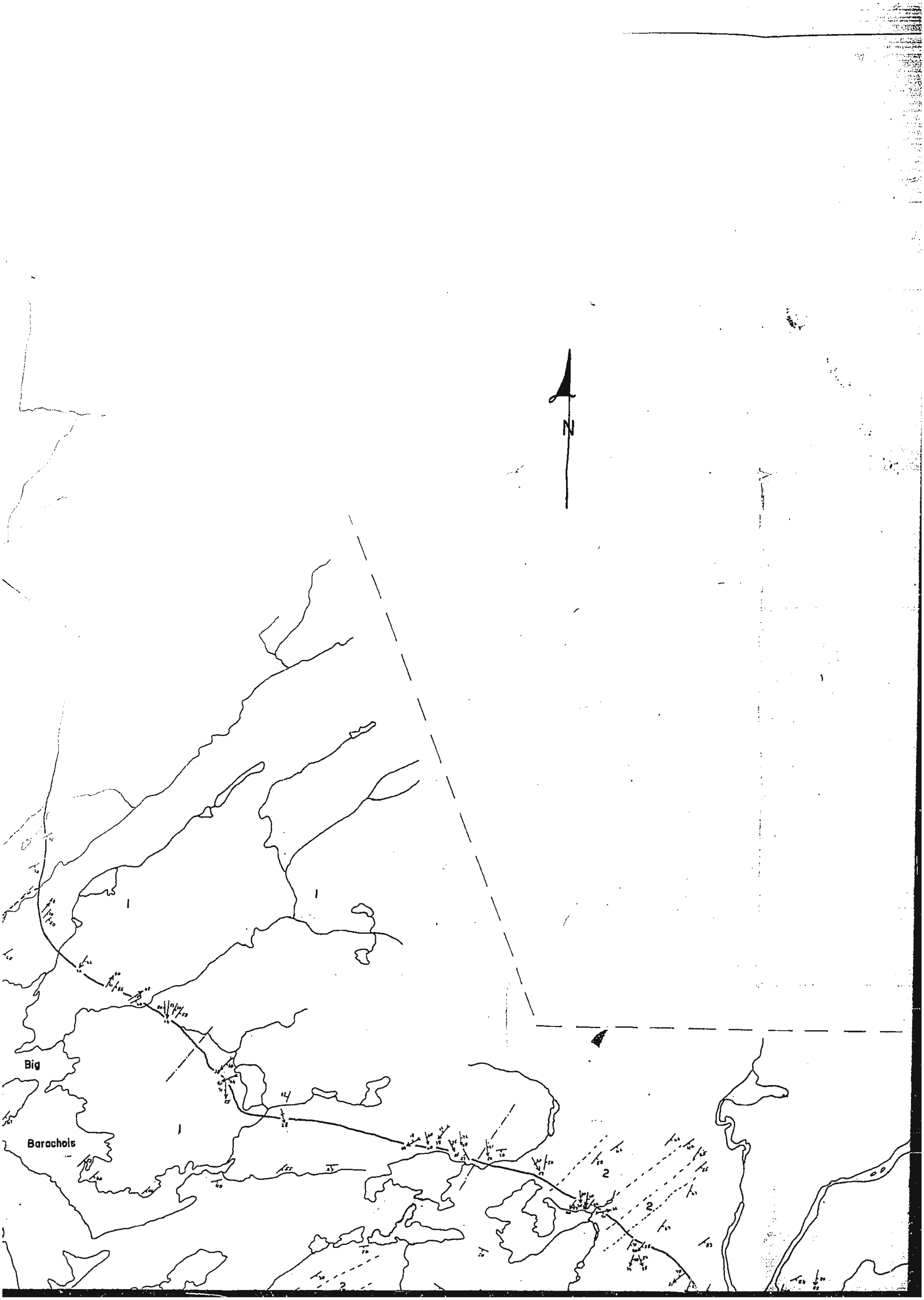
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LEGEND

WINDSOR POINT GROUP

- [8] Rhyolitic Sequence (Rhyolite with thi
- [6] Conglomeratic Sequence (Conglomera
- [5] Tuffaceous Sequence (Tuff with thin
- [4] Ignimbritic Sequence (Ignimbrites wi

CAPE RAY COMPLEX

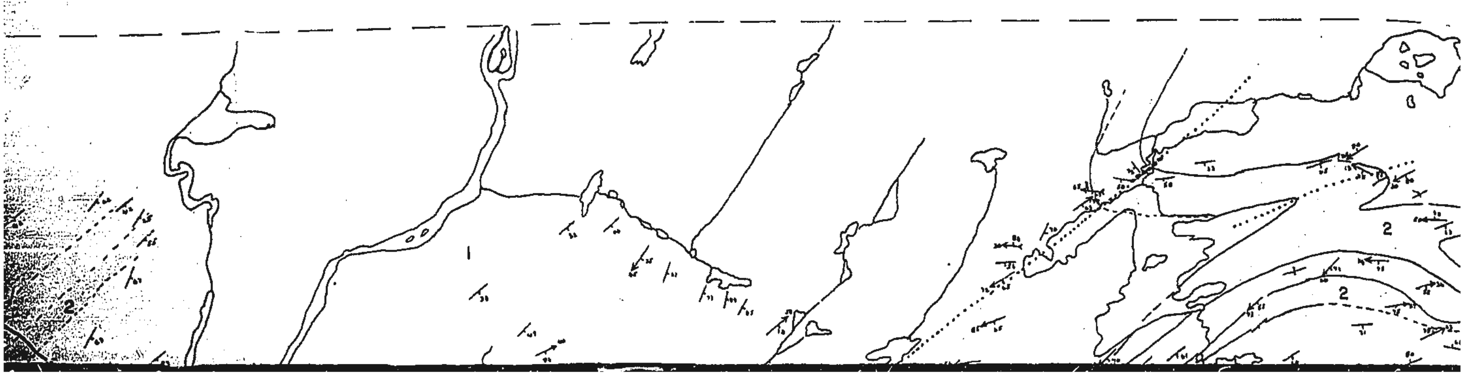
- [3b] Red Rocks Granite (Pink unfoliated
- [3a] Cape Ray Granite (Foliated Megacrys
- [3] Long Range Gneiss (Coarse, Retrogre

PORT aux BASQUES COMPLEX

- [2] Port aux Basques Granite (Pink
- [1a] Migmatite (Granitic Banded Gneiss)
- [1] Port aux Basques Gneiss (Bande

MINOR INTRUSIVES

- Diorite Dykes
- Aplite Dykes
- Pegmatite Dykes



LEGEND

GROUP

equence (Rhyolite with thin Shale bands)

ic Sequence (Conglomerate with thin Tuff bands)

Sequence (Tuff with thin Shale and Chert bands)

Sequence (Ignimbrites with thin Arkosic bands)

OMPLEX

Granite (Pink unfoliated Granite)

Granite (Foliated Megacrystic Granite)

Gneiss (Coarse, Retrogressed Leucogneiss)

QUES COMPLEX

Basques Granite (Pink Foliated Granite)

ranitic Banded Gneiss)

asques Gneiss (Banded Gneiss)

VES

es

s

Dykes

KEY

Schistosity (f_3)

Lineation (f_3)

f_6 Fold axis (Combined foliation and lineation)

f_5 Fold axis "

f_4 Fold axis "

f_3 Fold axis "

Geological Boundary (observed)

Geological Boundary (assumed)

Fault or Zone of Intense Deformation

Road (paved)

Road (unpaved)

Axial trace (f_3)

MEMORIAL UNIVERSITY of NEWFOUNDLAND

GEOLOGY

PORT aux BASQUES AREA

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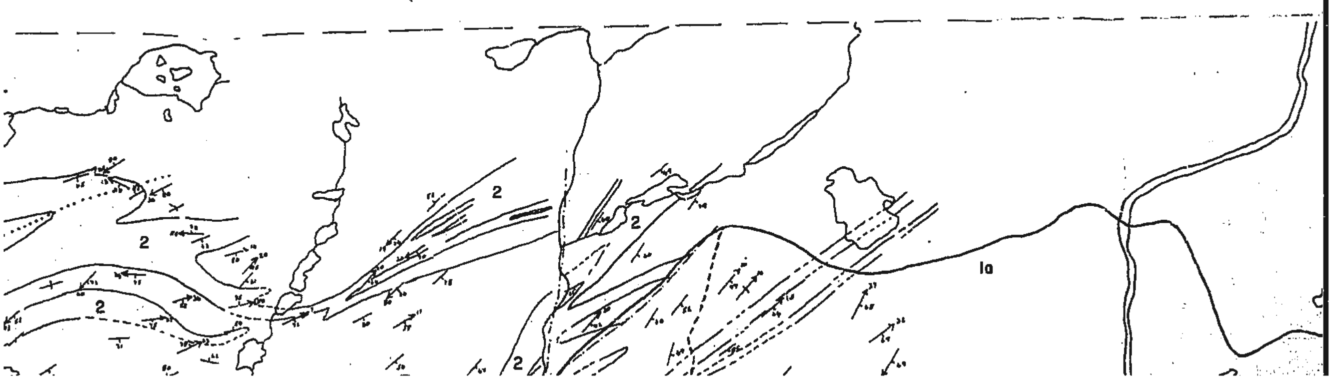

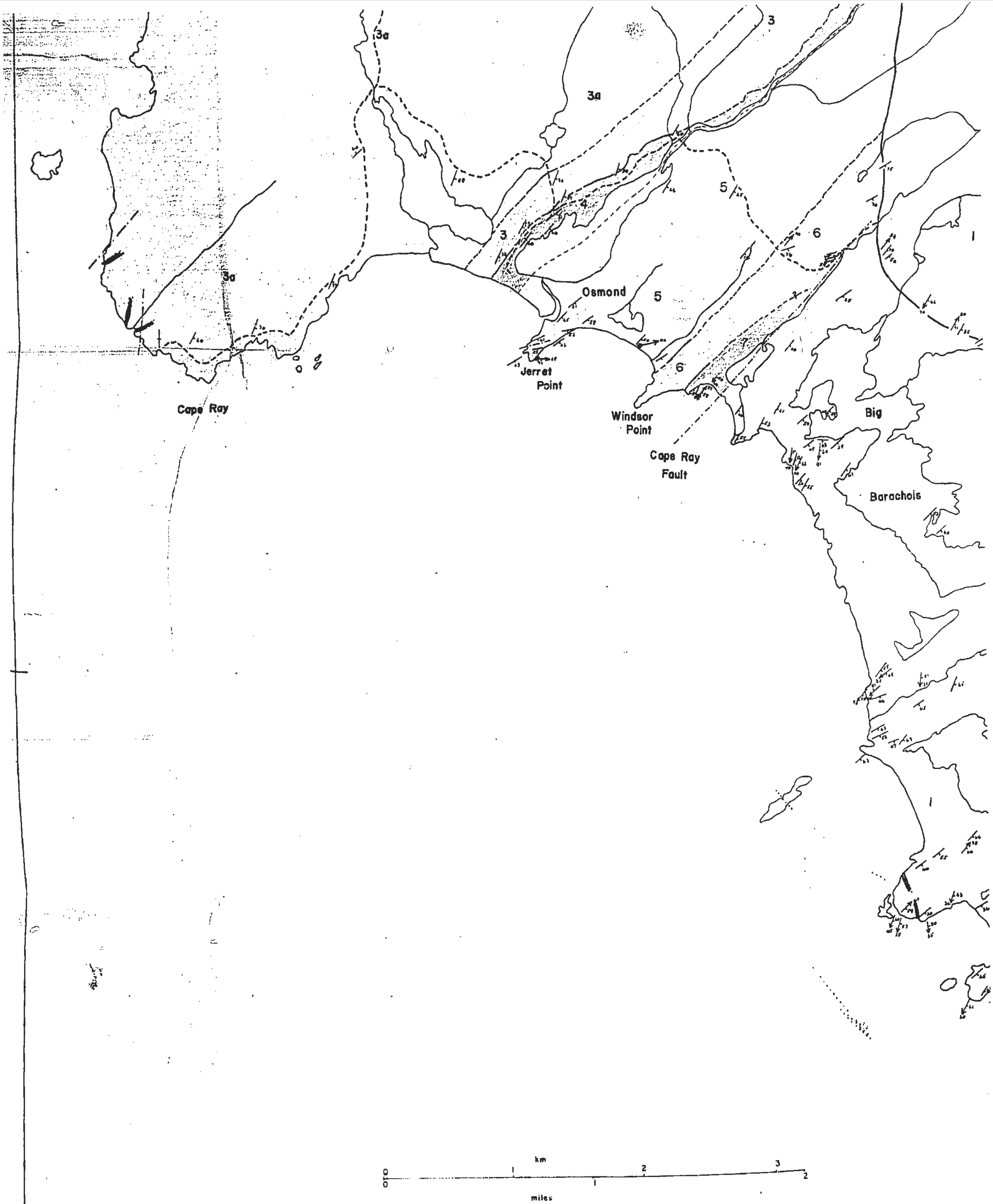
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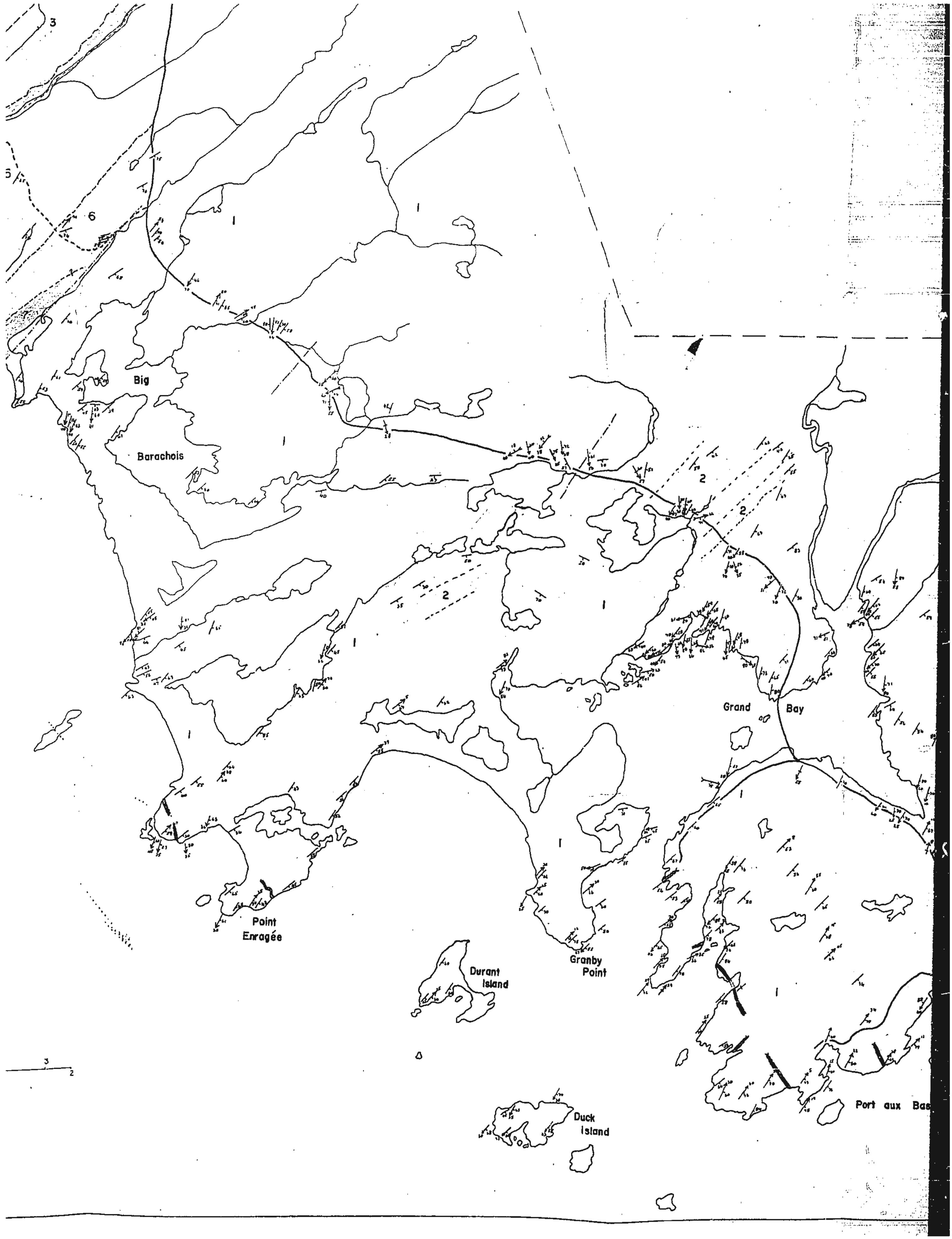

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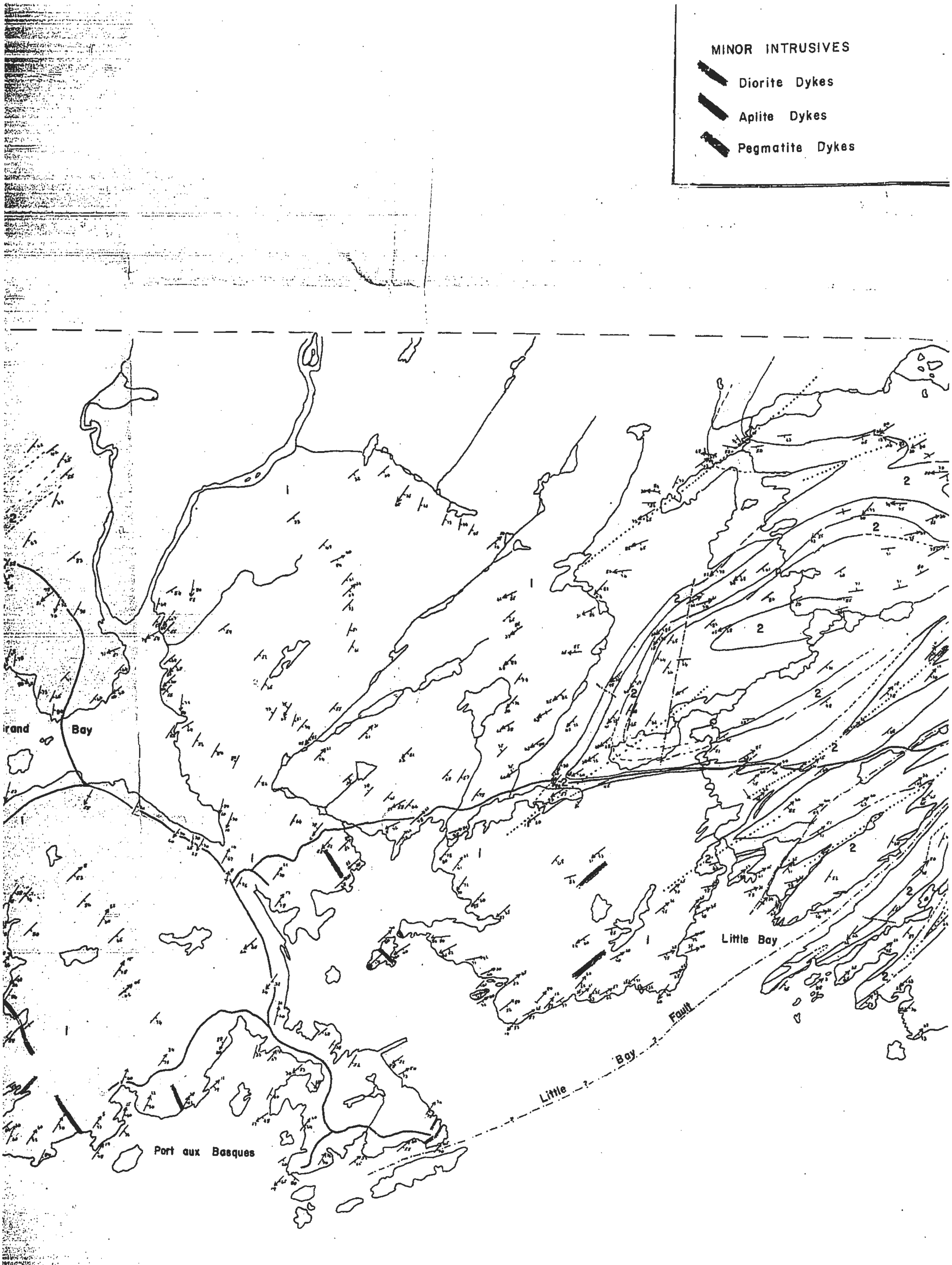
Granby
Point
Duck
Island
Port aux Bas


MINOR INTRUSIVES
Diorite Dykes
Aplite Dykes
Pegmatite Dykes
Grand Bay
Port aux Basques
Little Bay
Little ? Bay ? Fault

'RUSIVES

Dykes

Dykes

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GEOLOGY

PORT aux BASQUES AREA

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