THE GEOLOGIC DEVELOPMENT OF THE BAY D'ESPOIR AREA, SOUTHEASTERN NEWFOUNDLAND

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THE GEOLOGIC DEVELOPMENT OF THE BAY D'ESPOIR AREA, SOUTHEASTERN NEWFOUNDLAND

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ABSTRACT

Bay d'Espoir on the south coast of Newfoundland exposes a section across the southeastern marginal metamorphic belt of the Newfoundland Appalachians. Two major tectonostratigraphic divisions are recognized; in the south the Little Passage Gneisses of the older division (probably Precambrian), consisting of amphibolitic and psammitic gneisses intruded by tonalite, are overlain by metavolcanic and metasedimentary cover rocks of the younger division, the Baie d'Espoir Group (possibly Ordovician). The Little Passage Gneisses have been intruded post-tectonically by a megacrystic potash feldspar granite. Both this granite and the enclosing gneisses are extensively mylonitised and reconstituted close to the contact with the cover rocks and the gneissic foliations have been largely destroyed.

The Baie d'Espoir Group has undergone two regionally penetrative deformations, the second of which has produced a major recumbent south-east facing anticline, the Bay d'Espoir Nappe. These deformations are the cause of the mylonitised and reconstituted zone along the contact with the Little Passage Gneisses. Garnetiferous leucocratic granite and associated aplites and pegmatites have intruded the Little Passage Gneisses, the megacrystic granite, and the Baie d'Espoir Group after its first deformation but before its second; the intrusion coincided with the metamorphic climax of the Baie d'Espoir Group. Sheets of this garnetiferous granite have been tightly folded with the reconstituted gneisses near the contact with the cover.

It is concluded that the gneisses form the basement to the Baie d'Espoir Group and that the contact is now tectonic. Deposition of the Baie d'Espoir Group was along a continental margin which was initially of Atlantic-type but later changed to Andean-type. Deformation was probably caused by continental collision along the line of the Cape Ray Fault and the Lower Palaeozoic outcrop of central Newfoundland. Correlations with similar rocks in the Gander region, central Newfoundland, on the southwest coast of Newfoundland, and in Nova Scotia are proposed.

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CHAPTER I

INTRODUCTION

LOCATION

Bay d'Espoir (Map 1) is a fjord about 60 km. long occurring half way along the south coast of Newfoundland at latitude 48° and longitude 56°. It is connected with Hermitage Bay to the south by Little Passage. The present study (Map 2) extends from the head of Bay d'Espoir to the north side of Hermitage Bay. The principal settlements in the area are St. Alban's and Milltown together with some smaller communities in the upper 8 km. of Bay d'Espoir, and Gaultois at the junction of Little Passage and Hermitage Bay. Numerous other settlements in the lower reaches of both bays have been abandoned or resettled since 1900. Access is by road to St. Alban's and Milltown, or by coastal steamer.

GEOLOGICAL SETTING, PREVIOUS WORK AND GENERAL GEOLOGY

The Bay d'Espoir area lies on the eastern edge of the Newfoundland Central Mobile belt (Map 1, inset; Fig. 1). It is underlain by gneisses, granites and metamorphosed sedimentary and volcanic rocks. It forms part of the marginal metamorphic belt that is represented by the Gander Lake Group in northeast Newfoundland (Williams, 1964), and is continuous with the metamorphic rocks around Port-aux-Basques (Williams, Kennedy and Neale, 1970); these rocks probably extend into

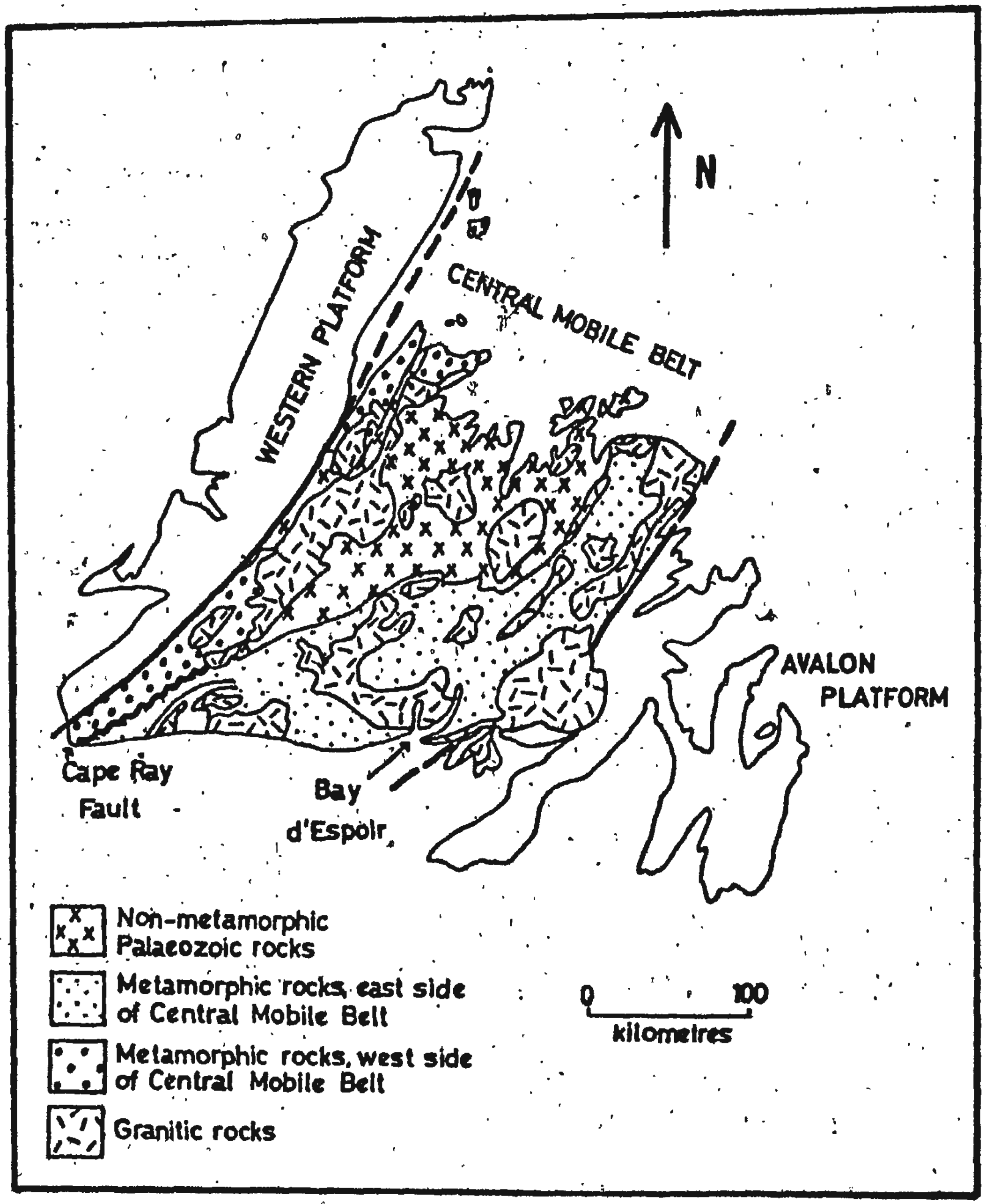


Fig.1. The principal geological divisions of the Newfoundland Central Mobile Belt.

south-central Newfoundland (Williams, 1970). They are separated from the metamorphic rocks on the western margin of the Central Mobile Belt by younger and less deformed Lower Palaeozoic rocks or, near Port-aux-Basques, by the Cape Ray Fault (Brown, 1973).

The first geological work done in the Bay d'Espoir-Hermitage Bay area was by Murray in 1870-71. He made a reconnaissance trip from Hermitage Bay, through Little Passage, to the head of Bay d'Espoir, and then inland to the Gander River. He noted pink porphyritic granite at Gaultois and gneisses in Little Passage; he thought it probable that the sediments he found exposed in Bay d'Espoir lay unconformably on the gneisses. His observations were incorporated in Howley's Geologic Map of Newfoundland (1907) and the sediments were tentatively referred to the Silurian.

Apart from the occasional examination of mineral showings no more geological work was done in the Bay d'Espoir area until the Newfoundland Geological Survey initiated two studies by Jewell (1939) and Widmer (1952). Jewell spent the 1937 field season mapping from the head of Bay d'Espoir to the north shore of Long Island and westwards to Northern Arm and North Bay. Widmer mapped from the south shore of Bay d'Espoir southwards to beyond Hermitage Bay. The two authors agreed on a three-fold division of the area into the North Bay Granite to the northwest of Bay d'Espoir, the Garrison Hills Granite south of the bay and extending westwards through Long Island towards Facheux Bay, and the sediments of the Baie d'Espoir Series cropping out along the shores of the bay between the two granites. They considered both granites to be intrusive into the sediments and attributed the gneisses that Murray recognized in Little Passage to contact metamorphism; they suggested that the granites might be two parts of one batholith. Jewell reported that the Baie d'Espoir Series consisted mainly of quartzite, argillite, graywacke, and amphibolite in the south, and chloritic slates and phyllites with sandstone in the north; metamorphism varied from biotite and garnet grades throughout most of the area to staurolite grade close to the granite. He recognized a few minor folds and several faults but did not attempt to determine the major structure. The series was thought to be Silurian by Jewell and Precambrian by Widmer.

The area was remapped by geologists of the Newfoundland and Labrador Corporation in the early 1950's. They arrived at similar conclusions to Jewell and Widmer with one exception. They dated the Baie d'Espoir Series as Ordovician on the basis of a very poorly preserved gastropod identified by the Geological Survey of Canada as "possibly Eotomaria sp."

Anderson (1965, 1967) and Williams (1971) mapped the area on the 1:250,000 scale for the Geological Survey of Canada. Although they distinguished the North Bay Granite from the Garrison Hills Granite, they agreed that both intruded the sediments, now renamed the Baie d'Espoir Group. Williams did, however, note the difference between the metamorphic rocks of Long Island and the Baie d'Espoir Group, and expressed doubt as to the relative ages of the two.

Williams (pers. comm. 1970) also noted that granite and gneiss similar to that in the Garrison Hills extended westwards along the south coast of Newfoundland. This was confirmed by seismic and gravity surveys (Dainty et al., 1966; Weaver, 1967). Williams, Kennedy and

Neale (1970) placed the rocks of Bay d'Espoir in a regional setting, they correlated them with the Gander Lake Group of Jenness (1963) on the northeast coast, as had been suggested by previous workers, and with the gneisses between La Poile and Port-aux-Basques in the west. The name, Hermitage Flexure, was proposed for the abrupt change of regional strike from southwesterly to just north of west in the Bay d'Espoir area. The flexure was attributed to folding of the Appalachian orogenic belt about a northerly trending axial surface.

STATEMENT OF THE PROBLEM

Previous work in the Bay d'Espoir area has established the general distribution of the major rock types. It has been the intention of this study to determine the structural and metamorphic history, and geologic relationships of the area.

The shores of Bay d'Espoir present the best exposure to be found anywhere in the belt of metamorphic rocks extending from the Gander region to Port-aux-Basques, and probably occupying a large area of Central Newfoundland. The determination of the geologic history of these metamorphic rocks is critical to the understanding of the geology of the Newfoundland Central Mobile Belt and the development of the Newfoundland Appalachians.

Most of the plate tectonic models for the geologic evolution of Newfoundland have in the past been based on the geology of the easily accessible northeast coast of the island (e.g. Dewey, 1969; Bird and Dewey, 1970; Strong, 1972). As a result emphasis has been placed on the post-Gander Lake-Baie d'Espoir Group events that are recorded in the rocks exposed on Notre Dame Bay. This emphasis is certainly unjustified in terms of the restricted area underlain by these later rocks (Fig. 1), and may also be unjustified in terms of their importance in the development of the Newfoundland Appalachians as a whole.

The detailed information that this study provides on the geology of the Bay d'Espoir area is essential for the interpretation of the early metamorphic rocks that underlie a large but inaccessible part of the island. No model for the evolution of Newfoundland is complete if this period of geologic history that these rocks record is ignored.

Not only is the Bay d'Espoir area well placed for an investigation of the origin of the Gander Lake - Port-aux-Basques metamorphic belt, it also includes the axial zone of the Hermitage Flexure. Attention has been paid to features that might indicate the origin of this structure; reconnaissance trips were made to Muddy Hole and Facheux Bay outside the area of detailed mapping, in order to determine the controls on the curvature of the geological structures around the flexure.

METHOD OF STUDY

The area of eastern Bay d'Espoir (Map 2) was mapped on 1:20,000 scale air photographs with particular attention being paid to the coastline where exposure is best, and to the contact zone of the North Bay Granite. A more general map (Map 1) is provided to show the position of the area in relation to the Hermitage Flexure. The structural trends of all ages are in a general way subparallel; they are hereafter collectively referred to as the regional strike. Map 1 draws heavily on the works of Jewell (1939), Widmer (1952) and Williams (1971). The major structure of the Baie d'Espoir Group was determined by using small scale tectonic structures (Wilson, 1961), and facing directions of bedding on cleavage and in minor folds (Shackleton, 1958). The metamorphic history and its relationship to deformation has been outlined using the textural methods of Zwart (1960), Rast (1965), and others.

Petrological nomenclature is based on Holmes (1920). In conformity with contemporary practice the metasedimentary rocks are more precisely defined thus:

Quartzite: more than 80 per cent quartz.

Psammite: 40-80 per cent quartz; remainder mainly feldspars and mica.

Semi-pelite: 10-40 per cent quartz; remainder mainly feldspars and mica.

Pelite: less than 10 per cent quartz; remainder dominantly mica.

Periods of deformation and metamorphism in the Baie d'Espoir Group have been given the abbreviations of Sturt and Harris (1961). The description of folds follows Fleuty (1964). The nomenclature for cleavage is that used by Williams (1972); the term schistosity is used where there has been substantial syntectonic mineral growth on the fabric; the distinction between schist and gneiss is that drawn by Van Hise (1904). Cataclastic rocks are named according to Higgins (1971).

The determinative plots of Deer, Howie, and Zussman (1966) have been used for the determination of mineral compositions, except for combined albite-Carlsbad twin determinations of plagioclase which have been made from the plot of Kerr (1959).

PRINCIPAL CONCLUSIONS

The rocks of Bay d'Espoir fall into four main divisions, the Little Passage Gneisses, the Gaultois Granite, the Baie d'Espoir Group, and the North Bay Granite (Fig. 2). The Little Passage Gneisses occur between Bay d'Espoir and Hermitage Bay, and form a basement to the rest of the rocks in the area; they have a complex structural and metamorphic history which pre-dates that of the Baie d'Espoir Group. They have been intruded post-tectonically by the Gaultois Granite, and the two divisions together comprise Jewell's Garrison Hills Granite. The Baie d'Espoir Group consists of metasedimentary and metavolcanic rocks and has been regionally deformed twice. Both deformations affected the Gaultois Granite and caused substantial reworking of the basement gneisses. The second deformation created a major recumbent fold, and the Baie d'Espoir Group is now in tectonic contact with the Little Passage Gneisses along the thrust at the base of the fold. The metamorphic peak in the Baie d'Espoir Group occurred between the two main deformations and was associated both spatially and in time with the intrusion of the synorogenic North Bay Granite in north-western Bay d'Espoir.

Correlations can be made, as has been suggested by earlier workers, with the Gander Lake and Port-aux-Basques regions, and with central Newfoundland; there are also strong similarities to the geology

This study		Jewell, 1939; Widmer, 1952.
North Bay Granite		North Bay Granite
Baie d'Espoir Group	Isle Galet Formation Riches Island Formation St. Alban's Formation Roti Steady Formation	Baie d'Espoir Series
Gaultois Granite		Garrison Hills Granite
Little Passage Gneisses	tonalite and tonalitic gneiss amphibolitic and psammitic gneiss	included in the Baie d'Espoir Series and the Garrison Hills Granite

Fig. 2. Principal geological divisions in the Bay d'Espoir area.

of northern Cape Breton Island. No evidence has been found for Devonian folding around the Hermitage Flexure, and the structures that define the flexure are considered to have been curved at the time of their inception.

This study describes the geological history of an area that is probably representative of a large part of the Newfoundland Central Mobile Belt. It is concerned with some of the most intense tectonic deformation that took place during the development of the Newfoundland Appalachians, and it provides much new information that is indispensable for any plate tectonic model.

CHAPTER 2

THE LITTLE PASSAGE GNEISSES

GENERAL STATEMENT

The Little Passage Gneisses are named after Little Passage which cuts across the regional strike between Bay d'Espoir and Hermitage Bay. They consist predominantly of amphibolites, psammites and tonalites and crop out in a belt passing east-west through Long Island. The belt extends eastwards to the Garrison Hills and westwards to Facheux Bay. To the north metasedimentary and metavolcanic rocks of the Baie d'Espoir Group are thrust onto the gneisses, and to the south the gneisses are intruded by the Gaultois Granite. Rocks similar to the Little Passage Gneisses are exposed in the core of the North Bay Granite to the northwest of the outcrop of the Baie d'Espoir Group (Plate 1).

In the Little Passage section (Map 3) two zones are recognized:

1. The Seal Cove Zone in the south.
2. The Stickland Cove Zone in the north.

The zones are distinguished by the amount of strain attributable to the two principal deformations, D1 and D2, that affect the overlying Baie d'Espoir Group. In the Seal Cove Zone these deformations are responsible for a slight S-fabric and some kinking of the gneissic foliation. In the Stickland Cove Zone the intensity of the deformation attributable to D1 and D2 increases northwards towards the contact with the Baie d'Espoir

Group; the gneissic foliation is folded and transposed and close to the contact with the Baie d'Espoir Group the gneisses have been tectonically reconstituted into schists and mylonites. The various structural trends in the Little Passage Gneisses are all sub-parallel to each other and to the strike of the Baie d'Espoir Group. They change from slightly north of east in eastern Bay d'Espoir to slightly south of east in Facheux Bay.

The gneisses are extensively intruded by granite veins. Those associated with the Gaultois Granite are most common in the Seal Cove Zone; they are deformed by both D1 and D2. Garnetiferous leucocratic granite veins are commonest in the Stickland Cove Zone; they are deformed by D2 only.

THE SEAL COVE ZONE

The components of the Little Passage Gneisses can be readily distinguished in the Seal Cove Zone where the masking effect of the cover deformations, D1 and D2, is slight. There are three principal lithologies, amphibolitic, psammitic, and tonalitic gneisses. The relationship between the amphibolitic and psammitic gneisses has not been determined; both acquired a gneissic foliation before they were intruded by tonalite. Further inhomogeneous deformation has imparted a tightly folded gneissic foliation to much of the tonalite; parts of it however have no more than a strong schistose fabric and still retain some igneous textures. In some places the foliation has been masked by later melting and is now represented by an indistinct ghost banding.

Amphibolitic Gneiss

Amphibolitic gneiss (Pl. 2) is exposed in bands up to 100 m. wide running parallel to the regional strike. The two most prominent bands are exposed just north of L'Anse à Flamme extending west to the Northwest Arm of Piccaire Harbour, and on the headland between Grip and Seal Coves. Smaller outcrops are common and xenoliths of amphibolitic gneiss occur throughout the tonalitic terrane.

Fabric. The gneiss in the two most prominent outcrops is finely banded. Mafic bands up to 3 cm. wide are separated by discontinuous feldspathic streaks which are rarely more than a few millimetres across; the ratio of mafic to feldspathic bands is generally about 3:1. A few early isoclinal intrafolial fold closures are visible in the feldspathic bands and an LS- fabric, axial planar to the folds and parallel to the banding, is the principal fabric in the gneiss; the mineral lineation is parallel to the fold axes. The fabric is defined by biotite and hornblende, and together with the gneissic banding forms augen around nodules of epidote with accessory apatite and zircon.

The gneissic banding and the principal fabric have been tightly folded by late similar-type folds (Pl. 2); the fold axes have a near vertical plunge and the trace of the axial planes trends parallel to the regional strike. A slight schistosity has been developed in the axial zones of the folds, where particular bands are generally twice as thick as they are on the limbs. Veins of tonalite cut across these late folds.

Petrography. The essential minerals in the amphibolitic gneiss are hornblende (40-70 per cent), plagioclase (10-30 per cent), biotite (5-15 per cent), and quartz (5-15 per cent); accessory minerals are epidote, allanite, sphene, apatite, zircon, opaque minerals (principally pyrite), sericite, and chlorite.

The hornblende occurs as xenoblastic porphyroblasts (Pl. 3) which have grown skeletally and include quartz, plagioclase, biotite, and opaques, with minor epidote and sphene. The porphyroblasts have a preferred orientation parallel to the early fold axes; they are up to 1 cm. long and 0.5 cm. across. The great majority of the inclusions are quartz with curved or embayed intergranular boundaries and no dimensional preferred orientation; they are very small, seldom exceeding 0.1 mm. across. There is a tendency for the quartz inclusions to be concentrated in the centres of the porphyroblasts and for these areas to have a lighter green colour than the edges. In the larger porphyroblasts there may be several parts of the crystal with this appearance separated by embayments and inclusions of coarser quartz and plagioclase of similar grain size to that in the matrix (0.5 mm.). The opaque minerals, locally associated with sphene, are evenly distributed in the hornblende grains.

The hornblende porphyroblasts have been strained by the later folding and many have been polygonized to form grains less than 1 mm. long; there is a slight preferred orientation of these grains within the axial planes of the later folds.

The pleochroic scheme of the hornblende is X: light brown, Y: olive green, and Z: emerald green. The extinction angle $Z \wedge c$ is 20°.

Biotite is unevenly distributed in the mafic bands. It shows a moderately developed S-type preferred orientation approximately parallel to the banding and may be included in the hornblende porphyroblasts. The grains are unstrained and are up to 1 mm. long; they commonly contain lenses of plagioclase between the cleavage planes (Pl. 4). Pleochroism is from very light brown (X) to reddish brown (Y and Z) and pleochroic haloes are common around zircon inclusions. In some places there is alteration to pale green chlorite.

Plagioclase and quartz occur together in the matrix. The grain size varies from 0.5 mm. in mafic bands to over 5 mm. in some of the feldspathic bands. The grains are equidimensional and most have strained extinction; some of the plagioclase grains are fractured and there has been some polygonal breakdown. The plagioclase is generally sericitized, but where fresh it is seen to be twinned on the albite law and unzoned; the composition is An38 ($\perp$ a $X' \wedge 010 = 20^\circ$).

Apatite and zircon occur as isolated grains in the matrix, the latter commonly being included in biotite. Sphene and the opaque minerals are intimately associated and tend to be concentrated in stringers parallel to the gneissic banding. The epidote forms colourless rims around light brown xenoblastic grains of allanite.

Psammitic Gneiss

There are several outcrops of psammitic gneiss in the southeast corner of Long Island. In the Northwest Arm of Piccaire Harbour it is in sharp tectonic contact with amphibolitic gneiss and is intruded by the tonalite of the Little Passage Gneisses and by the Gaultois Granite. Just north of Grip Cove a band of psammitic gneiss, 30 m. wide, is intruded by a dioritic variety of the tonalite, and at other localities, notably Seal Cove, gneiss of psammitic composition has indefinite relationships with surrounding tonalitic gneiss. Xenoliths of psammitic gneiss have not been found in the tonalite.

Fabric. Although the gneiss has an overall psammitic composition, in detail its lithology varies between a quartzite and a pelite. It is nearly always banded on a scale of up to 5 cm. with segregation of quartz and micas; an earlier banding is isoclinally folded by intrafolial folds (Pl. 5). A preferred orientation of some of the mica (mostly of the biotite) is moderately developed approximately parallel to the banding and the axial planes of the isoclinal folds. Late tight folds affect both the gneissic banding and the main fabric.

Petrography. The essential minerals of the psammitic gneiss are quartz (50-80 per cent), plagioclase (10-30 per cent), biotite and muscovite (together 5-15 per cent), with accessory sillimanite, zircon, chlorite, epidote, microcline, and opaque minerals (mostly pyrite).

The quartz is highly strained with undulose extinction, sutured boundaries, and ribbon structure; the grains have suffered partial polygonal breakdown. Grain size varies from 0.2 mm. in micaceous bands where the quartz is interstitial to 1 cm. in quartz rich bands.

Plagioclase occurs as xenoblastic grains up to 1 mm. in diameter; in the micaceous bands it is interstitial and much finer grained. It is partly sericitized but unstrained. In specimens from the outcrop at Piccaire sericitization is sufficiently slight for an optical determination of composition as An24 ($\perp$a X'$\wedge$010=5°; R.I. greater than quartz); many grains have a less calcic rim with a lower refractive index in which albite twins are not developed; where pericline twins cross into the rims there is a slight but abrupt change in orientation of the twin plane.

Biotite and muscovite are concentrated in bands and the biotite has a preferred orientation parallel to the banding; the muscovite has little preferred orientation although some grains are interleaved with biotite. The mica grains are up to 5 mm. long. They are unstrained, in places slightly chloritized, and pleochroic haloes around zircon are common in the biotite.

Rare equidimensional xenoblastic grains of sillimanite and interstitial grains of microcline occur in the micaceous bands. Epidote and opaque minerals are present as coatings on the foliation surfaces.

Tonalitic Gneiss

Tonalitic rocks, usually gneissic to some degree, but locally massive with only a slight fabric, form the greater part of the Seal Cove Zone. They underlie that part of southern Long Island that is not occupied by amphibolitic and psammitic gneisses or Gaultois Granite. Most of the gneisses and schists of the Stickland Cove Zone are of a similar composition and may have been derived from the tonalite.

The relationship of the tonalite to the amphibolitic and psammitic gneisses is best seen in the Northwest Arm of Piccaire Harbour where the folded gneissic foliation is cross cut by veins of tonalite (Pl. 2). In Little Passage this band of gneisses reappears just north of L'Anse à Flamme and the contact of the amphibolitic gneiss with the main body of the tonalite is clearly exposed. The tonalite is injected along the gneissic foliation and also cross cuts it, breaking the amphibolite into disoriented rectangular blocks up to 10 cm. across; within the blocks the gneissic foliation is gently folded, with the axial planes of the folds parallel to the foliation of the tonalite. Xenoliths of amphibolitic gneiss are common throughout the tonalite and often have a discordant gneissic foliation which may be tightly folded; the axial planes are parallel to the foliation in the tonalite (Pl. 6).

Intrusive contacts between the tonalite and a belt of psammitic gneiss are exposed on both sides of Little Passage between Grip Cove and Middle Island. The gneissic foliations in the two lithologies are vertical and concordant at the contact but away from it the banding of the psammitic gneiss is openly folded and is cut by veins of tonalite.

Fabric. Unlike the gneissic foliation in the amphibolitic and psammitic gneisses, that in the tonalite is inconsistently developed and there is a variation from a moderately foliated rock with the igneous plagioclase crystals still preserved to a highly contorted gneiss. Some of the gneiss is massive and the banding although often folded is only faintly visible. The xenoliths of amphibolitic gneiss reflect the degree of deformation (compare Pls. 6 and 7).

Where it is least deformed, locally between Seal Cove and Middle Island, the tonalite has a moderate S-fabric defined by biotite and rare fibrolitic sillimanite. The quartz and feldspar grains show a slight tendency to be elongated in the plane of the foliation, but the feldspar grains are more generally blocky with cataclastically rounded corners; the mica forms augen around them. There is no significant metamorphic segregation.

The mildly deformed tonalite grades over distances up to 30 m. into intensely deformed tonalitic gneiss in which irregular quartzo-feldspathic and mica rich bands have formed on a 1 to 2 cm. scale (Pl. 8). The banding has been isoclinally folded at least twice and the S-fabric formed parallel to the axial planes of the first recognizable folds has been partially transposed by the later deformation (Pl. 9). The fabric is defined by biotite, muscovite and rare fibrolite, and the texture is granoblastic. Where the gneisses are most deformed north of Middle Island, their origin is uncertain although their composition conforms with the tonalite. The xenoliths and bands of amphibolitic gneiss become progressively more deformed until they are either represented by mafic streaks or are not recognizable at all.

On Middle Island and on the headland south of Seal Nest Cove massive tonalite occurs with indistinctly folded biotite rich bands; the micas within the bands have an S-fabric parallel to the banding, but between the bands there is little preferred orientation. This type of tonalite is in intrusive contact with the tonalitic gneiss. It contains deformed xenoliths of amphibolitic gneiss and is considered to be anatectically remobilised (Pl. 10).

Petrography. The essential minerals present in the tonalite and its gneissic derivative are plagioclase (40-50 per cent), quartz (10-30 per cent), and biotite (10-20 per cent), with accessory sphene, zircon, chlorite, apatite, epidote, microcline, opaque minerals and locally garnet and sillimanite. North of Grip Cove there is a more basic variety of the rock with a quartz-diorite composition and accessory hornblende.

In the mildly deformed tonalite plagioclase occurs as square or slightly rectangular grains 2 to 3 mm. across. The grains are generally cracked or broken. Albite and pericline twins are common. Grains showing distinct twin planes have a composition of An28 ($\perp a\ X'\wedge 010=16^\circ$ and 10° respectively). Other grains, locally showing good crystal faces and everywhere having indistinct polysynthetic twinning, have normal and oscillatory zoning. These textures are thought to be of igneous origin. The quartz in these rocks is interstitial and has undergone partial polygonal breakdown.

In the tonalitic gneiss the feldspar and quartz have a decussate to polygonal texture with a grain size in the range 0.2 to 1 mm. The plagioclase is unzoned and has a composition of An34 ($\perp a\ X'\wedge 010=16^\circ$).

Most of the mica in the mildly deformed tonalite is biotite. It is pleochroic from straw yellow to dark brown and commonly has pleochroic haloes around zircon grains. It defines the schistosity but its preferred orientation may not be easily seen on the scale of a thin section; it forms augen around plagioclase grains and has been recrystallized. On the headland north of Seal Cove it has been altered to fibrolitic sillimanite with small grains of potassium feldspar in close association (Pl. 11). The sillimanite also appears to have been formed by alteration of plagioclase where it occurs as patches in the grains with the fibrolite needles showing a preferred orientation parallel to the albite twin planes. About half of the mica in the tonalitic gneiss is muscovite; the grains are completely recrystallized and up to 5 mm. long; many of them contain needles of fibrolite. Pale green chlorite with anomalous blue interference colours is generally present in both the mildly deformed tonalite and the gneiss as a post-tectonic alteration product of biotite.

Garnet is present in the tonalite opposite Middle Island. The grains are subidioblastic. They have overgrown some biotite grains but augen are formed around them by others. One garnet was observed to be completely enclosed in an unzoned plagioclase grain. The garnet is overgrown by the muscovite flakes of the tonalitic gneiss.

Hornblende is present in the quartz-dioritic variety north of Grip Cove. It generally occurs as scattered subidioblastic grains less than 1 mm. across with rare inclusions of quartz, sphene and opaque minerals. In a few places biotite forms augen around polygonized aggregates of the hornblende. The pleochroic scheme is X: light brown, Y: olive green, and Z: emerald green; Z∧c is 18°.

THE STICKLAND COVE ZONE

The Stickland Cove Zone is defined as that part of the Little Passage Gneisses where the gneissic foliation has been partly or completely transposed by deformations affecting the Baie d'Espoir Group. These deformations, of which there are two main ones, are hereafter denoted as D1 and D2, and the intervening period of mineral growth as MP1 (Sturt and Harris, 1961). In Little Passage the Stickland Cove Zone is about three kilometres wide (Map 3).

The gneisses which have been tectonically reduced to schists and then mylonites as the contact with the cover rocks is approached are of two principal kinds. There are firstly those containing essential quartz, plagioclase, and mica which may have been derived from the tonalite of the Seal Cove Zone, and secondly those with essential hornblende which are probably derived from the amphibolitic gneiss. Minor quartzites are also present and a few of the gneisses contain more than 10 per cent of microcline. Throughout the Stickland Cove Zone the gneisses have been intruded by dykes and sills of garnetiferous leucocratic granite. The dykes and sills are generally about 1 to 2 m. thick and have been deformed with the Little Passage Gneisses during the second deformation.

The descriptions of the rocks of the Stickland Cove Zone are based on a series of specimens of both the principal lithologies collected in Little Passage between Stickland and Day Coves. The presentation is intended to show the progressive effects of the two deformations and the intervening metamorphism northwards. In the sections to the west, north of Sam Hitches Harbour and on the west coast of Long Island, and to the east, at Dolland Bight, rocks of the Stickland Cove Zone have been thrust across those of the Seal Cove Zone and the progressive deformation of the gneisses is not as well seen.

The First Deformation, D1

Between Stickland Cove and Deer Cove the main fabric is S1. South of Stickland Cove F1 folds are common but are open and there has been no transposition of the previous fabric; north of Deer Cove S1 has been transposed by the second deformation.

Quartz-Plagioclase-Mica Gneiss

Fabric. The gneiss immediately south of the Stickland Cove Zone is coarsely micaceous and has a well developed 1 to 2 cm. banding; all primary textures have been destroyed. It is suggested that this gneiss has been derived from the tonalite because of its similar composition and the lack of any sharp break between the two lithologies. The gneissic banding is crenulated and openly folded by F1 as far south as Seal Nest Cove (Pl. 12); the micas are strained and partly polygonized (Pl. 13); at this locality there is no preferred orientation of minerals parallel to the axial planes of the F1 folds.

At Stickland Cove F1 folds in the gneiss are tight to isoclinal (Pl. 14). The micaceous and quartzo-feldspathic banding is still readily apparent curving around the fold hinges, but the micas are recrystallized and have a preferred orientation parallel to the axial planes of the F1 folds.

At Maria Cove the gneissic foliation has been completely transposed by the first deformation and F1 fold closures are rarely seen. A discontinuous banding on a 2 to 3 mm. scale may be preserved but generally the rock is a homogeneous mica schist.

Petrography. The essential minerals are quartz (20-30 per cent), plagioclase (30-40 per cent), biotite (5-20 per cent), and muscovite (5-20 per cent). Accessory minerals are sillimanite, hydromuscovite, apatite, garnet, sphene, zircon, potassium feldspar, epidote, allanite, and opaque minerals.

The quartz and plagioclase have strained extinction and a decussate texture in the less deformed rocks where the grain size is 0.5 to 1 mm. Further north around Maria Cove they are polygonized and the grain size is reduced to about 0.2 mm. The plagioclase is twinned on the albite law and has a composition of An24 ($\perp$a X'$\wedge$010=6°).

The mica flakes are up to 5 mm. long in the gneiss around Stickland Cove where they have been completely recrystallized during D1. Biotite and muscovite are closely intergrown in about equal proportions. The biotite is pleochroic from light brown (X) to dark reddish brown (Y and Z); pleochroic haloes are common around zircon grains.

Small garnet crystals (0.1 mm.) are commonly included in both biotite and muscovite of pre-D1 age. Fibrolitic sillimanite has formed at the edges and within pre-D1 mica flakes (Pl. 15). Sphene, zircon, apatite, and allanite rimmed with epidote are also of pre-D1 age. Rare potassium feldspar is present in the quartzo-feldspathic matrix and as lenses between the cleavage planes of biotite flakes; plagioclase also occurs as lenses in biotite. Hydromuscovite (Pl. 16, 17) is found in the matrix adjacent to biotite and sillimanite rich bands (Appendix 1).

<u>Amphibolitic Gneiss</u>

<u>Fabric</u>. The amphibolitic gneiss which is segregated into 1 cm. mafic and quartzo-feldspathic bands show the same progressive folding and transposition as the quartz-plagioclase-mica gneiss. South of Stickland Cove the S-fabric, defined by hornblende and biotite, is subparallel to the banding; it is folded by close F1 folds. In Maria

Cove the F1 folds are tight to isoclinal and an S1 axial planar schistosity is developed subparallel to the gneissic banding; the quartzo-feldspathic bands have a polygonal texture. Northwards towards Deer Cove S1 is transposed by the second deformation, first in the more micaceous bands and then in those rich in hornblende. Epidote nodules up to 4 cm. across are common and have augen formed around them by all the recognizable fabrics.

Petrography. The essential minerals of the amphibolitic gneiss are amphibole, principally hornblende, (40-70 per cent), plagioclase (10-30 per cent), quartz (5-15 per cent) and biotite (5-15 per cent). Accessory minerals are chlorite, sericite, apatite, zircon, sphene, opaque minerals, epidote and allanite.

The plagioclase and quartz have a polygonal texture. The grain size decreases northwards from 0.8 mm. in Stickland Cove to 0.2 mm. north of Maria Cove. The plagioclase is twinned on the albite law and has rare reverse zoning; the composition is An33 ($\perp$a X'$\wedge$010=15°) at its most calcic. The grains are partially sericitized.

Amphibole in Stickland Cove occurs as pre-D1 poikiloblastic grains up to 5 mm. long and having a good LS preferred orientation; it overgrows all of the other minerals. The grains consist mainly of hornblende with a pleochroic scheme X: light brown, Y: olive green and Z: emerald green, and an extinction angle (Z$\wedge$c) of 19°. Patches of tremolite-actinolite in crystallographic continuity with the hornblende are colourless and have extinction angles (Z$\wedge$c) of 11°. Northwards at Maria Cove hornblende without any associated tremolite-actinolite is recrystallized and defines an S fabric parallel to the axial planes of the F1 folds. The grain size is about 0.2 mm.

Biotite flakes at Stickland Cove are up to 3 mm. across and have the pre-D1 LS preferred orientation. They are pleochroic from light brown (X) to very dark brown (Y and Z) and have pleochroic haloes around zircon grains. They are partially altered to light green chlorite with anomalous blue interference colours. At Maria Cove the biotite has recrystallized and has a preferred orientation defining S1. The grain size is less than 0.5 mm.

Static Mineral Growth, MP1

In the Stickland Cove Zone north of Maria Cove, there has been prominent MP1 growth of plagioclase in both kinds of gneiss and their derived schists. The plagioclase is poikiloblastic and inclusions occupy up to 50 per cent of any one grain. Most grains are untwinned but a few show twinning on the albite and pericline laws; the composition is An32 ($\perp$a X'$\wedge$010=14°). The poikiloblasts are up to 3 mm. across but the inclusions consisting of quartz, biotite and/or hornblende rarely exceed 0.2 mm. The quartz has a polygonal texture whilst there is a preferred orientation of the biotite and hornblende parallel to and continuous with the S1 fabric (Pl. 18). The poikiloblasts have augen formed around them by the S2 schistosity (Pl. 19). The rocks containing MP1 plagioclase are generally coarser grained (1 to 3 mm. grain size) than those further south that have been reconstituted by D1 but show no MP1 mineral growth.

The Second Deformation, D2

The effects of D2 are seen at Maria Cove Point as crenulations, and between Deer Cove and the contact with the Baie d'Espoir Group an S2 schistosity is developed. The contact zone, where there has been intense cataclasis, can be traced westwards from Day Cove in Little Passage along the north coast of Long Island as far as Grip Island. Eastwards the contact is exposed in Hatcher Cove, and between Simmond's Baraswsy and Dolland Bight.

Quartz-Plagioclase-Mica Gneiss

Fabric. The gneissic banding may still be seen between Deer and Day Coves but generally the rock is a medium grained mica schist. At Deer Cove the S1 schistosity, the pre-D1 foliations, and the leucocratic granite veins are folded into tight asymmetric F2 folds. An LS fabric is defined by the micas; the lineation is parallel to the F2 fold axes and the schistosity is axial planar. Towards the west end of Long Island, the planar element of the fabric becomes less distinct.

The development of the fabric can be traced northwards from south of Deer Cove where the micas are polygonized around F2 fold closures but have no D2 preferred orientation (Pl. 15), to Day Cove where they are completely recrystallized subparallel to the axial planes of the isoclinal F2 folds. The recrystallized micas form augen around the MP1 plagioclase poikiloblasts (Pl. 19). The texture of the quartz and feldspar is granoblastic or decussate in the south, but at Day Cove ribbon structure is developed. Within 50 m. of the contact with the Baie d'Espoir Group the rock is a D2 mylonite with a 1 to 5 mm. banding dipping steeply to the north (Pl. 20); a few F2 fold closures are preserved separated by slides (Pl. 21) and MP1 leucocratic granite veins have become involved in the cataclasis.

Petrography. The essential minerals are quartz (20-30 per cent), plagioclase (30-40 per cent), biotite (5-20 per cent), and muscovite (5-20 per cent). Accessory minerals are chlorite, apatite, opaque minerals, epidote, allanite, potassium feldspar, and tourmaline.

The quartz and much of the plagioclase have a grain size of 0.5 to 1 mm. where the texture is granoblastic, and have strained extinction especially just to the south of the cataclastic zone. Within the cataclastic zone the grain size is reduced to 0.1 mm. or less. Some of the plagioclase occurs as MP1 poikiloblasts; within the cataclastic zone these grains are polygonized but may be recognizable as knots around which the fabric forms augen.

Biotite and muscovite occur as flakes between 1 and 3 mm. across and define the S2 schistosity. Although recrystallized by D2 they generally have slightly undulose extinction and may be bent or kinked. The biotite is pleochroic from light to very dark brown; it is commonly altered to chlorite which is pleochroic from light to dark green and has anomalous purple interference colours. Individual grains of mica are rarely recognizable in the mylonite.

Potassium feldspar and tourmaline may occur close to sills and dykes of leucocratic granite but are otherwise unimportant.

Amphibolitic gneiss

Fabric. Between Deer and Day Coves bands of amphibolite show the same progressive deformation as the quartz-plagioclase-mica gneiss. Segregation into quartzo-feldspathic and mafic bands which is clearly visible in the southern part of the Stickland Cove Zone (Pl. 22) is rarely seen on a mesoscopic scale north of Deer Cove, and towards the contact with the Baie d'Espoir Group there is a sharp decrease in grain size as the amphibolites become involved in the cataclastic zone. Epidote nodules are present even in the tectonic schists. The D2 fabric is defined by biotite and hornblende, the latter showing a strong linear preferred orientation parallel to the F2 fold axes. The texture of the quartz and plagioclase is polygonal with some development of ribbon structure near the cataclastic zone.

Petrography. The essential minerals are hornblende (40-70 per cent), plagioclase (10-30 per cent), biotite (5-15 per cent) and quartz (5-15 per cent). Accessory minerals are epidote, allanite, zircon, sphene, and opaque minerals.

Quartz and plagioclase occur as polygonal or decussate grains with a grain size of 1 mm. decreasing to 0.1 mm. near the contact with the cover. The plagioclase also occurs as MP1 poikiloblasts which have commonly undergone polygonal breakdown; it has a composition of An32 ($\perp$a X'$\wedge$010=14°).

Hornblende has recrystallized during D2 to form subidioblastic needles defining the strong lineation in the rock. The grains are up to 2 mm. long away from the contact, but in the cataclastic zone the grain size is sharply reduced to 0.2 mm. or less. The pleochroic scheme is X: light brown, Y: olive green, and Z: emerald green, and the maximum extinction angle, Z$\wedge$c, is 16°.

Biotite, which helps define the D2 fabric, occurs as grains up to 3 mm. across in Deer Cove; close to the contact with the cover the grain size is reduced to less than 0.5 mm. It is pleochroic from light (X) to dark brown (Y and Z) and has pleochroic haloes around zircon grains.

SUMMARY

The metamorphic history of the Little Passage Gneisses is summarized in Fig. 3. Three divisions have been made. The pre-tonalite division records the growth of minerals in the psammitic and amphibolitic gneisses before the intrusion of the tonalite. The second division included growth during the deformation and metamorphism of the tonalite but before the deposition of the Baie d'Espoir Group. The third division is that of basement reworking during the deformations of the Baie d'Espoir Group.

In the pre-tonalite division the earliest mineral textures preserved are those associated with the main fabric, parallel to the gneissic banding and axial planar to the intrafolial folds. The distinctive poikiloblasts of hornblende formed during this deformation in the amphibolites and their subsequent polygonal breakdown during the later tight folding make it relatively easy to establish the sequence of mineral growth in these rocks.

The metamorphic history of the tonalitic rocks is more difficult to establish because of the lack of porphyroblasts or any distinctive periods of mineral growth. The minerals have been divided into dynamic and static phases, and there may be several generations of each; there

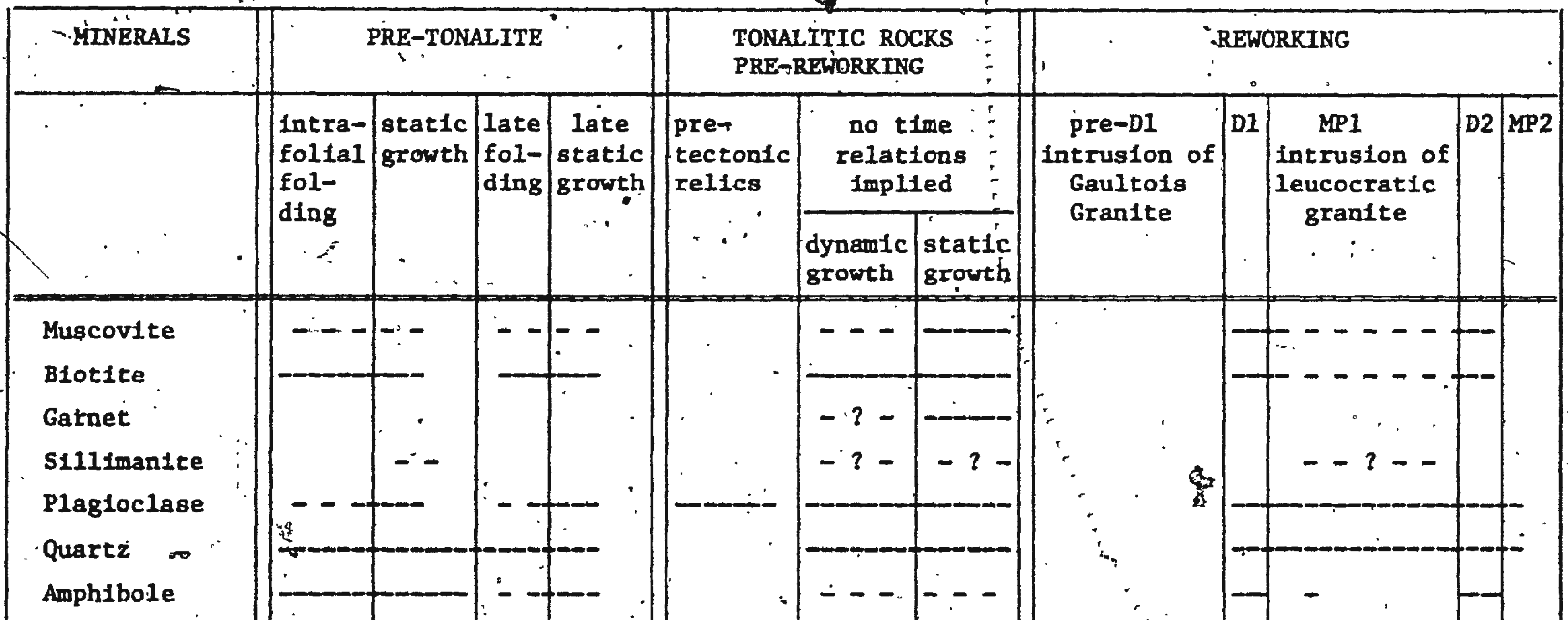


Fig. 3. The growth history of metamorphic minerals in the Little Passage Gneisses.

is no implication of a time relationship in Fig. 3, except that in general there has been a final period of static post-tectonic recrystallization. The pre-tectonic relics consist of oscillatorily zoned plagioclase of probable igneous origin.

The final division, that of reworking, includes the deformations and metamorphism that also affect the Baie d'Espoir Group. It consists of syntectonic growth during the first and second deformations and two periods of post-tectonic growth. The metamorphic peak occurred between the two deformations in the metasediments of the Baie d'Espoir Group, and this coincides with the particularly prominent growth of poikiloblastic plagioclase in the gneisses. After the second deformation there was only minor recrystallization, which was mainly restricted to quartz and plagioclase.

The age of the fibrolitic sillimanite which occurs in the tonalitic rocks is uncertain. In the Seal Cove Zone, it replaces biotite defining the main fabric and it may have grown during an early metamorphism of these gneisses, or later during the metamorphism of the Baie d'Espoir Group. The sillimanite in the Stickland Cove Zone replaces D1 biotite and so must have been formed during the metamorphism of the cover; it is most likely to have grown during the MP1 metamorphic climax.

Chlorite and sericite, which are locally important as alteration products after biotite and plagioclase, have been omitted from Fig. 3 because of the difficulty of determining the age of alteration.

CHAPTER 3

INTRUSIVE ROCKS

GENERAL STATEMENT

There are four groups of igneous rocks that intrude the Little Passage Gneisses after the formation of the gneissic foliation in the tonalite (Fig. 4). They are, in order of intrusion, the Seal Nest Cove Tonalite, the Gaultois Granite, a series of diabase and dacite dykes, and the North Bay Granite with other similar garnetiferous leucocratic granites. The two granites are of major areal extent and the North Bay Granite intrudes the Baie d'Espoir Group. Quartz veins of all ages are also found throughout the area.

THE SEAL NEST COVE TONALITE

The tonalite forms a small intrusion in Little Passage stretching from the north shore of Seal Nest Cove to Maria Cove Point. It cuts the gneisses but is intruded by pink aplites associated with the Gaultois Granite; it is, therefore, older than or contemporaneous with the granite.

The essential minerals of the tonalite are quartz (40 per cent), plagioclase (40 per cent), and biotite (15 per cent), with accessory sericite, clinozoisite, epidote, allanite, apatite, sphene, and opaque minerals.

Igneous intrusion	Intrusive into	Deformed by
North Bay Granite	All other rocks	D2
Diabase and dacite dykes	Baie d'Espoir Group (in part); Gaultois Granite; Little Passage Gneisses	D1 and D2
Gaultois Granite	(no contact seen with the Baie d'Espoir Group); Seal Nest Cove Tonalite; Little Passage Gneisses	D1 and D2
Seal Nest Cove Tonalite	(no contact seen with the Baie d'Espoir Group); Little Passage Gneisses	D1 and D2

Fig. 4. The igneous rocks that intrude the Little Passage Gneisses.

Fabric. The intrusion lies on the southern edge of the Stickland Cove Zone and has been deformed with varying intensity by the first deformation, D1. Throughout the intrusion the S1 fabric is developed, defined by a moderate preferred orientation of biotite; this fabric forms augen around plagioclase phenocrysts. The matrix has a polygonal or decussate texture. The northern end of the intrusion, in an area where the gneisses are isoclinally folded by F1, has also suffered brittle deformation either during D1 or D2; it is cross cut by numerous joints and faults which offset the Gaultois Granite aplites.

Petrography. The quartz and much of the plagioclase occurs in a granoblastic groundmass with a grain size of 0.2 mm. The grains have curved or embayed grain boundaries; the quartz commonly has strained extinction and has undergone partial polygonal breakdown. The plagioclase also occurs as blocky, subhedral phenocrysts up to 2 mm. long (Pl. 23). It is twinned on the Carlsbad, albite, and pericline laws and has oscillatory zoning; in the sharply defined core the composition is An20, decreasing to An5 in the surrounding zone and then increasing to An20 in the rim. Within each major zone there are a number of less well defined minor oscillatory zones. The albite zone is generally sericitized.

Biotite occurs as 0.5 to 1 mm. xenoblastic flakes overgrowing the quartz and plagioclase. It is pleochroic from light brown (X) to very dark greenish-brown (Y and Z).

Needles of clinozoisite are common in the plagioclase grains. Epidote occurs as anhedral to subhedral grains with a prismatic form; it commonly has a six sided core of pale brown allanite. Apatite forms small hexagonal prisms in the matrix. Sphene and the opaque minerals are intimately associated in anhedral grains up to 0.5 mm. across.

THE GAULTOIS GRANITE

The Gaultois Granite forms the northern shore of Hermitage Bay and is named after the outport of Gaultois on the southeast corner of Long Island. It extends northwards into Long Island as far as Wreck Cove in the west and Seal Cove in Little Passage. Intrusion by associated pegmatites and aplites, and partial replacement of plagioclase in the gneisses by potassium feldspar (Pl. 24), have affected much of the southern half of Long Island. The granite extends eastwards towards the Garrison Hills, and westwards it occupies most of the area south of the Baie d'Espoir Group at Facheux Bay; it may be continuous with a similar intrusion around Burgeo.

The Gaultois Granite is pink and megacrystic, and is cut by numerous aplite and pegmatite veins (Pl. 25). In most places it has a simple LS-tectonite fabric which is attributed to the first deformation of the Baie d'Espoir Group, D1. Its relationship to the Little Passage Gneisses is best shown by the aplite and pegmatite veins; these cut across the folded foliations of all the gneisses of the Seal Cove Zone (Pl. 8), but are folded by the F1 folds of the Stickland Cove Zone (Pl. 14). Xenoliths of amphibolitic gneiss in which the gneissic foliation pre-dates the fabric in the granite are common around Gaultois (Pl. 26).

The contact between the main body of the granite and the gneisses is generally indistinct because of the effects of potassium metasomatism.

Microcline has grown interstitially and as porphyroblasts replacing plagioclase in areas of tonalitic gneiss as far north as Seal Nest Cove; it is especially common in the Little Bay Fault zone. The only two localities where sharp contacts between granite and gneiss were found are on the coast to the north of L'Anse à Flamme and on the island immediately to the east. At the first locality the edge of the granite is marked by a zone of cataclasis about 1 m. wide in which the microcline phenocrysts have been partially destroyed, but the gneiss has hardly been affected; the zone is crossed by Gaultois Granite aplites and by the later D1 fabric. On the first island to the east of L'Anse à Flamme mildly deformed tonalite is separated from granite by an irregular 3 cm. band in which fine grained quartz and microcline are concentrated; the only apparent difference between the rocks on each side of the band is the presence of microcline in the granite; the contact is interpreted as metasomatic and gradational. The granite immediately adjacent to the contact has been formed from the tonalite with the replacement of plagioclase by microcline. The earlier foliation in the tonalite has been inherited by this metasomatic part of the granite; it has been enhanced during the first deformation of the Baie d'Espoir Group, with the formation of augen around the microcline grains.

At the western end of Long Island just to the north of Wreck Cove and in the country north of Blunder Cove, the Gaultois Granite has been overthrust by gneisses of the Stickland Cove Zone intruded by garnetiferous leucocratic granite. Xenoliths of foliated Gaultois Granite, deformed by D1, are found in the leucocratic granite, which has only been affected by the second deformation, D2 (Pl. 27). The

Gaultois Granite in this area has been more strongly deformed than in Little Passage and in several places is partially mylonitized. It is interbanded with tonalite which may be equivalent to the mildly deformed tonalite of the Little Passage Gneisses or may be a microcline-free variety of the granite itself.

The essential minerals of the Gaultois Granite are quartz (25 per cent), microcline (30 per cent), plagioclase (20 per cent), and biotite (15 per cent). Accessory minerals are chlorite, sericite, muscovite, apatite, epidote, sphene, zircon, hornblende, and opaque minerals.

<u>Fabric</u>. Except in the west of Long Island the Gaultois Granite has only been mildly deformed and retains its igneous megacrystic texture; microcline phenocrysts are set in a coarse grained matrix of quartz, plagioclase, and biotite. There is a slight to moderate preferred orientation of biotite producing an L or LS-tectonite fabric, which forms augen around the phenocrysts. The deformation has caused fracturing of the feldspars and partial polygonal breakdown of the microcline. The quartz in the matrix is intensely strained and has complex sutured grain boundaries; in the equigranular variety of the granite at Piccaire Harbour, ribbon quartz helps to define the LS-fabric.

The pegmatites are too coarse to pick up a fabric but the aplite veins, which contain little mica, have a fabric defined by the stretching of quartz and microcline grains.

At Blunder and Wreck Coves in the western part of Long Island, the granite has been more intensely deformed than elsewhere by the deformations of the Baie d'Espoir Group. It has bands up to 1 m. thick of probable D2 protomylonite. In most of the granite, the microcline phenocrysts have survived, although everywhere strained and in many places partially recrystallized. An LS-fabric defined by biotite, muscovite and ribbons of quartz and microcline forms augen around the phenocrysts. Within the matrix the grain boundaries are scalloped or embayed and in a few places the texture is granoblastic. In the protomylonite the phenocrysts are crushed and streaked out, and the matrix is much finer grained; the grain boundaries are curved to straight and a granoblastic texture is common. Further brittle deformation associated with north dipping thrust faults has caused severe fracturing of the rock in this area.

<u>Petrography</u>. Microcline generally occurs as subhedral prismatic phenocrysts up to 5 cm. long, and as smaller (3 mm.) dendritic grains in the groundmass. In the southern half of Piccaire Harbour all the microcline is in the groundmass and at the west end of Long Island many of the phenocrysts have been cataclastically destroyed. All of the microcline grains have good crosshatched twinning and many of the less deformed phenocrysts are twinned on the Carlsbad law. All of the other minerals in the rock are found as inclusions in the microcline and some grains show an oscillatory zoning which appears to have been inherited from replaced plagioclase.

The plagioclase grains are mostly subhedral and prismatic with a grain size up to 5 mm. They have complex oscillatory zoning and are twinned on the albite and, rarely, the Carlsbad and pericline laws. The composition varies from An38 in the core to An20 in the rim ([1]a X'Λ010=20° to 0°). Most of the grains are partly sericitized especially in the more calcic zones. Myrmekitic intergrowths with quartz are common adjacent to microcline grains.

Quartz is everywhere interstitial and intensely strained. It varies in grain size from 5 mm. to less than 0.1 mm. depending on the amount of strain and recrystallization.

The biotite has been polygonized after deformation and the grains are unstrained. They define the schistosity and form augen around the feldspar grains. The pleochroic scheme is X: light brown, Y: reddish brown, Z: very dark brown, and there are numerous pleochroic haloes. Much of the biotite has been altered to pleochroic green chlorite with anomalous purple interference colours, and lenses of potassium feldspar which occur between the cleavage planes. Where the rock has been partially mylonitized about half of the mica is muscovite.

Sphene and the opaque minerals occur as small dendritic aggregates in the groundmass and are associated with rare hornblende (pleochroic scheme X: light brown, Y: olive green, Z: emerald green; $Z \wedge c = 15^{\circ}$). Rare disseminated covellite occurs amongst the opaque minerals at the southeast end of Little Passage.

DIABASE AND DACITE DYKES

Diabase dykes intrude the Gaultois Granite at Piccaire and L'Anse à Flamme. In both cases the dykes are much altered and have been back-veined by the granite. They have a slight S-fabric which is attributed to the first deformation, D1. They are vertical and strike 80° and 50° respectively.

In the Stickland Cove Zone, at Hatcher Cove and Harbour le Gallais, amphibolites have been deformed with the Little Passage

Gneisses producing F2 folds in an S1 fabric. Despite the intense reconstitution, they retain a slight crosscutting relationship and lack any relict gneissic banding; they are, therefore, probably the deformed equivalents of the diabase dykes and are distinct from the amphibolitic gneiss. Rocks with a similar mineralogy and structural history to these later amphibolites occur in the Isle Galet Formation of the Baie d'Espoir Group; at least some of these are probably intrusive dykes and sills.

A dacite dyke of similar age is exposed on Middle Island in Little Passage (Pl. 28), where it intrudes tonalitic gneiss and cuts Gaultois Granite pegmatites; it dips 20° towards the east. It has two slightly developed S-fabrics and is intruded by garnetiferous leucocratic granite aplites; the second fabric S2 is associated with ptygmatic folding of the aplites.

As far as can be determined all the dykes were intruded after the formation of the basement gneisses and the intrusion of the Gaultois Granite, but before the deformation of the Baie d'Espoir Group; it is suggested, therefore, that they may have been feeders to the volcanic rocks in the Baie d'Espoir Group and their lateral equivalents.

The Diabase Dykes of Southeast Long Island

The essential minerals are plagioclase (50 per cent), biotite (25 per cent), and hornblende (15 per cent), with accessory chlorite, sericite, sphene, apatite, quartz, potassium feldspar, calcite, and epidote.

Fabric. The original igneous texture is preserved in many of the plagioclase grains which occur as subhedral to euhedral laths.

The remainder of the plagioclase together with accessory quartz forms a granoblastic matrix with embayed grain boundaries. The S-fabric is defined by a very weak preferred orientation of biotite. Unstrained poikiloblasts of potassium feldspar over 1 cm. across have grown after the formation of all the other minerals in the rock.

Petrography. The plagioclase laths are up to 2 mm. long. They are twinned on the albite, Carlsbad and pericline laws; the composition is An43 (Carlsbad-albite ⊥ 010, X' 010=14° and 3°); they are mostly heavily sericitized. Myrmekite occurs at the boundaries between the plagioclase and potassium feldspars.

Biotite occurs as xenoblastic grains up to 2 mm. across. Its pleochroic scheme is X: light brown, Y: olive green, and Z: very dark brown. Much of the biotite is altered to green chlorite.

Hornblende forms subhedral prisms up to 2 mm. long and some grains have simple twins. It has a pleochroic scheme X: light brown, Y: olive green, and Z: emerald green; Z$\wedge$c is 19°.

Sphene occurs as euhedral diamond shaped crystals. Calcite and epidote are alteration products, sparsely disseminated through the rock and forming coatings on joint surfaces. The potassium feldspar poikiloblasts may be due to late stage contamination from the surrounding granite.

Intrusive Amphibolites of the Stickland Cove Zone

The essential minerals of the amphibolites are hornblende (40 per cent), and plagioclase (50 per cent). Accessory minerals are quartz, apatite, sphene, opaque minerals (mostly pyrite), sericite, epidote, and calcite.

<u>Fabric</u>. The rock has a very well polygonized texture. Hornblende defines both S1 and the D2 LS-tectonite fabrics. It occurs in irregular concentrations up to 2 mm. across, which are inequidimensional in the plane of S2 and elongated parallel to the D2 lineation and the F2 fold axes. Within the concentrations hornblende and plagioclase are evenly distributed in the proportions 80:20. Most of the hornblende grains have recrystallized during D2 as needles less than 0.1 mm. across, parallel to the D2 lineation. In several concentrations however acicular crystals and larger xenoblastic grains up to 1 mm. across define the tightly folded S1 fabric (Pl. 29).

Most of the plagioclase is polygonized with straight grain boundaries. A few relict MP1 porphyroblasts can be recognized, with an included D1 fabric; they show partial breakdown to a polygonal texture.

<u>Petrography</u>. The hornblende varies in grain size from 0.1 to 1 mm.; it is polygonized and unstrained. The pleochroic scheme is X: light brown, Y: olive green, and Z: emerald green; Z$\wedge$c is 20°.

Plagioclase has a very well developed polygonal texture with a grain size of 0.1 mm.; it is unstrained and very rarely twinned. The few MP1 porphyroblasts that have survived the second deformation are about 1 mm. across; they contain numerous small inclusions of quartz and a few hornblende grains defining S1; they are sericitized and partially polygonized.

Calcite, epidote, and pyrite commonly occur as segregations and veins; the veins have been folded by F2.

The Dacite Dyke on Middle Island

The essential minerals are plagioclase (40 per cent), quartz (20 per cent), biotite (20 per cent), and potassium feldspar (10 per cent), with accessory sphene, apatite, zircon, clinozoisite, sericite, and opaque minerals.

Fabric. The rock has only been slightly deformed and igneous plagioclase phenocrysts are preserved within a granoblastic matrix with embayed and curved grain boundaries. Both S1 and S2 are weakly developed and are defined by biotite which forms augen around the plagioclase phenocrysts. The grains defining S1 are not strained and are overgrown by larger grains forming the second schistosity.

Petrography. Quartz and untwinned plagioclase grains up to 0.2 mm. across form the granoblastic matrix. Plagioclase phenocrysts up to 4 mm. long occur as euhedral laths with Carlsbad and albite twins (Pl. 30). Their composition is An45 and they commonly have narrow rims of composition An26 (^{1}a X' 010=24° to 8°). The phenocrysts contain inclusions of clinozoisite and are partly altered to sericite in the more calcic cores.

Biotite occurs as flakes up to 1 mm. long; it is pleochroic from light brown (X) to dark reddish brown (Y and Z) and has pleochroic haloes.

THE NORTH BAY GRANITE AND ASSOCIATED INTRUSIONS

The North Bay Granite crops out to the northwest of Baie d'Espoir and is exposed on the coast at Pomley Cove in Lampidoes Passage, and at North, East, and Facheux Bays. The granite extends northwestwards past Facheux Bay into south central Newfoundland. It is a leucocratic medium grained and approximately equigranular rock, generally gray in colour but in some places pink. It is characterized by the presence of small ruby red crystals of garnet; in the main body of the granite these are rare, but in the aplites and pegmatites that cross cut its outer margins they are very common.

Within the core of the North Bay Granite is a band of basement gneiss, two kilometres wide and extending across North Bay to the country north of Facheux Bay (Pl. 1). It is intruded by granite veins but the main contact is metasomatic and gradational; the gneissic banding becomes less and less distinct as the rock becomes more homogeneous until it disappears altogether and the rock shows every evidence of having been magmatic.

The granite intrudes the Baie d'Espoir Group in Lampidoes Passage and northwards towards Roti Steady. The contact is rarely well defined, being usually a zone of dyke and sill intrusion up to 3 km. wide (Pl. 31). The grade of MP1 metamorphism in this zone is higher (sillimanite grade) than elsewhere in the Baie d'Espoir Group (garnet grade or lower). Around Roti Steady the contact is overlain and hidden by a thrust sheet of the Baie d'Espoir Group; where it reappears, south of Rocky Hill, the country rocks are mainly schists of a metasedimentary appearance, but they include possible basement gneisses and some intensely deformed ultrabasic rocks. The granite contacts in Northern Arm and Facheux Bay were only briefly examined; they are either intrusive into the Baie d'Espoir Group, as in East and Facheux Bays, or faulted.

Most of the North Bay Granite has a very slight tectonic fabric, visible on a mesoscopic scale only. The marginal dykes and sills, however, have been folded and boudinaged during the second deformation, D2 (Pls. 32, 33 and 34) and have acquired a moderately well developed S2 fabric. The granite is unaffected by first deformation structures and its intrusion is considered to be post-D1.

On the southern shore of Bay d'Espoir and westwards to Great Jervis Harbour, the reconstituted Little Passage Gneisses are intruded by dykes and sills of leucocratic granite. The granite is commonly pegmatitic and rich in garnet. It has been intensely deformed by the second deformation of the Baie d'Espoir Group (Pls. 35 and 36), but not by the first, and at the head of Sam Hitches Harbour it contains xenoliths of Gaultois Granite with a previously acquired S1 fabric (Pl. 27). The leucocratic granite in this area does not intrude the Baie d'Espoir Group which is separated from it by a D2 thrust fault. The similarity in petrography and time of intrusion between the granite dykes and sills, and the North Bay Granite suggests that they belong to the same intrusion; this intrusion is probably continuous under the outcrop of the Baie d'Espoir Group. An isolated dyke of garnetiferous leucocratic granite intrudes the metavolcanic rocks of Snook's Harbour.

The essential minerals of the leucocratic granites are quartz (25 per cent), microcline (30 per cent), plagioclase (20 per cent), biotite (10 per cent), and muscovite (10 per cent), with accessory chlorite, sericite, apatite, zircon, opaque minerals, (including molybdenite in the marginal sills), garnet, and tourmaline. Garnet, tourmaline, and muscovite are especially common in the pegmatites, aplites, and marginal dykes and sills.

Fabric. The fabric in the leucocratic granites varies greatly in intensity. In the core of the North Bay Granite, the S-fabric is barely visible, whilst south of the outcrop of the Baie d'Espoir Group the granite is always very well foliated and in places is mylonitized.

In the least deformed rock no fabric can be seen on a microscopic scale. Blocky grains of plagioclase lie in a decussate matrix of quartz; the micas have no preferred orientation but some of the flakes are strained and bent. Large poikolitic grains of potassium feldspar have grown around the other minerals in the rock. In the dykes and sills at the margins of the North Bay Granite in Lampidoes Passage, there is a slight preferred orientation of the mica, and the feldspars are strained and cataclastically broken down around their edges; the quartz generally has sutured boundaries, but in places is partially polygonized.

The leucocratic granite close to the basement cover contact on the southern shore of Bay d'Espoir contrasts with that to the north in the intense development of its LS-tectonite fabric (Pls. 35, 36 and 37). The fabric is axial planar to tight or isoclinal folds and the lineation is parallel to the horizontal fold axes. It is defined by muscovite and ribbon structure in streaked out quartz and feldspar grains. Augen have been formed around relict igneous feldspar, garnet and muscovite grains. Towards the south the intensity of the strain decreases and some of the leucocratic granite veins in the Seal Cove Zone have no obvious folds or fabric (Pl. 38).

Petrography. Where the granite has not been significantly deformed, plagioclase forms subhedral prismatic grains up to 4 mm. across which have oscillatory zoning but which normally have only simple twins (Pl. 39); the composition varies from An18 in the cores to An2 at the edges ($\perp$a X' $\wedge$ 010=3° to 14°; refractive index less than Lakeside Cement). The grains have been partially sericitized especially in the more calcic zones.

The plagioclase grains occur in a matrix of quartz with a decussate texture and strained extinction; the grain size of the quartz is between 1 and 3 mm.

Flakes of muscovite and biotite, which may be altered to green chlorite, are disseminated throughout the rock. They are up to 1 mm. long and may be strained or bent. The biotite is pleochroic from light brown (X) to very dark brown (Y and Z).

Anhedral poikolitic microcline grains, up to 1 cm. across, have overgrown all the other minerals in the rock. The quartz inclusions are rounded and unstrained whilst the plagioclase occurs as prismatic crystals; the grain size of the inclusions is less than 1 mm. The microcline has cross hatched and Carlsbad twinning and in unstrained. Myrmekite is common at microcline-plagioclase grain boundaries.

In the deformed granite south of the outcrop of the Baie d'Espoir Group, augen of microcline, plagioclase, and rare muscovite are preserved in a cataclastic matrix. The feldspar grains are strained and sericitized; cross hatched twinning is common in the microcline but the plagioclase is generally untwinned; most of the grains are about 1 cm. across, although where the rock is pegmatitic grains as large as 5 cm.

are found. Euhedral garnet which is common in this area generally has a grain size of 1 to 2 mm. Tourmaline where present occurs as needles up to 1 cm. long, approximately parallel to the D2 lineation; it is black in hand specimen and pleochroic from colourless (e) to very dark green (o).

Quartz and feldspar grains, 0.1 mm. across or less, occur in the matrix and have a decussate or polygonal texture; the inequidimensional grains have a very good LS preferred orientation. Within the matrix quartz and to a lesser extent microcline form lenses and stringers. These, together with scattered mica flakes, define the fabric; they are up to 1 mm. across and the grains that compose them are annealed and may be as much as 2 mm. long.

QUARTZ VEINS

Quartz veins of all ages intrude the rocks of the Bay d'Espoir area. Veins that have been deformed by the second deformation of the Baie d'Espoir Group are particularly common near the contact zone of the North Bay Granite. They also intrude the St. Alban's Formation at St. Alban's and Conne River; in these localities they are locally rich in pyrite and pyrrhotite. In the graphitic schists of the Isle Galet Formation, at least some of the numerous quartz segregations may be the result of pre-tectonic veining.

Post-tectonic veins up to 3 m. wide intrude all the structural divisions of the area and have no apparent relationship to any granite bodies. The most prominent veins occur near Flobber Cove on Bois Island, just south of Raymond Point (Pl. 40) and at Blunder Cove on Long Island

(Pl. 41). The vein at Blunder Cover has minor pyrite and chalcopyrite mineralization.

SUMMARY

Four groups of igneous rocks were intruded after the formation of the Little Passage Gneisses. Their observed relationships to each other, and to the Baie d'Espoir Group and its deformations, are summarized below:

1. The Seal Nest Cove Tonalite was intruded by Gaultois Granite aplites and was deformed by D1.

2. The Gaultois Granite was intruded by diabase dykes and by garnetiferous leucocratic granite; it was deformed by both of the deformations of the cover; xenoliths of Gaultois Granite, already deformed by D1, were included in leucocratic granite which was then deformed by D2.

3. The diabase and dacite dykes intruded the Gaultois Granite; they were deformed by both deformations of the cover and the dacite dyke on Middle Island was intruded by leucocratic granite after D1 but before D2. Similar basic dykes and sills intruded the Baie d'Espoir Group.

4. The garnetiferous leucocratic granites (including the North Bay Granite) intruded the Gaultois Granite, the dacite dyke on Middle Island, and the Baie d'Espoir Group; they were affected by the second deformation of the cover but not by the first; their intrusion approximately coincided with the peak of metamorphism in the Baie d'Espoir Group.

CHAPTER 4

THE BAIE D'ESPOIR GROUP

GENERAL STATEMENT

The Baie d'Espoir Group forms the belt of metasedimentary and metavolcanic rocks that lies between the Little Passage Gneisses in the south and the North Bay Granite in the north. Its outcrop extends westwards beyond Facheux Bay where it wedges out between the North Bay and Gaultois Granites (Williams, 1971). Northeast of Bay d'Espoir the group extends across the island and is equivalent to the Gander Lake Group on the north coast (Anderson and Williams, 1970; Kennedy and McGonigal, 1972); in the two areas there are similar lithologies, styles of deformation, and relationships to the basement gneisses and intruding granites.

Age

The age of the Baie d'Espoir Group is uncertain. The geologists of the Newfoundland and Labrador Corporation reported finding a fossil in black slate opposite the southern end of Riches Island at the mouth of Little River (Dunlop, 1954); "it was sent to L. J. Weeks of the G.S.C. who had Dr. Wilson section it and she found it to be of undoubted organic origin and to be a gastropod of Ordovician age, probably Middle Ordovician". She identified it as ? Eotamaria sp. Dunlop also reported part of a trilobite pygidium from "north of Barasway de Cerf, again in black shale. It has a late Cambrian to lower Ordovician aspect but was too imperfect for age identification". In both cases the rocks where these fossils were found are at the garnet grade of metamorphism.

Anderson (1967, and as quoted in Williams, 1971) reported finding crinoidal debris and Streptelasma in less deformed biotite grade metasediments near St. Alban's.

If the Baie d'Espoir Group can justifiably be correlated with the Gander Lake Group, the work of Kennedy and McGonigal (1972) would indicate a pre-Middle Ordovician age. They reported fragments of deformed and metamorphosed Gander Lake Group rocks in a mélange at the base of the Davidsville Group; the latter has been definitely dated as Middle Ordovician from several fossil occurrences (Jenness, 1963).

A radiometric age has been derived for the North Bay Granite of 573 m.y. ± 40 m.y. using the Rb/Sr method (Dr. R. Cormier, pers. comm. 1973). The granite intrudes the Baie d'Espoir Group and so a Precambrian age is implied for it. A full discussion of the radiometric age determinations is included in Appendix 2.

Structure, Metamorphism and Stratigraphy

The Baie d'Espoir Group has been regionally deformed twice (D1 and D2). It has been metamorphosed to between biotite and sillimanite grade with the metamorphic peak generally occurring between the first and second deformations (MP1), but locally during (MS2) or after (MP2) the second deformation. The MP1 metamorphic grade is generally higher close to the North Bay Granite. Almost all the rocks of the Baie d'Espoir Group have been inverted to form the lower limb of a large scale southeast facing F2 recumbent fold, the Bay d'Espoir Nappe, which lies in contact with the reconstituted Little Passage

Gneisses along the Day Cove Thrust; the limb length of this fold may exceed 15 km. A second major fault, the Big Rattling Brook Thrust, runs westwards from Conne River to beyond Roti Steady where it forms the base of a thrust sheet that overlies the North Bay Granite contact.

Four formations are recognized, two south of the outcrop of the Big Rattling Brook Thrust and two forming the thrust sheet itself, (see Fig. 5 and Map 2). The thickness quoted for each formation in Fig. 5 is extremely tentative; structural complications, including folds and faults, make it impossible to calculate accurate figures. This is particularly so of the Isle Galet Formation where competent volcanic rocks are separated by incompetent graphitic schist which in many places has been tectonically disrupted; furthermore rapid facies changes which are traceable along strike in the formation indicate that the original thickness was probably very variable.

Similarly the original stratigraphic succession is not certain. The contact between the Riches Island and Isle Galet Formations is conformable, but that between the Riches Island and St. Alban's Formations is everywhere the Big Rattling Brook Thrust. It is probable however that the thrust dies out eastwards and that these two formations are also conformable; whereas in the west at the granite contact the thrust superimposes biotite grade metasediment on granite and staurolite schist, at Conne River its importance is so diminished that no distinction can be made between the rocks immediately on either side of it. The relationship of the Roti Steady and St. Alban's Formations has not been determined, but the contact is probably a thrust fault. It is marked by a valley in which there is no exposure, and across which there

Formations from NW to SE	Lithology	Approx. thickness	Nature of contact
Roti Steady Fm.	semipelitic biotite and graphitic schist	1300 m.	
St. Alban's Fm.	pelite; siltstone; metagraywacke	3000 m.	thrust?
Riches Is. Fm.	semipelitic chlorite schist; psammite	700 m.	BRBT; conformable?
Isle Galet Fm.	acid and basic volcanic rocks; graphitic schist; metagraywacke	1700 m.- 3000 m.	conformable
Basement	reconstituted gneiss		Day Cove Thrust

Fig. 5. The stratigraphy of the Baie d'Espoir Group.

BRBT = Big Rattling Brook Thrust.

is a marked change in lithology from the biotite grade pelites and siltstones of the St. Alban's Formation to the garnet-staurolite schists of the Roti Steady Formation.

In summary, whilst the position of the Roti Steady Formation is unknown, the probable stratigraphic order of the rest of the Baie d'Espoir Group is the St. Alban's Formation at the base, the Riches Island Formation in the middle, and at the top the Isle Galet Formation. It should be noted that this succession is based on formation contacts that probably run parallel to the strike of the original depositional slope. No allowance has been made for facies changes across strike or for diachronous stratigraphic boundaries. It is likely that the different formations are in part lateral equivalents of each other.

THE ST. ALBAN'S FORMATION

The name, St. Alban's Formation, is proposed for the rocks that crop out along the entire coastline of Bay d'Espoir north of the Big Rattling Brook Thrust (Map 2). Northwestwards the formation extends inland as far as the fault that separates it from the Roti Steady Formation; northeastwards the limit of its outcrop has not been determined. It consists of a monotonous succession of fine grained distal flysch (Walker, 1967) and has been mildly metamorphosed in the greenschist facies. It has been less intensely deformed than any of the other formations of the Baie d'Espoir Group; the first deformation formed sporadic tight to isoclinal folds in apparently wet sediment, and the second caused large open concentric folds and overturned most of the rocks to form part of the lower limb of the Bay d'Espoir Nappe.

<u>Lithology</u>. The formation consists of fine grained flysch and the ideal Bouma sequence is used to describe it (Bouma, 1962; Walker, 1965); the sequence is shown in Fig. 6. In the St. Alban's Formation division b is generally missing and division a, if present at all, is represented by very rare thin lenses of grit. The common lithology is interbedded light brown calcareous siltstone and dark gray pelite (Pl. 42). The silt beds are generally between 3 and 6 cm. thick and are separated by 10 to 60 cm. of pelite; they form divisions c and d. They are well laminated with ripple drift lamination, minor slumping and load casts predominant in the lower half of each bed (division c) (Pl. 43) and parallel lamination with microscopic grading in the top half (division d) (Pls. 44, 45). The lower part of the pelite may also have indistinct parallel lamination and be a finer grained variety of division d. Most of the pelite has no sedimentary structures and is considered to belong to division e. Division b where it occurs is of almost the same grain size as the remainder of the siltstone beds but is recognizable as a division of parallel laminations overlain by the ripple drift laminations of division c. Around Brant Cove there are poorly graded lenses of grit at the bases of some of the sequences which may represent division a. The clasts are badly sorted, sub-angular and up to 5 mm. across; they are of mixed lithologies and are set in a dark gray marly matrix.

In the cliffs to the west of Morrisville, siltstone beds occur that are up to 3 m. thick; apart from some minor ripple drift lamination they are massive and structureless. In the same area there are slumped beds up to 30 cm. thick, extending for distances of 4 or 5 m. In the

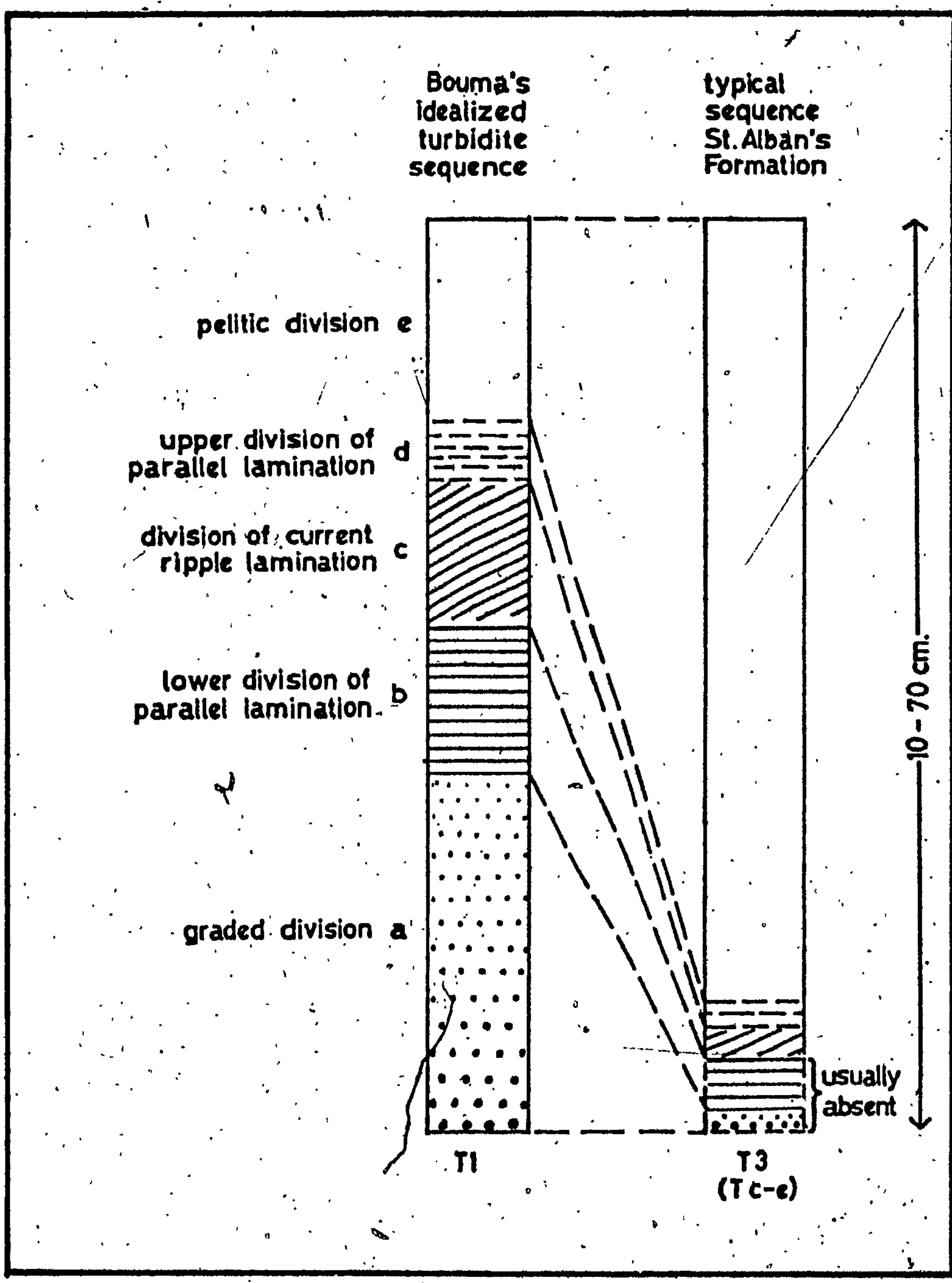


Fig.6. Bouma's idealized turbidite sequence, and a typical sequence from the St. Alban's Formation.

present, inverted orientation of the beds, the direction of slumping is towards the northwest.

Carbonate nodules are common in the St. Alban's Formation occurring in particular in the pelite; in many places they are concentrated at one horizon and everywhere they are inequidimensional in the plane of the bedding. Also occurring throughout the formation are beds of pale green quartz-muscovite phyllite which appear to have no genetic relationship to the flysch and may be of volcanic origin; they are rarely more than 3 cm. thick.

Sedimentary structures on bedding surfaces were not observed. If present, they have been obscured by the tectonic deformation; S1 is generally subparallel to the bedding and the bedding surfaces are corrugated by its intersection with S2.

Fabric. There are two fabrics developed in the St. Alban's Formation, one related to each of the major deformations of the Baie d'Espoir Group (Pl. 46). The first one, S1, is a penetrative cleavage and is axial planar to rare tight to isoclinal F1 folds up to 6 m. in amplitude; in most places it is subparallel to bedding. It is defined by a preferred orientation of the micas in the pelites and the more micaceous siltstones; the mica is generally muscovite but close to the Big Rattling Brook Thrust the metamorphic grade during D1 was higher and there has been growth of syntectonic biotite. There is no recognizable preferred orientation in the mica-poor beds.

Tectonic dewatering structures (Maxwell, 1962; Powell, 1972) are common where F1 folds occur; they are particularly well developed on Man of War Head in St. Alban's harbour. Near the hinges of the folds well laminated siltstone beds become chaotic and flow structures have formed. The siltstone beds may be completely broken, but the broken ends are rounded and are not the result of brittle fracture. There has commonly been injection of siltstone dykes into the pelitic beds along the S1 cleavage planes (Pls. 47, 48); the dykes are about 5 to 6 cm. long and 1 cm. thick. The dewatering features suggest that the S1 cleavage was initially formed by mechanical rotation and has since been enhanced by subsequent crystal growth.

The S1 fabric has been overgrown by MP1 biotite (Pl. 49) and locally near the Big Rattling Brook Thrust by garnet; south of Roti Steady there has also been MP1 growth of potassium feldspar porphyroblasts. Inclusion trails of S1 are common in the biotite and feldspar but not in the garnet.

The second deformation folds in the St. Alban's Formation are open and concentric with approximately flat lying axial planes. Within 500 m. of the Big Rattling Brook Thrust these folds become close to tight and the thrust itself is probably of D2 age. Throughout the St. Alban's Formation the S2 fabric in the pelites is a crenulation cleavage (Pls. 46, 49) and in many places there is differentiation into mica-rich and relatively mica-poor bands; the wavelength of the crenulations is 0.2 to 0.5 mm. Within the siltstone the S1 fabric is crinkled but there is no metamorphic differentiation whilst in the very mica-poor beds no recognizable preferred orientation has been developed at all either during D1 or D2. Where the second deformation cleavage or crenulation is developed, pre-D2 biotite (Pl. 49) and potassium feldspar have been bent and fractured, and garnet grains have augen formed around them.

Close to the Big Rattling Brook Thrust where the F2 folds are tighter, the cleavage in the pelite is better developed and locally a penetrative S2 schistosity has been formed. In the silty beds quartz has become concentrated on the crests of some of the minor folds with a wavelength of less than 3 cm.; the grains are coarser than elsewhere in the bed and are flattened parallel to the schistosity.

Petrography. The pelite beds in the greater part of the St. Alban's Formation are composed of muscovite (70 per cent), quartz (10 per cent), biotite (5 per cent), pyrite (5 per cent), graphite, zircon and sphene; where the metamorphic grade is higher near the Big Rattling Brook Thrust about half of the mica is biotite. The muscovite flakes are about 0.2 mm. across and define S1; they have been bent and partially recrystallized during the second deformation. Quartz occurs between the mica grains as lenses less than 0.05 mm. across; it tends to be concentrated away from D2 microfaults and strain bands. Biotite is mostly present as scattered xenoblastic grains about 0.5 mm. across, which have grown statically after the first deformation; many grains contain S1 inclusion trails and are bent by F2 folds. Close to the Big Rattling Brook Thrust syntectonic biotite with a grain size of 0.3 mm. has grown parallel to the S1 fabric. The pleochroism is from colourless (X) to slightly reddish brown (Y, Z). Pyrite occurs as xenoblastic grains which have grown interstitially and are about 0.5 mm. across. Graphite is locally disseminated and detrital sphene and zircon occur.

The siltstone beds consist of quartz (40 per cent), calcite (30 per cent), muscovite (20 per cent), pyrite, biotite, graphite, zircon, sphene, and locally garnet and potassium feldspar. The quartz occurs as well sorted subangular grains less than 0.05 mm. across, in a calcareous matrix. The muscovite flakes which define S1 in the more micaceous siltstone beds are up to 0.1 mm. in length. Pyrite aggregates up to 1 mm. across are especially common where D2 microfaults in pelitic beds extend into the siltstones. Biotite has locally overgrown S1 and on the hill south of Roti Steady potassium feldspar grains up to 0.5 mm. across also enclose it; the latter have been polygonized during the second deformation. Idioblastic garnet porphyroblasts up to 0.8 mm. in diameter occur in massive siltstone just south of Frenchman's Cove; they contain inclusions of quartz grains, which are clustered in the centres of the porphyroblasts, and graphite, which forms six-rayed stars; S2 forms augen around the garnet.

The beds of grit near Brant Cove contain a variety of subangular, poorly sorted clasts in a marly matrix of about 0.2 mm. grain size. The clasts consist of fine grained calcite (30 per cent), very fine grained psammite with a slight pre-existing fabric (30 per cent), basalt or diabase with lath shaped plagioclase phenocrysts up to 1 mm. long (10 per cent), and pelite with a pre-existing penetrative cleavage and a crenulation cleavage continuous with S2 in the matrix (10 per cent).

THE RICHES ISLAND FORMATION

The name, Riches Island Formation, is proposed for the metasediments that crop out south of the Big Rattling Brook Thrust and north of the metavolcanic rocks of the Isle Galet Formation; in the west it is intruded by the North Bay Granite (Map 2). The coarse mica schist occurring where the granite contact reappears northwest of

St. Alban's may also belong to this formation.

There are four principal lithologies which, at the garnet grade of metamorphism, are: 1. pale green semipelitic chlorite schist with thin quartz-garnet beds, 2. black graphitic and pyritic quartzite, 3. gray psammite, and 4. gray and brown mica schist; an isolated outcrop of amygdaloidal basic volcanic rock occurs on Riches Island. The stratigraphically lower part of the formation, north of Roti Bay and beneath the Big Rattling Brook Thrust, consists principally of semipelitic chlorite schist with some interbedded graphitic schist and thin bedded psammite; the middle part, cropping out east and west of Roti Bay, is composed of psammite and mica schist; on Riches Island, eastwards up Little River, and westwards on the north half of Bois Island, the upper part of the formation consists of semipelitic chlorite schist with subordinate graphitic quartzite.

The Riches Island Formation is more intensely deformed than the St. Alban's Formation. Evidence of the first deformation is preserved as a schistosity in MP1 porphyroblasts and in microlithons between S2 strain bands; rare F1 folds occur as detached isoclinal closures in thin quartz-garnet beds. F2 folds are tight or isoclinal and S2 is either a penetrative or a differentiated crenulation schistosity. Close F3 folds overturned towards the north are locally common and in a few places the fracture cleavage associated with these folds becomes a crenulation cleavage.

The metamorphism of the Riches Island Formation varies from biotite grade just below the Big Rattling Brook Thrust east of Bay d'Espoir, through garnet grade over most of the outcrop, and increases to staurolite grade within 3 km. of the North Bay Granite; rare sillimanite occurs in the schists within 100 m. of the contact and kyanite is present in the contact zone northwest of St. Alban's.

Semipelitic Chlorite Schist

Lithology. Just south of the Big Rattling Brook Thrust on the east side of Bay d'Espoir, the Riches Island Formation has only been metamorphosed to biotite grade. The chlorite schist occurring in this area is a gray phyllitic rock with a few thin beds of brown siltstone about 1 to 3 cm. thick. It has a good S2 schistosity, but is otherwise similar to the rocks of the St. Alban's Formation.

Southwards and westwards the metamorphic grade increases and the rock becomes a pale green, fine grained, garnetiferous chlorite schist. Thin quartz-garnet beds about 1 cm. thick are common (Pl. 50), generally being separated by 10 cm. or more of schist; on Riches Island one such bed has an exceptional thickness of 2 m. Also occurring in the schist are quartzite beds up to 5 cm. thick, and rare poorly sorted pebble beds; the subangular quartz pebbles are up to 1 cm. across and lie in a matrix of schist.

Towards the contact with the North Bay Granite, the grade of metamorphism increases and the schist becomes medium grained. Porphyroblasts of staurolite up to 1 cm. long are developed. Chlorite is absent and its place is taken by biotite giving the schist a brown colour.

Fabric. In the biotite and garnet grade schist, the S1 schistosity is defined by a preferred orientation of chlorite, muscovite, and inequidimensional grains of quartz and graphite. It has been overgrown post-tectonically by porphyroblasts of garnet (Pl. 51) up to 0.5 mm. across and chlorite (Pl. 52) up to 2 mm. long; these have preserved the fabric as straight inclusion trails.

Mesoscopic F2 folds (Pl. 50) with a wavelength of 2 cm. and upwards are common in the quartz-garnet and quartzite beds and a crenulation schistosity has formed in the schist with the maximum strain occurring on the hinges of the folds. In some places the quartz-garnet beds have been ptygmatically folded; and the S2 schistosity forms augen around them; these folds may have been initiated during the first deformation.

The S2 crenulation schistosity is undifferentiated on the limbs of the F2 folds and there are only a few microfaults; S1 has been crenulated (wavelength 0.3 mm.) and there has been further growth of mica and chlorite parallel to S2 during the second deformation, locally forming a penetrative schistosity. On the hinges of the mesoscopic F2 folds the strain was more intense and there has been marked differentiation with concentration of mica along microfaults and on the limbs of crenulations. The S1 fabric is, in most places, preserved in the quartz-rich centres of the microlithons, but where the strain was most intense the mica-rich domains are wider and may amalgamate to form micaceous strain bands 1 cm. or more wide.

The S2 schistosity forms augen around the porphyroblasts of garnet and chlorite (Pls. 51, 52) and generally is at an angle of 20° or more with the included fabric.

The third deformation has caused kinking in the micaceous bands but where there has been little or no D2 metamorphic differentiation, it has not affected the previous fabric. The kink bands are about 0.5 mm. across and form an angle of 30° to 70° with S2; the mica has recrystallized and there has been minor differentiation.

The quartz-garnet beds vary from moderately micaceous to mica-free. In the micaceous beds the S1 fabric is well developed and is overgrown by clusters of idioblastic garnet. The S1 fabric has been crenulated during the second deformation but microfaulting and differentiation have only occurred at the edges of the beds where mica and chlorite are particularly concentrated. In the mica-free quartz-garnet beds, a polygonal texture was formed in the quartz during the first deformation and there was growth of garnet and minor chlorite interstitially between the polygons which are generally about 0.1 mm. across; the second deformation caused strained extinction and the development of a decussate texture in the quartz on the crests of F2 folds. The quartz-garnet beds that were ptygmatically folded and subjected to the greatest strain during the second deformation have undergone an annealing recrystallization. Annealed quartz grains are up to 3 mm. across and the D1 polygonal texture is preserved within them by an included web of MP1 chlorite and garnet (Pl. 59). Subsequent strain, probably associated with the third deformation has caused undulose extinction and partial polygonal breakdown of these grains.

Where the metamorphic grade was highest close to the North Bay Granite, the schist is medium to coarse grained. The S1 fabric is defined by biotite and muscovite grains up to 1 mm. long; chlorite is rarely present. Garnet porphyroblasts are common and are overgrown by poikiloblastic staurolite with straight inclusion trails of quartz defining S1 (Pl. 54). Fibrolitic sillimanite has formed by the breakdown of biotite and muscovite in the schist within 100 m. of the granite (Pl. 55). S2 is a crenulation schistosity in which the crenulations have a wavelength of 2 to 5 mm. and the micas are recrystallized; the schistosity forms augen around the garnet and staurolite porphyroblasts. The groundmass is granoblastic and the quartz has embayed grain boundaries. The age of the sillimanite with respect to the second deformation is not certain but it is most likely to be pre-tectonic. In the schist at the granite contact northwest of St. Alban's, kyanite occurs parallel to S2 (Pl. 56).

Petrography. The quartz content of the semipelitic schist is generally about 40 per cent, decreasing to less than 10 per cent in mica-rich strain bands; muscovite and chlorite make up most of the rest in biotite and garnet grade rocks, but at higher grades half of the mica is biotite and chlorite is absent. Garnet and staurolite porphyroblasts rarely form more than 10 per cent of the schist although the quartz-garnet beds may be more than 50 per cent garnet. Accessory minerals are fibrolite (locally), tourmaline, plagioclase, apatite, sphene, zircon, opaque oxides, and graphite.

Chlorite occurs in two forms, as xenoblastic flakes in the matrix of the schist, and as large idioblastic porphyroblasts (Pl. 52). In both forms it is pleochroic from colourless to pale green and has pleochroic haloes; it has anomalous blue and purple interference colours except for the few grains in the staurolite schist which are brown. The porphyroblasts are about 2 mm. long and have a preferred orientation.

They have S1 inclusion trails of quartz, muscovite and opaque minerals, and there are generally thin mica-free zones of quartz adjacent to the (001) faces. The grains generally have polysynthetic twinning parallel to (001) and some have been kinked during the second deformation.

Biotite also has two forms. In most of the garnet grade rocks, it has only grown as xenoblastic MP1 poikiloblasts, but locally it has grown syntectonically in the D2 strain bands and in the staurolite grade rocks it defines S1. It has a pleochroic scheme of colourless (X), light brown (Y), and dark reddish brown (Z).

The garnet porphyroblasts vary from xenoblastic to idioblastic in the same thin section. The xenoblastic grains are generally dendritic and tabular parallel to the included fabric, S1. Amalgamation of grains is common. Most of the garnets contain graphitic inclusions defining S1 (Pl. 51) or, where S1 is poorly developed, forming six-rayed stars (Pl. 57); in the staurolite grade rocks many of the garnets have single biotite flakes in their centres on which they have apparently nucleated (Pl. 58). The rims of the porphyroblasts are generally free of inclusions.

The staurolite porphyroblasts are idioblastic and up to 1 cm. long; they have diamond shaped cross-sections and cruciform twins. The crystals are crowded with quartz inclusions defining S1 and are faintly pleochroic from colourless (X) to pale straw yellow (Z).

Amongst the less common minerals plagioclase occurs locally in the fine grained groundmass; it rarely has polysynthetic twinning. Tourmaline is commonest near the granite contact where it occurs as idioblastic needles and is pleochroic from colourless (e) to pale greenish-brown (o).

Graphitic Quartzite

Lithology. On Riches and Bois Islands there are beds up to 50 m. thick of very fine grained, jet black, graphitic quartzite within the semipelitic schist succession. The quartzite has a poorly developed cleavage which is only seen on weathered surfaces and in thin section; individual hand specimens appear to be massive and may even have a conchoidal fracture. The rock weathers to a distinctive deep red-brown colour. Some of the quartzites contain amphibole rosettes and north of Flobber Cove on Bois Island a graphitic rock consisting entirely of medium-grained amphibole occurs; the rock is porous and it is assumed that the amphibole crystals were at one time held together in a matrix that has since been dissolved.

Fabric. The S1 fabric is defined by a very fine scale banding of graphite in the granoblastic quartz matrix. Where muscovite and biotite are present, these have a preferred orientation parallel to the banding of the graphite. The fabric is overgrown by rosettes of amphibole in which graphite inclusion trails are preserved. In the more micaceous rock, the second deformation has caused some flattening of S1 around the amphibole grains, but generally the rock is so massive that S2 is only present as a fracture cleavage.

Petrography. In most places the graphitic quartzite consists of quartz (80 per cent) and graphite with minor mica (20 per cent). The grainsize is less than 0.05 mm. and the texture is polygonal; quartz segregations occur in which the grains are up to 0.1 mm. across.

The amphibole rosettes are up to 5 mm. across and are composed of acicular crystals radiating from a centre. In hand specimen they appear black because of included graphite but in thin section they are colourless. The maximum extinction angle Z∧c is 14° and the 2V is about 80° and negative; the amphibole is probably tremolite. It may be altered to a clinochlore variety of chlorite which is colourless, has first order gray interference colours and a very small 2V.

Psammite and Mica Schist

Lithology. The belt of psammitic rocks that extends along strike from Roti Bay and occupies the middle part of the Riches Island Formation varies in detail from mica schists to quartzite and includes some typical semipelitic chlorite schists with quartz-garnet beds. The division is, however, dominated by beds of psammite varying from 3 cm. to 5 m. in thickness with sharp tops and bottoms and faint laminations. The beds are separated by semipelitic or pelitic mica schist (Pl. 59) which has a banding on a 1 to 3 mm. scale. The schist beds are generally less than 1 m. thick in the north of the outcrop but southwards around Roti Point they may reach 30 m. in thickness.

A badly sorted pebble bed, 2 m. thick, and containing quartzite clasts from sand size up to 3 cm. across occurs at the mouth of Roti Bay. The clasts lie in a matrix of semipelitic biotite schist; they are moderately rounded and flattened parallel to S2.

Fabric. The penetrative schistosity in the psammite is defined by a moderate to good preferred orientation of mica and chlorite. It is overgrown by poikiloblastic garnet grains and is therefore concluded to be S1. S2 is represented by a fracture cleavage in the axial zones of F2 folds; it has caused little reorientation of minerals. The quartz matrix in most of the psammitic rocks is polygonized and garnet has grown around the polygonal grains. Where an S2 fracture cleavage is developed, there has been recrystallization of the quartz during D2; a coarser grained, moderately well developed, polygonal texture has been produced and individual grains of quartz include garnet that still outlines the D1 texture.

There is a gradation from psammite to mica schist. In the more quartz-rich schists, the S2 fabric which is generally defined by muscovite and biotite is a crenulation schistosity, but as the amount of mica increases it becomes penetrative; there is no significant metamorphic differentiation. S1 is preserved as inclusion trails in garnet and chlorite porphyroblasts around which S2 forms augen. The quartz in the schists is generally inequidimensional and aligned parallel to S2. The third deformation has locally caused crenulation of S2; muscovite grains which have grown across the schistosity may be related to this deformation.

<u>Petrography</u>. The psammite consists of up to 80 per cent quartz with minor muscovite, biotite, chlorite, and garnet. In the semipelitic and pelitic schists, muscovite and biotite are present in equal proportions whilst chlorite is of minor importance and is generally restricted to thin quartz-rich beds.

The quartz grains are everywhere less than 0.1 mm. across; they have straight grain boundaries and are unstrained (Pl. 60) except in the psammite beds where S2 is a fracture cleavage.

The micas define the fabrics and have a grain size of between

0.5 and 1 mm. Muscovite also occurs in aggregates which are about 1 mm. across and have augen formed around them by S2 (Pl. 61). Later muscovite flakes growing across S2 are up to 2 mm. long. Biotite is pleochroic from pale brown to dark reddish-brown.

Locally chlorite partially defines S1 in the psammite but generally it occurs as unoriented aggregates at the edges of quartz-rich beds. It also forms idioblastic porphyroblasts about 1 mm. long, that include S1 and have augen formed around them by S2. It is pleochroic from colourless (X) to pale green (Y and Z) and has anomalous blue and purple interference colours.

Garnet grains are skeletal and interstitial in the psammite, forming webs up to 1 mm. across with included grains of quartz. In the schists the garnet is subidioblastic and the grain size varies from 0.5 to 2 mm.; the grains contain graphitic inclusions defining S1.

Volcanic Rocks

Lithology. One occurrence of volcanic rock was found in the Riches Island Formation. It is on the east side of Riches Island and is associated with a belt of graphitic quartzite. The rock is a dark gray, fine grained, amygdaloidal metabasalt occurring in a flow 1 m. thick. The amygdales are filled with calcite; they have been flattened in the plane of S2 and stretched parallel to the F2 fold axes (Pl. 62).

Fabric. The S2 fabric is defined by biotite, and a banding of the opaque minerals and plagioclase in the fine grained groundmass. The biotite occurs in patches and streaks about 5 mm. across, and the streakiness has been enhanced by minor metamorphic segregation; F2 intrafolial folds are locally preserved by an en echelon arrangement of the grains.

Petrography. The metabasalt consists of plagioclase (40 per cent), biotite (30 per cent), iron oxide (10 per cent), chlorite (10 per cent), and quartz (10 per cent). Amygdales filled with calcite locally form 30 per cent of the rock.

The plagioclase, quartz, and iron oxide form a very fine grained groundmass in which the length : width ratio of most grains is 10 : 1 and the length is rarely more than 0.1 mm. Quartz locally forms segregations in which grains are 0.2 mm. across, strained, and partially polygonized. Rare, larger grains of plagioclase (0.3 mm. across) have survived the deformation; they have albite twinning and the composition is An45 ($\perp$a X' $\wedge$010=25°).

Biotite occurs as flakes up to 1 mm. long; it is disseminated in the groundmass or concentrated in aggregates. It is pleochroic from pale yellow (X) to deep yellow-brown (Z).

THE ISLE GALET FORMATION

The name, Isle Galet Formation, is proposed for the rocks that crop out to the south of the Riches Island Formation and overlie the Little Passage Gneisses along the Day Cove Thrust (Map 2). The formation is dominated by metavolcanic rocks, principally acid crystal tuff or quartz porphyry, and amphibolite. It includes a wide variety of metasediments of marked lateral inconsistency. The principal metasediment is black, graphitic and pyritic, semipelitic schist, with subordinate green semipelitic chlorite schist and metagraywacke; one bed of siliceous marble, 10 m. thick, was found east of Snook's Harbour on Bois Island. The coarser sediments are generally polymict with poorly sorted, subangular fragments; they are restricted to the eastern part of the area around Barasway de Cerf and the east end of Bois Island. The contact of the Isle Galet Formation with the Riches Island Formation is conformable and gradational over a distance of 100 m.; it is chosen where black graphitic schist becomes dominant over green chloritic schist and roughly coincides with the appearance of substantial amounts of volcanogenic rock.

The rocks of the Isle Galet Formation have undergone both of the main deformations of the Baie d'Espoir Group. Evidence of the first deformation is preserved locally as an S1 schistosity where the S2 schistosity is poorly developed, on F2 fold hinges, within D2 microlithons, or in MP1 and MS2 porphyroblasts. The second deformation has caused tight to isoclinal F2 folds and an LS-tectonite fabric ranging from a crenulation to a penetrative schistosity. Tectonic displacements have taken place during D2 and probably during D1 in the incompetent semi-pelitic members, which in many places separate layers of igneous rock; the Day Cove Thrust is marked by one such semipelitic schist which has become a tectonic mélange and contains fragments of reconstituted basement. Probable D2 slide zones are present in some of the acid igneous rocks themselves and are marked by coarse muscovite schist.

The metamorphism of the Isle Galet Formation is everywhere at least at garnet grade. Over most of the area the metamorphic peak was MP1, but around Simmond's Barasway there was MS2 garnet growth. At

Snook's Harbour all garnet growth was MP1, but the garnet has been overgrown by MP2 staurolite.

Acid Igneous Rocks

Lithology. In most places the acid igneous rocks of the Isle Galet Formation have been so deformed that it is not certain whether they were originally tuffs, lavas, or even hypabyssal intrusions. Many of them are definitely crystal tuffs and none of them are clearly flows or intrusions; for the sake of convenience a tuffaceous origin is assumed in the nomenclature used in the following description. The rocks characteristically contain euhedral crystals up to 5 mm. across set in a fine grained matrix. In most places the matrix is quartzo-feldspathic with varying developments of sericite depending on the degree of tectonic deformation; in some places however the matrix is micaceous and the rock grades into a schist.

The quartzo-feldspathic variety generally occurs as massive unbedded sheets (Pl. 63) between 6 and 100 m. thick, in places forming continuous outcrops for several kilometres. The only parts of the rock that show any bedding are lenses of lapilli tuff (Pl. 64) occurring within the sheets east of Flobber Cove on Bois Island, and just to the west of Raymond Point on Long Island; the lenses are up to 1 m. thick and have gradational boundaries. The lapilli consist of similar material to the surrounding rock and contain rare euhedral phenocrysts (Pl. 65). They are subangular and poorly sorted, and may be up to 2 cm. across in their longest dimension; this is however exaggerated up to two times by tectonic flattening. Deformation has imparted an excellent schistosity to the crystal tuff (Pl. 66) and the schistosity surfaces are coated with muscovite and locally dotted with lenses of biotite, 1 to 5 mm. across. Augen have formed around the crystals except close to the Day Cove Thrust where there has been mylonitization and an even-grained texture has developed. Prominent jointing in two directions at right angles and perpendicular to the boundaries of the sheets causes a castellated appearance in cliff faces. The rock weathers white except where it contains sulphide minerals as at Copper or Little Copper Heads on Bois Island; in these places it is a rusty brown or locally malachite green. It is resistant to erosion and forms high cliffs and headlands from Simmond's Barasway along the south coast of Bois Island to Western Head, and from Dolland Bight to Patrick's Harbour.

On Isle Galet, Brimball Head, and to the southeast of Raymond Point, the quartzo-feldspathic tuff is intimately associated with and grades vertically and laterally into gray micaceous crystal tuff. The tuff is crudely bedded and there has been slight sorting of crystal fragments; the sorting was not sufficient to form graded bedding and other sedimentary structures are lacking. In many places the tuff has a slightly cherty appearance and cleavage fragments are brittle; thin beds up to 4 cm. thick of well laminated chert are common.

Fabric. The fabric associated with the first deformation is generally not preserved because of overprinting by S2. An exception is on the hinge of a large isoclinal F2 fold southeast of Raymond Point in a sheet of quartzo-feldspathic crystal tuff; S2 is only moderately developed in the core of the fold. S1 is defined by muscovite and a slight dimensional preferred orientation of quartz and feldspar in the matrix; it is developed at and parallel to the edges of the sheet and can be traced around the fold hinge. MP1 porphyroblast growth is generally lacking in the acid tuffs because they are of the wrong composition for the formation of garnet, the principal MP1 mineral. In one band of micaceous tuff near Flobber Cove on Bois Island (Pl. 67), the S1 schistosity defined by muscovite and elongate quartz and feldspar grains has been preserved in MP1 and MS2 albite porphyroblasts and is also overgrown by MP1 biotite.

The S2 fabric is almost everywhere well developed and along the southern shore of Bay d'Espoir is associated with a stretching lineation parallel to the F2 fold axes. This lineation is rarely seen further north but stretching in the same direction is shown by the lapilli tuff east of Flobber Cove. S2 in the quartzo-feldspathic tuff is defined by muscovite and inequidimensional quartz and feldspar; the lineation is defined by a slight stretching of the crystals which is accentuated by the augen formed around them. Biotite occurs in lenses with a longest dimension of between 1 and 5 mm.; the lenses lie in the plane of S2 and are elongated parallel to L2. The quartz and feldspar in the matrix may have a moderately polygonal texture, but in most places a slight ribbon structure is developed. Although the crystals have locally been broken down into polygonal aggregates, in most places they have survived the deformation intact.

The micaceous tuffs have a much more prominent S2 fabric because of their composition. The penetrative schistosity is defined principally by muscovite with small amounts of biotite occurring mostly in microscopic lenses. Lenses of quartz, feldspar, and calcite are also common; like the biotite lenses they have dimensions of a few millimetres, are flattened in the plane of S2 and are elongated parallel to L2. There is sporadic metamorphic differentiation. Where there has been extensive growth of MP1 albite porphyroblasts, these have hindered the transposition of S1 and the second fabric is no more than a crenulation cleavage. The quartz and feldspar in the matrix of the micaceous tuff does not generally show ribbon structure and may have a polygonal texture; many of the crystals retain some semblance of their original subhedral outlines in the sheltered tails of augen.

Close to the Day Cove Thrust most minor thrusting and sliding in the Baie d'Espoir Group has occurred in incompetent semipelitic schist. There are however zones of intense tectonic degradation in the quartzo-feldspathic tuff, most notably at Patrick's Harbour on Long Island and in the cliffs north of Dolland Bight. As far as can be determined the deformation was of D2 age. The rock has been reduced to a coarse muscovite schist with a 3 to 5 mm. tectonic banding and numerous isoclinally folded quartz segregations; the muscovite which constitutes only about 20 per cent of the rock forms an anastomosing schistosity between knots of quartz and feldspar; the latter vary greatly in grain size but generally have a good polygonal texture.

Evidence of the third deformation is preserved where a banding is developed in the micaceous tuff and the intensely tectonized zones of the quartzo-feldspathic tuff. Generally only a slight crenulation is developed but in some places there are microfaults and minor metamorphic differentiation. Nowhere is S2 transposed by S3 in the Isle Galet Formation.

Petrography. About 20 per cent of the quartzo-feldspathic tuff is composed of crystals; about 40 per cent of these are quartz and 60 per cent microcline; plagioclase is rare. The matrix in the least deformed specimens contains quartz (30 per cent), microcline (30 per cent), plagioclase (20 per cent), muscovite (10 per cent), and minor amounts of biotite, chlorite, epidote, zircon, and opaque minerals, principally sulphides. The amount of muscovite increases at the expense of the feldspars with increasing deformation.

The least deformed specimens of this rock are found in the core of the isoclinal fold 100 m. southwest of Raymond Point. The crystals retain most of their original outlines. The quartz crystals are commonly bipyramidal and up to 2 mm. across (Pl. 68); many of the corners are slightly rounded, and deep, smooth, vermicular embayments filled with fine grained quartz and feldspar extend into some of the crystals. Almost all of the crystals have undulose extinction but only a few have been broken down into smaller grains; in such cases the grain boundaries are sutured. Microcline crystals are prismatic and have cross hatched and Carlsbad twinning; they are 2 to 5 mm. across. Many were fractured before the solidification of the rock and the parts of the crystal have become separated and can no longer be matched; others have been tectonically fractured and broken down into polygonal aggregates. Plagioclase crystals are rare and have everywhere been partially replaced by potassium feldspar; they have albite and pericline twinning, and their composition is An8. There has been slight alteration to sericite.

The matrix of the rock has a grain size of less than 0.1 mm. It consists principally of quartz and feldspar; the grain boundaries are curved and ribbon structure may be developed. Muscovite, chlorite, and biotite are also present, but most of the biotite together with rare tetragonal prisms of zircon occurs in lensoid aggregates; it is pleochroic from straw yellow (X) to dark brown (Y and Z).

In most areas the strain was greater than in the rock described above. Large crystals are generally ovoid with muscovite flakes, 1 mm. across, forming augen around them. In the matrix the grain boundaries between the quartz and feldspar are straight and the grains are markedly inequidimensional. Where the rock has been tectonically reduced to a mica schist, the polygonal quartz grains vary in size from 0.1 mm. to 4 mm.; feldspar is rare; muscovite flakes are commonly 5 mm. across and are segregated in bands and bent around quartz aggregates.

The micaceous and bedded crystal tuff may contain up to 20 per cent crystals between 1 and 5 mm. across; they are similar to those in the quartzo-feldspathic tuff. The matrix contains up to 50 per cent mica with a grain size between 0.1 and 0.5 mm.; most of the mica is muscovite, but there may be substantial amounts of biotite which is pleochroic from colourless or straw yellow (X) to brown (Z). Quartz and feldspar in the matrix have a granoblastic texture with curved or straight grain boundaries. Calcite commonly occurs either disseminated or in 2 to 5 mm. aggregates with augen formed around them. The MP1 albite porphyroblasts that have grown in the tuff near Flobber Cove are about 1 mm. across and xenoblastic; they are crowded with quartz inclusions to the extent of about 30 per cent of their volume and only rarely do they show indistinct polysynthetic twinning; the composition is approximately An20 (refractive index). The only other MP1 porphyroblastic mineral in the acid volcanic rocks is garnet, and this occurs as very rare poikiloblastic grains up to a millimetre across in the most biotite-rich tuffs.

Basic Igneous Rocks

Lithology. The basic igneous rocks of the Isle Galet Formation are everywhere metamorphosed to amphibolites and in many places the original igneous texture has been destroyed by deformation or metamorphic mineral growth. They occur as concordant sheets which may be either intrusive or extrusive, as discordant dykes, or as bedded tuffs. They are similar in appearance and deformational history to the metadiabase dykes intruding the Little Passage Gneisses.

The largest of the concordant sheets extends from just north of Hatcher Cove across Little Passage to Harbour le Gallais and has a maximum thickness of about 100 m. It is bounded above and below by tectonically disrupted, graphitic, semipelitic schist and isolated fragments up to 20 m. long may occur in the schist (Pl. 69). The amphibolite is a fine grained, dark green rock with a moderately well developed LS-fabric, although close to the schist it is intensely deformed. The main part of the sheet is cut up into lenses by joints and small shear zones; the lenses are generally between 2 and 10 m. wide and 1 m. thick and are flattened parallel to the fabric. There is no good evidence for distinguishing between an intrusive or an extrusive origin.

Similar thinner sheets of amphibolite occur on Isle Galet, Bois Island, and around Barasway de Cerf, and in many places are associated with slightly discordant dykes. Bedded amphibolite tuff is particularly common at Simmond's Barasway and across Bois Island. The beds are between 1 and 15 cm. thick and in many places consist of rapidly alternating layers rich and poor in amphibole; they are intimately associated and interbedded with acid volcanic tuff. Hornblende rich mica schists also commonly occur with the tuffs; the origin of these rocks is uncertain because of the destruction of the primary textures.

The amphibolite on the north side of Bay d'Espoir differs from that on the south side in having undergone more metamorphic recrystallization; it is medium grained and is characterized by radiating amphibole rosettes.

Fabric. The original texture of the basic igneous rocks is preserved in the centre of the Harbour le Gallais sheet where deformation was not intense and growth of hornblende during metamorphism was largely restricted to replacement of original ferromagnesian minerals. The rock is fine grained and is formed of an intergrowth of prismatic plagioclase and hornblende; chlorite locally takes the place of hornblende. Iron oxides are present interstitially defining a crude tectonic fabric.

The first deformation fabric defined by trails of iron oxide can be recognized in the massive amphibolite where it has been overgrown by MP1 hornblende. In the bedded amphibolite tuff, fine grained hornblende with a good preferred orientation defines S1 (Pl. 70). MS1 and/or MP1 metamorphism has caused the growth of hornblende rosettes on foliation surfaces and these have been folded around tight to isoclinal F2 folds. The second deformation has not caused transposition of the first schistosity except in the few places where the rock contains substantial amounts of biotite; in these places the biotite defines the S2 fabric and together with the inequidimensional felsic minerals forms augen around the hornblende grains (Pl. 71).

Where S1 is not well defined, MP1 hornblende rosettes have a random orientation and overgrow the fabric; they are best developed on Bois Island and around Baraswayde Cerf (Pl. 72). The rosettes have formed by acicular growth out of each end of the pre-existing prisms. The crystals are curved and radiating, but are in crystallographic and optical continuity with the prismatic nucleus; they extend into and partially replace the feldspars, which are broken down into a fine grained granoblastic matrix. Small quartz veins and segregations are generally formed in these rocks.

The second deformation fabric is not well developed in the amphibolites of the Isle Galet Formation except near the Day Cove Thrust. In most places it is represented by microscopic crush zones, in which plagioclase has been broken down into a fine grained polygonal matrix and hornblende needles have been rotated into the plane of flattening; these crush zones form augen around the MP1 hornblende rosettes. Where there has been more intense deformation at Harbour le Gallais and at the entrance to Little Passage, a hornblende schist has been formed in which the amphibole defines an LS-fabric. The fabric forms augen around a few relict igneous plagioclase grains, and an uneven distribution of hornblende reflects the original igneous texture.

Petrography. The amphibolite with igneous textures preserved contains plagioclase (40 per cent), hornblende (40 per cent), and accessory iron oxide, sphene, quartz, calcite, epidote, clinozoisite, and sericite; locally chlorite takes the place of hornblende.

The plagioclase occurs as subhedral prismatic grains about 2 mm. long. It has polysynthetic twinning and the composition is An33 ($X \wedge 010 = 15°$). It may be replaced by patches of hornblende with a consistant orientation within each feldspar grain. In most places however replacement by hornblende involves the complete breakdown of the feldspar crystals and the growth of randomly oriented needles of hornblende from neighbouring crystals. The feldspar that is the result of this process is very fine grained (less than 0.1 mm.) and is xenoblastic with sutured or scalloped grain boundaries; it is associated with quartz. The composition, estimated by comparison of refractive indices with quartz is between An20 and An25. All the plagioclase is slightly sericitized.

Where igneous textures are preserved, hornblende occurs as prismatic grains about 2 mm. long; no pre-existing ferromagnesian minerals have been found. Almost everywhere there is at least incipient acicular growth extending from the main crystal. This growth has a characteristic form; the needles grow principally out of the ends of the hornblende prisms, and curve around and fan out to one side; fans formed at opposite ends curve around in opposite directions producing an S-shaped rosette which may be as much as 1 cm. in length. The hornblende is pleochroic from light brown (X) through olive green (Y) to emerald green (Z) and has pleochroic haloes; the maximum extinction angle, Z∧c is 13°.

Among the accessory minerals the iron oxides are ubiquitous and occur interstitially. Calcite, epidote, clinozoisite, and quartz occur mainly where there has been substantial growth of hornblende; the calcite is disseminated and interstitial and is associated with subhedral epidote grains up to 0.3 mm. across; clinozoisite needles are common in plagioclase grains; quartz generally occurs as segregations or veinlets in which it has a good polygonal texture with grains up to 0.5 mm. across. Sphene is found locally in interstitial aggregates. Where chlorite has taken the place of hornblende, it is pleochroic from colourless to pale green and has dark blue anomalous interference colours.

In some of the basic tuffs and calc-silicate beds quartz constitutes up to 30 per cent of the rock forming a granoblastic polygonal matrix. Biotite, where it occurs, is pleochroic from straw yellow to dark brown, and the grains are generally less than 1 mm. across.

Graphitic Schist

Lithology. The principal non-volcanic lithology in the Isle Galet Formation is graphitic schist. At the base of the formation a graphitic schist member extends from the east of the area south of Little River to Lampidoes Passage in the west. Around Barasway de Cerf and Simmond's Barasway this schist gives way southwards to coarser sediments interbedded with volcanic rocks. In the west, coarser sediments are rare.

The graphitic schist is generally metamorphosed to garnet grade, where it occurs on Bois Island and along strike. It is a fine grained graphite-gray rock with locally occurring silty beds up to 5 mm. thick; these may be graded. The principal schistosity surface which may be S1 or S2 has a graphitic sheen. The schist is everywhere very limonitic and in freshly broken specimens the limonite can be seen to be derived from pyritic coatings on schistosity surfaces. Along the south coast of Bois Island around Snook's Harbour a local MP2 metamorphic peak has caused the growth of staurolite porphyroblasts; in this area the graphite content is less and the rock grades into a light coloured muscovite schist. In general the graphitic schist has behaved incompetently during deformation and has been folded into complex F2 and F3 folds; no F1 folds have been recognized.

On the south side of Bay d'Espoir, the graphitic schist is subordinate to more competent volcanic rocks. Movement during the second deformation in this area has been concentrated in the schist which has become tectonically disrupted. It consists of a mass of lensoid fragments, about 10 cm. across and 1 cm. thick, separated by anastomosing D2 shear surfaces. It commonly includes numerous quartz segregations which may be dismembered F2 fold cores. In some places it incorporates slices of the surrounding rocks and is a mélange; the most notable instances of this are southwest of Raymond Point where it contains amphibolite (Pl. 69), and along the Day Cove Thrust where lenticles of reconstituted basement are included. Bedding and S1 are nowhere traceable for more than a few metres and in most places bedding is completely unrecognizable; traces of S1 may be preserved within the lenses of schist formed during the second deformation.

Fabric. In the lower part of the Isle Galet Formation, the principal fabric in the graphitic schist is locally S1. Everywhere it has been crinkled and folded during the second deformation and commonly a differentiated crenulation schistosity, S2, is developed; in many places there has been complete transposition of the first fabric.

S1 is a penetrative schistosity subparallel to bedding defined by a preferred orientation of muscovite with local biotite; graphite and pyrite form coatings on the schistosity surfaces. In a few places quartz grains are elongated parallel to the fabric but generally they have a polygonal texture.

The S1 fabric is overgrown by porphyroblasts of garnet, chlorite, and locally biotite, all of which contain inclusion trails of quartz and graphite. Across most of the area growth was static (MP1) and the inclusion trails are straight. At Simmond's Barasway however garnet growth continued during the second deformation (MS2) and the trails are curved. Some of the trails are S-shaped with an apparent rotation of less than 180° and more generally in the order of 30° to 60°; other trails indicate no rotation of the porphyroblasts relative to S1, but preserve instead the progressive developments of D2 augen. In the inlier of graphitic schist close to the North Bay Granite at Pomley Cove aggregates of muscovite possibly formed by alteration of sillimanite have augen formed around them by S2.

The second fabric, S2, has generally formed by crenulation of S1. In a few places the crenulations are open with only slight segregation of micas and pyrite on the limbs and along microfaults. In most places however they are tight and the S1 fabric has been completely transposed to form a composite S2 fabric with muscovite and quartz bands several millimetres across.

In Snook's Harbour and for a mile westwards along the southern shore of Bois Island, the graphitic schist has been metamorphosed to staurolite grade. Although the garnet porphyroblasts within the rock have straight inclusion trails of S1 and augen are formed around them by S2 (Pl. 73), the staurolite overgrows S2 and F2 microfolds (Pl. 74). This is the only known occurrence of MP2 porphyroblast growth in the Baie d'Espoir Group. In the same rock biotite has overgrown S1 and has augen formed around it by S2 (Pl. 75); the slightly curved inclusion trails indicate that growth continued during the early part of the second deformation.

The graphitic schist on the southern shore of Bay d'Espoir has suffered much more intense deformation that that to the north. The irregular lenses of schist into which the rock has been sliced are coated with graphite and a banded S2 fabric is developed within them. S1 has survived as coatings on quartz segregations and in a few places in the quartz-rich parts of the D2 banded fabric. Porphyroblasts of garnet, where present, have augen formed around them by the banded fabric but none were observed with an included fabric. A phyllitic lineation parallel to the main F2 fold axes is commonly present on the surfaces of schist fragments.

<u>Petrography</u>. The graphitic schist is semipelitic in

composition, generally containing muscovite (40 to 50 per cent), quartz (30 to 40 per cent) with accessory biotite, calcite, and siderite; pyrite, altering to limonite, and graphite give it its rusty, black colour; garnet, staurolite, and chlorite occur as porphyroblasts.

Muscovite occurs as fine grained flakes less than 0.1 mm. across where it defines S1. In rocks where there is a banded S2 fabric, it is generally coarser grained, and at Snook's Harbour where the metamorphic grade was relatively high, the flakes are up to 2 mm. across. Muscovite also occurs in knots, possibly replacing sillimanite in the schist close to the North Bay Granite; the knots have augen formed around them by S2. Where staurolite is present, it is partially altered to sericite.

Quartz on the north side of Bay d'Espoir is generally unstrained and has a polygonal texture with straight grain boundaries; the grain size varies from 0.1 mm. in the less metamorphosed rocks to over 1 mm. at Snook's Harbour. On the south side of the bay, in the more deformed schist, the quartz has ribbon structure and the grain boundaries are sutured; the grain size varies from less than 0.1 mm. to 5 mm. in the area of one thin section.

Graphite and pyrite occur interstitially, generally as coatings on mica flakes, and as inclusions in porphyroblasts.

Garnet porphyroblasts, whether static or syntectonic, may be idioblastic (grain size between 0.5 and 1 mm.) or poikiloblastic (up to 3 mm. across); the poikiloblasts generally have a tabular form parallel to S1. Chlorite porphyroblasts occur as idioblastic flakes up to 2 mm. across and have commonly been kinked during D2; the chlorite is pleochroic from colourless to pale green and has anomalous blue interference colours. The MP2 staurolite porphyroblasts occurring around Snook's Harbour are xenoblastic and contain numerous quartz inclusions; many grains have grown mimetically on the S2 schistosity and may be up to 5 mm. across; the staurolite is pleochroic from colourless (X, Y) to straw yellow (Z), and many of the grains are altered to sericite. (Appendix 3).

Semipelitic Chlorite Schist

Schist of the same lithology as occurs in the Riches Island Formation crops out locally in the Isle Galet Formation. The most important occurrences are at Simmond's Barasway and along the southeast shore of Bois Island. For a description of this rock, the reader is referred back to the description of the Riches Island Formation. It should be noted however that the schist occurring at Simmond's Barasway differs from that elsewhere in that the garnet porphyroblasts it contains have curved S-shaped inclusions trails (Pls. 76, 77) and augen that developed progressively during growth (Pl. 78). The garnet therefore grew syntectonically during the second deformation. The amount of apparent rotation is less than 180° and generally about 60°.

Metagraywackes

Lithology. Metagraywacke occurs around Barasway de Cerf in association with amphibolite, acid crystal tuff, and graphitic schist. In places it is gradational with micaceous crystal tuff. It occurs in beds 1 to 5 cm. thick separated by shale partings less than 1 cm. thick. Small scale cross bedding is common, although in some places this is absent and the beds may be graded.

Generally the clasts are sand size quartz and feldspar, but on the promontory on the west side of Barasway de Cerf the rock is very poorly sorted and contains isolated pebbles of quartz, biotite gneiss, and tonalite up to 5 cm. across (Pl. 79).

Fabric. An S2 fabric is developed in the matrix of the metagraywacke and is defined by inequidimensional quartz and minor mica and chlorite. It forms augen around the clasts which may be flattened and slightly elongated parallel to the F2 fold axes.

The S1 fabric is preserved as straight inclusion trails of quartz within very rare MP1 dendritic garnet grains; it makes a small angle with S2. The S2 fabric is slightly discordant with the bedding.

Petrography. In most places about 40 per cent of the metagraywacke is matrix with a grain size of 0.1 mm. or less, and the remainder is clasts between 0.5 and 1 mm. across. Where the rock contains pebbles, these range up to 5 cm. across but do not form more than 10 per cent of the rock.

The matrix is composed of quartz (60 to 90 per cent), feldspar, mostly plagioclase (up to 30 per cent), and mica and chlorite (10 per cent). The quartz and feldspar grains may have a polygonal texture but are more generally elongated with embayed grain boundaries.

The sand size clasts are quartz (80 per cent) and plagioclase (20 per cent). The quartz grains have generally been broken down into polygonal aggregates with straight grain boundaries and undulose extinction. The plagioclase grains have not been polygonized but are partially sericitized; many of them have polysynthetic twinning; their compositions range from An20 to An35 (X∧010=0° to 17°).

In general the pebbles are subrounded and are composed of polygonized quartz. Just northwest of Barasway de Cerf, however, angular to subangular pebbles of gneiss and tonalite occur. The gneiss is composed of quartz (40 per cent), plagioclase (40 per cent), biotite (15 per cent), and accessory zircon, apatite, sphene, epidote, sericite, and opaque minerals; the plagioclase is untwinned and has a composition of about An20 (refractive index); the gneiss has a banded fabric defined by biotite and quartz segregations. The tonalite is composed of quartz (40 per cent), plagioclase (40 per cent) with minor biotite, zircon, sericite, epidote, and opaque minerals; the plagioclase is partially sericitized, may have polysynthetic twinning, and has a composition of An30 (X∧010); both the quartz and the plagioclase occur as subhedral grains and there is no tectonic fabric.

THE ROTI STEADY FORMATION

The name, Roti Steady Formation, is proposed for the rocks that crop out to the northwest of the St. Alban's Formation, and to the east of the North Bay Granite and its migmatitic contact zone. The formation only occurs inland and exposure is fair to poor. It consists principally of semipelitic biotite schist and graphitic schist in approximately equal proportions; hornblende schist occurs in a few places. Garnet and staurolite are present in the biotite schist and contain inclusion trails of the S1 schistosity; they have augen formed around them by the S2 schistosity.

A few pegmatite and aplite veins of garnetiferous leucocratic granite intrude the Roti Steady Formation but the contact with the North Bay Granite is abrupt and faulted; the fault is probably a gently southeast dipping thrust, in keeping with the general structure of the area. The contact with the St. Alban's Formation is also abrupt and a thrust fault, probably dipping eastwards, is proposed for this.

Semipelitic Biotite Schist

Lithology. The schist is pale green, garnetiferous, and fine grained with little bedding and no sedimentary structures preserved. A few slightly silty beds are present but they rarely exceed 5 cm. in thickness; no grading was observed.

Fabric. S1 is preserved as straight inclusion trails of quartz and graphite in garnet porphyroblasts, but otherwise the first fabric has been completely transposed during the second deformation; the inclusion trails commonly make an angle of up to 70° with S2.

Garnet and staurolite porphyroblasts have grown during the MP1 metamorphism and augen are formed around them by S2. Muscovite and biotite define S2 which is an unbanded penetrative schistosity in a granoblastic quartz matrix.

S2 has been crenulated by F3 folds and there has been minor recrystallization of muscovite.

Petrography. The schist contains quartz (30 per cent), muscovite (30 per cent), biotite (20 per cent), garnet (10 per cent), and accessory staurolite and opaque minerals. The silty beds contain up to 50 per cent quartz.

The quartz forming the matrix is polygonal with curved to straight grain boundaries; it is rarely more than 0.1 mm. across in the schist but may be up to 0.5 mm. in the silty beds.

Biotite has a grain size of 0.2 mm. and either defines S2 or has no preferred orientation; the unoriented grains may be kinked and have augen formed around them by the fabric. It is pleochroic from colourless (X) to dark reddish brown (Y, Z) and has many pleochroic haloes.

Muscovite defines the S2 fabric and the grain size is 0.2 mm. In places it occurs in circular patches 1 mm. across with quartz but no other minerals; S2 is continuous through the patches.

Garnet and staurolite porphyroblasts are idioblastic. The garnet grains are up to 1 mm. across; they contain S1 inclusion trails but have clear outer rims. The staurolite prisms are up to 2 mm. long and have few inclusions; they are pleochroic from colourless (X) to straw yellow (Z).

Graphitic Schist

Lithology. Graphitic schist forms about half of the exposure in the Roti Steady Formation, but was nowhere observed in contact with the biotite schist. It is black, pyritic, medium grained and thinly bedded; it weathers to a rusty brown colour.

Fabric. The S1 fabric is preserved as straight graphite inclusion trails in MP1 biotite, but is otherwise completely transposed by the second deformation. The biotite is kinked and has augen formed around it by S2, which is defined by muscovite, graphite, and pyrite; it is an unbanded penetrative schistosity.

Petrography. The graphitic schist consists of quartz (40 per cent), biotite (20 per cent), muscovite (20 per cent), with accessory graphite, pyrite, and apatite.

The quartz forms a granoblastic matrix with a grain size of about 0.1 mm. The grains are equidimensional and have curved to straight grain boundaries.

Biotite has grown statically and occurs as randomly oriented xenoblastic grains up to 1 mm. across. It is pleochroic from colourless (X) to reddish brown (Y, Z) and has many pleochroic haloes.

Muscovite defines the S2 fabric, the flakes are generally about 1 mm. across.

Hornblende Schist

Lithology. Bands of hornblende schist up to 30 cm. thick occur concordantly within the graphitic schist. They are not bedded but they show no evidence of an igneous origin. The rock is gray and fine grained with scattered porphyroblasts of hornblende.

Fabric. The fabric in the hornblende schist is parallel to S2 in the graphitic schist. It is defined by cataclastic zones of fine grained feldspar and quartz in the matrix, and by scattered grains of acicular hornblende. The hornblende porphyroblasts are broken or bent where they are crossed by the cataclastic zones, and augen are formed around them by the D2 hornblende needles.

Petrography. The hornblende schist contains plagioclase (40 per cent), hornblende (20 per cent), quartz (20 per cent), biotite (10 per cent) and accessory sphene, epidote, and opaque minerals.

Plagioclase and quartz form a granoblastic matrix. The grain size is less than 0.1 mm. in the cataclastic zones where the grains are inequidimensional; elsewhere polygonal grains with straight grain boundaries are up to 0.3 mm. across. The plagioclase is untwinned; it has an approximate composition of An25 (refractive index).

Hornblende occurs as unoriented prismatic grains up to 2 mm. long and as finer needles 0.5 mm. long parallel to S2. Its pleochroic scheme is X: colourless, Y: light green, and Z: olive green; the extinction angle Z$\wedge$c is 18°. There is minor alteration to reddish brown biotite.

SEDIMENTARY FACIES

St. Alban's Formation

The principal lithology in this formation is interbedded brown calcareous siltstone and dark gray pelite. It has already been described in terms of Bouma's ideal turbidite sequence. The common occurrence of base cut-out sequences indicates that it belongs to the distal facies described by Walker (1967, 1970).

The beds of quartz-muscovite phyllite which are interbedded with the siltstone and pelite do not appear to have any genetic relationship with the turbidites. They are recrystallized and retain no original textures; however their composition and their occurrence as thin but persistent beds suggest that they may be fine grained acid tuffs.

Riches Island Formation

The principal lithologies of this formation are garnetiferous chlorite schist, psammite and mica schist, and graphitic quartzite. On the east side of Bay d'Espoir there is a gradation with increasing metamorphic grade from the siltstone and pelite of the St. Alban's Formation to the garnetiferous chlorite schist of the Riches Island Formation. It is therefore suggested that this lithology is metamorphosed flysch; since the rock is fine grained and the quartz-garnet beds, representing the coarser fraction, are subordinate to the schist, it is likely that the flysch is of the same distal type as that forming the St. Alban's Formation.

The psammites and mica schists, which occur around Roti Bay in the middle part of the formation, do not show any of the typical features of turbidites such as graded bedding or Bouma sequences. They may be comparable with the massive sandstone beds that are included in many turbidite deposits and have been variously described as fluxoturbidites, grain-flow deposits, or channel fills (Dzulynski, Ksiazkiewicz, and Kuenen, 1959; Stauffer, 1967; Piper and Normark, 1971; Moore, 1973). This comparison can only be tentative since the more specific features of this type of sediment, for instance dish structure and characteristic sole marks, have not been recognized.

The fine grained graphitic quartzites grading locally into graphitic amphibolites and schists have been derived from carbonaceous sands and shales; the amphibole-rich rocks are presumed to have been calcareous. The high content of carbon indicates deposition under stagnant, anaerobic conditions during interruptions in turbidite sedimentation (Pettijohn, 1957). Whether the lack of water circulation was due to great depths or to bathymetric restrictions is uncertain. The occurrence of most of the graphitic rocks at the top of the Riches Island Formation and in the Isle Galet Formation suggests that volcanism may have created local semi-isolated basins suitable for their deposition.

Isle Galet Formation

This formation is dominated by volcanic rocks, consisting of amphibolites, acid crystal tuffs, and possibly quartz porphyries. Associated with these are graphitic schists which occur principally on Bois Island and to the west, and metagraywackes which are restricted to the area around Barasway de Cerf. Garnetiferous chlorite schist of the type already interpreted as metamorphosed distal flysch forms a small outcrop north of Simmond's Barasway, and a quartz-rich marble occurs on Bois Island interbedded with volcanic rocks and graphitic schist. The thickness of the Isle Galet Formation increases from about 1700 m. in the east to about 3000 m. at the west end of Bois Island; much of the increase is in the graphitic schists in the lower part of the formation.

As has already been mentioned the state of deformation in the acid volcanic rocks makes it difficult to distinguish between tuff, lava, and hypabyssal intrusion. It has however been suggested above that the majority of the rocks, if not all, are tuffs; this origin is indicated by the lapilli tuff lenses that occur in the quartzo-feldspathic rock, by the crude bedding and the composition of the more micaceous bands, by primary fracturing of crystals where deformation was slight, and by the lack of flow banding or intrusive features.

The tuffs are interbedded with graphitic schists and meta-graywackes, and have not been eroded to form clasts in these rocks. A similar association was noted by Kinkel (1962, 1966) and Schermerhorn (1970) in the volcanic rocks of the Iberian Pyrite Belt, and was considered to indicate submarine extrusion. The lithology of the Bay d'Espoir tuffs also suggests a subaqueous origin; they consist of evenly distributed crystals in a fine grained matrix with restricted occurrences of lapilli and no observed accidental lithic fragments. Similar rocks have been described by Fiske (1963) from the Ohanapecosh Formation, Washington, and by Fiske and Matsuda (1964) from the Takiwa Formation, Japan. They attribute the fine grain size to shattering of lithic fragments and crystals by sudden quenching in water. The tuffs they describe, however, contain more coarse material than those in the Baie d'Espoir Group and the Iberian Pyrite Belt, and they also differ in having good turbidite-type grading in some of the members. Schermerhorn invokes mass-flow of the type described by Stauffer (1967) to explain the lack of grading and this explanation may be applicable to the tuffs of the Isle Galet Formation.

The sheets of amphibolite that occur with the acid volcanics and associated sediments may be either intrusive or extrusive. If extrusive, they show no definite evidence of either submarine or subaerial eruption. The associated basic tuffs are interbedded with graphitic and chloritic schists and are presumed to have been deposited in water.

The principal metasediments in the Isle Galet Formation are the graphitic schists, which have already been ascribed to deposition in a restricted environment, possibly caused by the formation of submarine volcanoes. Eastwards they grade into medium grained and coarse metagraywackes which may be cross-bedded or graded. The grain size, composition, and sedimentary structures vary rapidly both laterally and vertically and Bouma's turbidite sequences are generally not recognizable. Where the rock is pebbly, the pebbles are variously rounded or angular and generally consist of vein quartz, granite and gneiss; clasts of a volcanic origin are noticeably lacking except where the metagraywacke grades into micaceous crystal tuff. The deposits correspond with the pebbly and conglomeratic flysch facies of Walker (1970) and are of a much more proximal nature than the other flysch deposits of the Baie d'Espoir Group. The nature of the clasts indicates a source area consisting of granite and gneiss, and the lack of volcanic debris implies that the volcanic centres, at least locally, were not raised above sea level and so subject to erosion.

Roti Steady Formation

This formation consists of graphitic schist and fine grained biotite schist with thin siltstone beds. The biotite schist is similar in general appearance to some of the rocks interpreted as distal turbidites in the Riches Island Formation, and this origin is tentatively proposed for it. The graphitic schist which forms about half of the formation is considered to have been deposited in an euxinic environment.

Conclusions

The Baie d'Espoir Group was deposited in two principal environments. The St. Alban's, Riches Island, and Roti Steady Formations consist mainly of fine-grained distal flysch and carbonaceous euxinic deposits. The Isle Galet Formation is the product of submarine volcanism, with associated deposition of carbonaceous sediments and proximal flysch; the clastic rocks appear to have been derived from a nearby granitic and gneissic terrane.

The local stratigraphic order which has been derived at formation contacts indicates that the volcanic rocks lie above the distal turbidites. It is evident however from the lack of feeder dykes in the flysch that the principal facies variation was lateral and not vertical. It is possible that the suspected fine grained tuff beds in the St. Alban's Formation are a distal expression of subaerial volcanism related to the submarine volcanic rocks described from the Isle Galet Formation.

METAMORPHIC HISTORY

The metamorphic history of the Baie d'Espoir Group is summarized in Figs. 7 and 8.

MS1

Syntectonic metamorphism during the first deformation caused the growth of platy minerals and the recrystallization of quartz and plagioclase to form the first fabric.

In the St. Alban's Formation S1 was initially formed during dewatering in the early stages of the deformation. It was accentuated by subsequent metamorphic growth of muscovite and locally biotite in the pelitic rocks. The S1 fabric in the other formations is defined by muscovite, chlorite, biotite, and inequidimensional quartz and feldspar; hornblende may have grown in some of the amphibolites. The grade of metamorphism was higher than in the St. Alban's Formation, and the intense deformation of the rocks has destroyed any evidence there may have been of an early stage of dewatering.

MP1

In most of the Baie d'Espoir Group the minerals that grew statically after the first deformation and before the second indicate that the metamorphism reached its peak at this time. The exceptions are at Simmond's Barasway and east of Rocky Hill where the peak appears to have coincided with the second deformation, and around Snook's Harbour where a probable MP1 peak was followed by higher grade MP2 metamorphism.

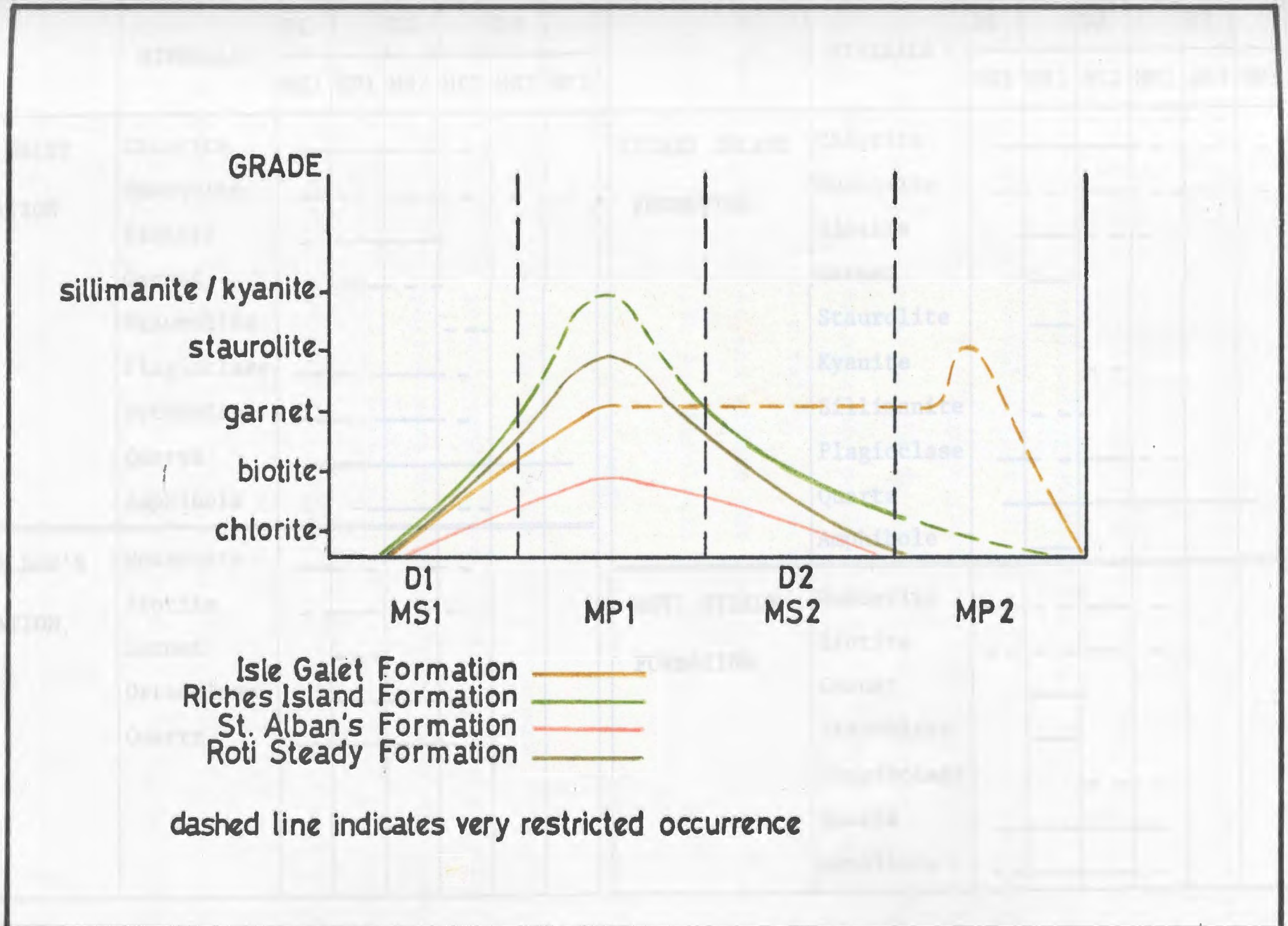


Fig.7. Variations of maximum metamorphic grade with time in the Baie d'Espoir Group.

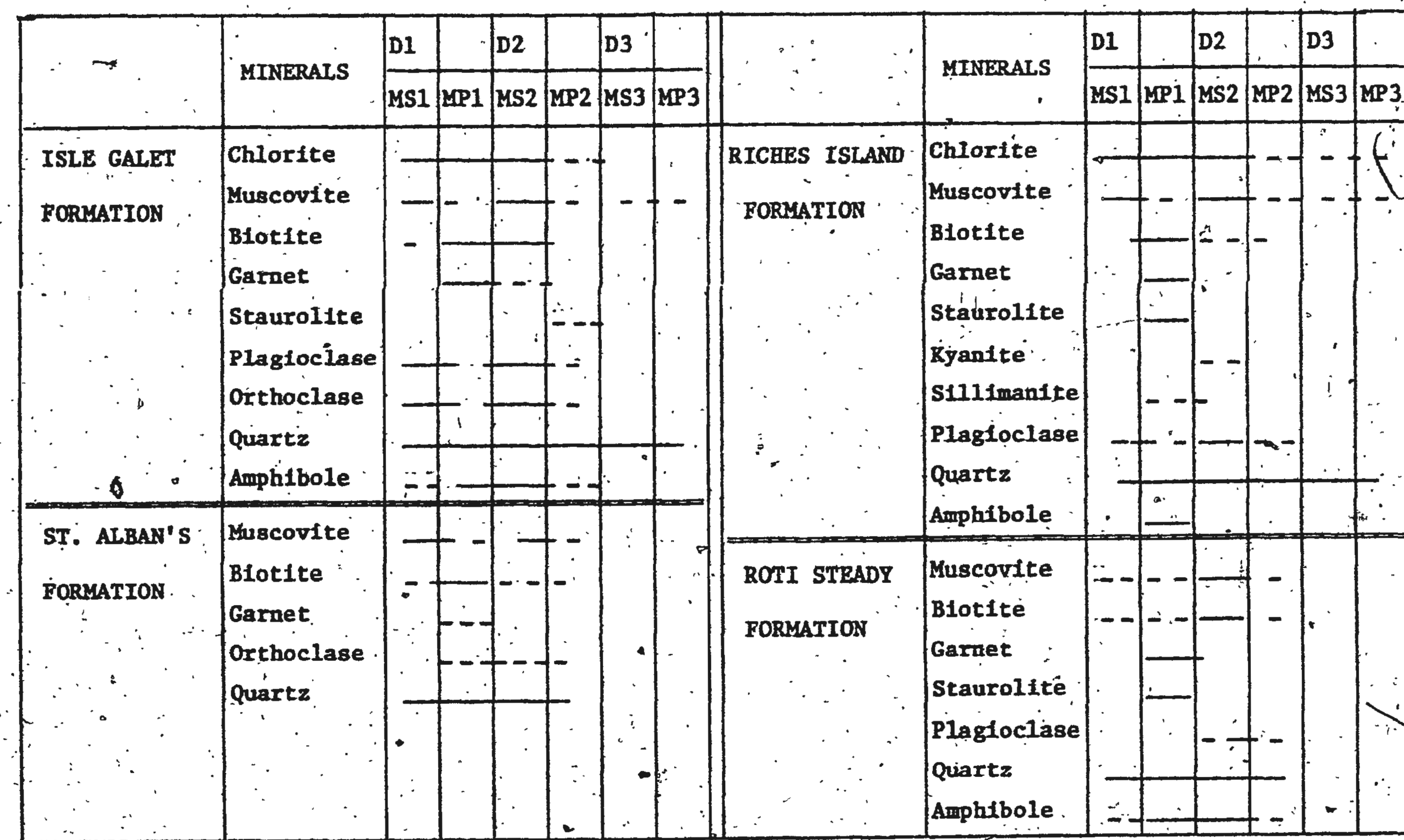


Fig. 8. The growth history of metamorphic minerals in the Baie d'Espoir Group.

- dashed lines indicate very restricted occurrence.

The MP1 metamorphism in the St. Alban's Formation is represented by static biotite growth in the pelites and siltstones. In most of the Riches Island and Isle Galet Formations garnet and chlorite porphyroblasts with straight inclusion trails of S1 grew in the semipelitic schists. Most of the hornblende growth and the destruction of the igneous textures in the amphibolites of the Isle Galet Formation also took place at this time. The higher grades of metamorphism have a marked spatial relationship to the North Bay Granite whose intrusion coincided with the MP1 metamorphic peak. Within 2 to 3 km. of the contact, staurolite with straight S1 inclusion trails overgrows garnet in the semipelitic schist and within the contact zone itself there has been alteration of biotite to fibrolitic sillimanite.

MS2

In the semipelitic and graphitic schists around Simmond's Barasway the principal garnet growth took place during the second deformation and the porphyroblasts contain S-shaped inclusion trails or developing augen. East of Rocky Hill in schists that are probably part of the Riches Island Formation, there has been syntectonic growth of kyanite parallel to S2. In all the other rocks of the Baie d'Espoir Group, MS2 mineral growth was restricted to recrystallization of biotite, muscovite, chlorite, quartz and feldspar; in most of the St. Alban's Formation the metamorphic grade was only sufficient for the recrystallization of muscovite and bent unrecrystallized flakes of biotite still survive.

MP2

Generally MP2 mineral growth was restricted to polygonization and annealing. Around Snook's Harbour, however, a local metamorphic peak in the Isle Galet Formation caused the growth of staurolite porphyroblasts in graphitic muscovite schist; they overgrow MP1 garnet and F2 folds.(Appendix 3).

Later Mineral Growth

Recrystallization of chlorite, muscovite, and quartz has taken place locally in the semipelitic and graphitic schists of the Riches Island and Isle Galet Formations where F3 folding occurs. Retrogressive metamorphism principally affects staurolite, which has been altered to sericite, especially around Snook's Harbour. There has also been minor alteration of garnet and biotite to chlorite.

Facies and Facies Series

The mineralogy of the metamorphic rocks forming the Baie d'Espoir Group is roughly comparable to that described from the Scottish Highlands by Barrow (1893, 1912) and subsequently by many other authors. The full succession of Barrow's zones is seen in the Bay d'Espoir area, although kyanite is of very restricted occurrence and has grown later than most of the other metamorphic minerals, whilst staurolite is the common index mineral occurring between the garnet and sillimanite zones. Sillimanite growth in the highest grade rocks only reached the early stage of fibrolite formation from biotite (Chinner, 1961), and the breakdown of staurolite did not occur. The peak metamorphic grade varies from the greenschist facies to the upper amphibolite facies. The rarity of kyanite may indicate a slightly lower pressure facies series than the kyanite-sillimanite series of Miyashiro (1961) which was based on the Dalradian metamorphic rocks of Barrow.

CHAPTER 5

STRUCTURAL GEOLOGY

GENERAL STATEMENT

The Bay d'Espoir area has two principal tectonic components:

1. The basement rocks of the Little Passage Gneisses and the Gaultois Granite.
2. The cover rocks of the Baie d'Espoir Group, intruded synorogenically by the North Bay Granite.

The Little Passage Gneisses underwent a complex history of deformation before the intrusion of the Gaultois Granite and the deformations affecting the Baie d'Espoir Group. This history included at least two periods of gneiss formation separated by the intrusion of a tonalitic pluton. Only a few remnants of the early formed gneisses remain, occurring as sheets and xenoliths in the tonalite. The second period of gneiss formation was one of inhomogeneous strain and caused localized zones of intense deformation.

The main structure in the Baie d'Espoir Group is a major southeast facing recumbent anticline, the Bay d'Espoir Nappe, which was formed during the second of two regionally penetrative deformations (see Map 2 and sections). The lower limb of the fold lies in contact with the Little Passage Gneisses along the Day Cove Thrust. The gneisses in the Stickland Cove Zone, extending 3 km. south of the thrust, have been deformed and partially reconstituted during the deformations of the Baie d'Espoir Group. The Bay d'Espoir Nappe is divided into two parts by the Big Rattling Brook Thrust. The lower part which includes the Riches Island and Isle Galet Formations has an autochthonous root around the southeastern edge of the North Bay Granite. The upper part consisting of the St. Alban's and Roti Steady Formations forms a thrust ~~sheet transported above the granite.~~ Away from the North Bay Granite, which appears to have acted as a rigid block interfering with the formation of the nappe, the Big Rattling Brook Thrust loses its significance.

There is a general parallelism of structures of all ages in the Bay d'Espoir area. This regional trend has a southwesterly strike in the east of the area and curves around to a westerly strike in the west (see Map 1); the amount of curvature differs in structures of different ages, but does not vary systematically with time. The outcrop pattern formed by the change of strike was named the Hermitage Flexure by Williams, Kennedy, and Neale (1970).

The structural geology of Bay d'Espoir is described in three sections:

1. Pre-Baie d'Espoir Group structures in the Little Passage Gneisses.
2. Baie d'Espoir Group structures in the Little Passage Gneisses and associated granitic rocks.
3. Structures formed in the Baie d'Espoir Group and at the margins of the North Bay Granite.

PRE-BAIE D'ESPOIR GROUP STRUCTURES

The structures formed in the Little Passage Gneisses before the intrusion of the Gaultois Granite and the deformation of the Baie d'Espoir

Group can be examined in the rocks of the Seal Cove Zone in the southern half of Little Passage.

Amphibolitic and Psammitic Gneisses

These gneisses occur as sheets and xenoliths in the tonalite and tonalitic gneiss, and they represent an early period of gneiss formation. The general strike of the foliation and of the outcrops is parallel to the foliation in the enclosing tonalitic rocks; whether this is an original orientation or has been caused by later deformation is unknown.

The rocks have a fine banding with isoclinal intrafolial folds up to 2 cm. across. The axes of the folds generally have a steep plunge, but this may be a false impression since most outcrops are flat and horizontal axes are difficult to recognize. The principal schistosity is axial planar to the folds and parallel to the axes of the intrafolial folds.

The gneissic banding and the principal schistosity are folded by tight similar type folds with vertical axial planes parallel to the regional strike and near vertical axes (Pl. 2); the folds have a wave-length of up to 5 m. A schistosity is developed in the cores of the folds and cuts across the banding.

Tonalite and Tonalitic Gneiss

Tonalitic rocks derived from an igneous pluton form the greater part of the Little Passage Gneisses. Tonalite veins cut across the late similar type folds in the amphibolitic and psammitic gneisses, and xenoliths of amphibolitic gneiss occur throughout the main body of the pluton. The deformation was inhomogeneous causing the formation of less deformed blocks separated by belts of banded gneiss. Locally there has been evidence of post-deformation remelting.

The least deformed tonalite has a good foliation but there is no metamorphic differentiation and the rock retains some igneous textures; the foliation is vertical. The xenoliths of amphibolitic gneiss which the rock contains have a pre-existing gneissic banding (Pl. 6). They have a dimensional preferred orientation in the plane of the foliation and their banding is tightly folded around axial planes parallel to the foliation. The fold axes have no preferred plunge and there are no infolds of tonalite, so the age of the folding is uncertain; Kennedy and McGonigal (1972) report similar xenoliths from the granitic gneiss around Gander Lake in which tight folds have axial planes at an angle to the surrounding foliation.

An isoclinally folded gneissic banding (Pl. 9), which pre-dated the Gaultois Granite, is present in the tonalitic rocks in several parts of Little Passage. It is vertical and strikes parallel to the foliation in the less deformed tonalite; the fold axes are horizontal. The xenoliths of amphibolitic gneiss have been flattened and isoclinally folded by the deformations causing the gneissic banding, and they may contain infolds of tonalitic gneiss (Pl. 7). The larger xenoliths and some of the sheets of amphibolitic gneiss have been flattened to form basic bands in the gneiss and locally these have been boudinaged; the boudinage axes are vertical and at right angles to the fold axes.

In most places the variation from the less deformed tonalite to the gneiss takes place over distances of about 30 m. although isolated relics of relatively undeformed rock less than 1 m. across may survive within the gneissic terrane. The principal outcrop of the less deformed tonalite is in the south of the area around Seal and Grip Coves where the belts of gneiss are generally less than 100 m. across. Northwards the deformation was more widespread and north of Middle Island only gneisses are present.

Partial melting after deformation has locally masked the gneissic banding (Pl. 10). The remelted rock has only a weak schistosity, probably attributable to the deformations of the Baie d'Espoir Group. In many places biotite rich bands which may define isoclinal folds provide evidence of the earlier gneissic banding. On the headland east of Middle Island, the remelted tonalite is in intrusive contact with the gneiss; both rocks contain flattened xenoliths of amphibolitic gneiss.

BAIE D'ESPOIR GROUP STRUCTURES IN THE LITTLE PASSAGE GNEISSES AND GAULTOIS GRANITE

The Little Passage Gneisses and the Gaultois Granite have been deformed extensively by the first and second deformations of the Baie d'Espoir Group (D1 and D2) and have been affected by later minor folding and widespread faulting. The intensity of the two main deformations increased northwards towards the Day Cove Thrust at the basement-cover contact. The gneisses of the Seal Cove Zone and much of the Gaultois Granite have been only slightly affected, whilst in the Stickland Cove Zone deformation was intense and involved folding, transposition of the gneissic banding, and mylonitization. The aplite and pegmatite veins associated with the Gaultois Granite have been deformed during both deformations, but the garnetiferous leucocratic granite veins which are common in the Stickland Cove Zone and similar to the North Bay Granite, generally crosscut the first folds and are folded by the second. These granite veins form convenient markers, but have been used with caution because of the various ages of granite intrusion noted elsewhere in the Bay d'Espoir-Gander Lake belt (Kennedy and McGonigal, 1972).

D1 Structures in the Gaultois Granite and Seal Cove Zone

Throughout most of its outcrop the Gaultois Granite has a moderately developed LS-tectonite fabric which also affects the aplite and pegmatite dykes and the metadiabase dykes that cut the granite. The foliation is vertical or steeply north dipping, and the lineation is horizontal trending parallel to the regional strike. The fabric clearly post-dates the gneissic banding since it occurs in rocks that cross-cut this banding. It is associated with the F1 folds in the Stickland Cove Zone, and at Sam Hitches Harbour Gaultois Granite xenoliths with the pre-existing fabric are included in leucocratic granite that was subsequently deformed by the second deformation (Pl. 27).

A first deformation fabric was not recognized in the gneisses of the Seal Cove Zone and is probably inseparable from previous fabrics to which it would be subparallel. Kink bands occur locally in the tonalitic gneiss and may be attributable to D1 or a later period of deformation; they have steep dips and the angle they form with the gneissic foliation generally exceeds 60°.

D1 Structures in the Stickland Cove Zone

As far as can presently be determined the Little Passage Gneisses in the Stickland Cove Zone had a well defined banding before the first deformation of the Baie d'Espoir Group. This banding together with the intruding aplites and pegmatites of the Gaultois Granite has been folded by F1 folds with horizontally trending axes and axial planes dipping north at 60° or more. In the area around Middle Island in Little Passage the folds are open and of flexure-slip type (Pl. 12); their wavelength is generally in the order of 10 m. Northwards the folds become tighter (Pl. 14) and at Stickland Cove they are commonly isoclinal and of similar type; an axial planar schistosity is developed. The Seal Nest Cove Tonalite formed a rigid block in the area of tight to isoclinal folds in Little Passage. It has a slight S1 fabric and has been extensively fractured; the fracturing post-dates the fabric and may be of late D1 or D2 age.

North of Maria Cove Point the effects of the first deformation have been masked by D2 structures. F1 fold closures are rare and the first fabric is generally only seen in F2 fold closures, in MP1 plagioclase porphyroblasts (Pls. 18, 19), and in xenoliths in the leucocratic granite that have been sheltered from D2. Although the rocks appear from their similar composition and gradational contact to have been derived from the banded gneisses of the Seal Cove Zone, they are largely unbanded and much finer grained. It is probable that they were reduced to mylonite-schists or even true mylonites during D1 (Higgins, 1971) and that MP1 mineral growth has obscured much of the cataclastic texture. The metadiabase dykes that occur in the Stickland Cove Zone just to the south of the Day Cove Thrust do not appear to have suffered the same degree of cataclastic breakdown as the gneisses; there was significant syntectonic growth of hornblende during both D1 and D2 even in the most deformed areas (Pl. 29). A similar resistance by amphibolites to cataclastic breakdown was noted by Johnson (1961) and Higgins (1971).

D2 Structures in the Stickland Cove Zone

The most prominent structures in the Stickland Cove Zone were formed during the second deformation. Except locally west of Bay d'Espoir and between Blunder and Wreck Coves on Long Island, D2 structures were not observed in the main body of the Gaultois Granite or in the gneisses of the Seal Cove Zone.

The F2 folding of the gneissic banding and leucocratic granite veins shows a progressive development northwards. At Maria Cove Point in Little Passage, the folds are of flexural slip type; they form crenulations a few centimetres across or larger open folds up to 10 m. in wavelength. The fold axes are approximately horizontal and the axial planes dip steeply to the north. At Deer Cove the folds are close to tight (Pl. 22) and at the back of the cove a large asymmetric syncline 40 m. across is visible in the cliff. An axial planar schistosity is present in this area and there is a mineral growth lineation parallel to the fold axes. Further north at Day Cove the folds are isoclinal.

Cataclastic rocks (Pl. 20) have been formed during the second deformation in a zone varying from 50 to 500 m. wide just to the south of the Day Cove Thrust. The zone runs along the north coast of Long Island and extends eastwards to Dolland Bight. In most of the rocks there was significant syntectonic mineral growth and they belong to the mylonite-schist and blastomylonite categories of Higgins (1971). True mylonites are rare, occurring within 50 m. of the Day Cove Thrust at a few localities on the north coast of Long Island, and in exposures at Day Cove and north of Dolland Bight. The metadiabase dykes and leucocratic granite veins within the cataclastic zone have been less affected than the gneisses and the D1 cataclastic rocks. The amphibolites recrystallized with the growth of hornblende defining the second fabric; the granite veins have suffered some breakdown, in several places becoming protomylonites, and at Day Cove becoming involved with the gneisses in the formation of a true mylonite.

The D2 fabric in the Stickland Cove Zone is of the LS type with the lineation (Pl. 37) parallel to the F2 fold axes. Along parts of the north coast of Long Island there is a decrease in the relative importance of the schistosity with respect to the lineation, indicating a change in k-value (Flinn, 1962) similar to the changes noted by Johnson (1967) in the Moine thrust zone; unfortunately there are no strain indicators in the rocks suitable for a precise measurement. The increase in the importance of the lineation is associated with more pronounced rodding and rolling of leucocratic granite veins (Wilson, 1953).

All the F2 folds within the zone of cataclastic rocks are isoclinal. They are generally defined by leucocratic pegmatite veins which are intensely flattened parallel to S2 (Pl. 36) and only show a crosscutting relationship on the hinges (Pl. 35). Intrafolial folds of a pre-existing banding, possibly a D1 mylonitic banding were observed west of Patrick's Harbour on Long Island; the hinges of the folds are up to 3 cm. across and the limbs are extremely attenuated or non-existent (Pl. 21).

D2 boudins have formed in some of the granite veins north of Dolland Bight, but otherwise they are rare. The boudinage axes are normal to the fold axes.

D2 Structures in the Gaultois Granite

The Gaultois Granite between Wreck and Blunder Coves has suffered more intense deformation than elsewhere on Long Island. A strong LS-fabric is developed and there are bands of protomylonite up to 1 m. thick parallel to it. The fabric overprints S1 and has the same attitude as the D2 structures in the Stickland Cove Zone to the north.

The geology was not closely studied to the west of Bay d'Espoir but one feature of the second deformation in the Gaultois Granite is worthy of note. Along the length of the deep inlet northwest of Muddy Hole, and probably causing its preferential erosion, is a zone of cataclasis. The Gaultois Granite has been broken down to form a protomylonite and locally a mylonite; it has a horizontal lineation and a well developed north dipping foliation, which cuts across the D1 fabric. The zone has a similar attitude and style of deformation to the rocks immediately below the Day Cove Thrust. It differs however in being separated from the Baie d'Espoir Group by 3 km. of only mildly deformed granite, and thus does not mark the basement-cover contact.

Post-D2 Structures

Fold structures post-dating the second deformation were observed at only one locality in the Little Passage Gneisses, in blastomylonite about 2 km. west of Patrick's Harbour on the north coast of Long Island. They consist of open crenulations in S2 with a wavelength of up to 3 cm. and overturned towards the north. The axial planes which have no associated cleavage dip south at about 40°, and the fold axes have a sub-horizontal east-west trend. Late folds with a similar attitude are locally common in the Baie d'Espoir Group.

Faults

Thrust and strike slip faults. In the western half of Long Island a number of east-west striking thrust faults (Pl. 80) and associated north-south strike-slip faults form prominent escarpments that dominate the topography (Pl. 81). The fault planes of the thrust faults dip north at about 30° to 60° and crosscut the less steeply dipping D2 fabric and mylonitic zones. One of these faults forms the contact between the Little Passage Gneisses and the Gaultois Granite just north of Wreck Cove.

The strike-slip faults have near vertical fault planes which are exposed on the north coast of the island. They offset the second deformation structures causing displacements of up to 500 m. on the Day Cove Thrust at Harbour le Gallais. Slickensides were observed on some fault planes plunging gently towards the north.

The faults appear to be associated with extensive brittle fracturing of the Gaultois Granite between Blunder and Wreck Coves. The sense of movement on the faults is the same as that of the second deformation structures, but opposite to that of the later folds. Their timing with respect to the third phase folds is unknown and it is possible that they represent a late brittle stage of the second deformation.

The Little Bay Fault. This fault is exposed on both sides of Little Passage between Seal Nest and Grip Coves, and it forms a prominent linear feature southwestwards to Little Bay. In Little Passage it is marked by a zone of brecciation about 50 m. wide in which the gneisses and the Gaultois Granite have been broken into lensoid fragments a few centimetres across. Biotite has generally been altered to dark green chlorite which coats the shear surfaces. The rock is permeable and has been rotted by ground waters. No consistent slickenside directions were observed.

Movement took place after the intrusion of the Gaultois Granite but cannot be dated with respect to the deformations of the Baie d'Espoir Group because of the poor development of these structures in this area. The fault runs parallel to the Hermitage Bay Fault which is marked by a similar unconsolidated and chloritized breccia (J. Malpas, pers. comm. 1973); it is possible that these two structures are genetically related.

STRUCTURES IN THE BAIE D'ESPOIR GROUP

Two principal periods of deformation affected the Baie d'Espoir Group. These were followed by localized minor folding and kinking.

The First Deformation, D1

St. Alban's Formation

Folds. The rocks of the St. Alban's Formation are less deformed than any other part of the Baie d'Espoir Group and the first deformation structures are well preserved. They consist of locally developed tight to isoclinal folds up to 6 m. in wavelength with horizontal axes trending northeast. There has been thickening on the crests of the folds in the siltstones, which may show flow structures indicating that they were unconsolidated during deformation. The folds occur around Man of War Head in St. Alban's harbour (Pl. 82), and at Brant Cove and east to Morrisville. The S2 cleavage crosses the F1 folds obliquely and they are folded by F2. They are inverted by the major F2 folding so that they now face downwards to the north. There is no major F1 structure and the facing directions on S2 are consistent.

Cleavage. The S1 cleavage, which is axial planar to the folds, is subparallel to the bedding in areas where folds do not occur. As has already been described it is associated with dewatering and siltstone beds have been injected along cleavage planes (Maxwell, 1962) (Pls. 47, 48). Subsequent metamorphic growth has enhanced the fabric.

Riches Island, Isle Galet and Roti Steady Formations

Folds. Deformation and metamorphism were more intense in these formations than in the St. Alban's Formation. A few small scale F1 fold cores up to 3 cm. across have been recognized in the quartz-garnet beds of the semipelitic schist in the Riches Island Formation. They have become detached from their limbs and are oblique to S2 which forms augen around them. Near Flobber Cove a tight F1 fold in interbedded acid and basic volcanic tuff and with a wavelength of over 1 m. has been refolded by a tight F2 fold. The axis of the first fold forms a large angle with that of the second and results in a type 1 interference pattern (Ramsay, 1967).

Schistosity. In most places the first schistosity has been transposed by the second deformation. It is preserved on the hinges of F2 folds, between S2 crenulation schistosity planes, and in MP1 porphyroblasts (Pls. 51, 67, 73).

Major structure. It is not known whether the first deformation formed any major structure in these formations of the Baie d'Espoir Group. It is assumed in the description of the D2 structures that it did not. This assumption is supported by the consistency of facing directions on S2 (although bedding top determinations are not plentiful), and the lack of repetition in stratigraphic units or any symmetry of distribution which might suggest the two limbs of a major F1 fold. When the F2 folds are unfolded, bedding is uninverted.

The Second Deformation D2

St. Alban's Formation

Folds. F2 folds are predominantly of the flexural slip type with only minor thinning on the limbs in pelite beds. They are open to tight, recumbent, and face towards the south (Pls. 82, 83). The axial planes dip gently to the southeast north of St. Alban's and Conne River, and gently to the northwest further south; the axes are subhorizontal and trend northeast. The wavelength of the folds ranges from 1 m. upwards with smaller folds being parasitic on larger ones. In general the largest recumbent anticlinal folds that can be observed in the exposures along the coast have a long inverted lower limb and a short upper limb. Near the Big Rattling Brook Thrust the folds are tight to isoclinal and become similar in style with marked thinning on the limbs especially in the pelitic beds.

Cleavage. An axial planar crenulation cleavage is associated with the F2 folds throughout most of the formation (Pl. 46); it occurs in the pelite beds but does not significantly affect the siltstones. It becomes a penetrative schistosity and is subparallel to the bedding close to the Big Rattling Brook Thrust.

Major structure. The facing directions, asymmetry of the folds, and cleavage-bedding intersections imply that the rocks exposed on the present land surface form the lower limb of a major south-facing recumbent anticline and that the upper limb has been eroded (section E-F). The open nature of many of the folds and the shortness of the limbs with respect to the hinge zones results in a steep dip for the majority of the sediments in the St. Alban's Formation and a large angle between the bedding and S2; this suggests that the rocks presently exposed may be close to the hinge of the major structure. To the east of Bay d'Espoir where the Big Rattling Brook Thrust is insignificant the structure in the St. Alban's Formation is continuous with that in the Riches Island Formation. Westwards however the St. Alban's and Roti Steady Formations form the upper part of the Bay d'Espoir Nappe which cuts discordantly across the North Bay Granite and the core of the lower part of the nappe (section C-D).

Roti Steady Formation

Only a small part of the area mapped is underlain by the Roti Steady Formation and the internal structure is not well known. Open F2 crenulation folds occur with slightly northeast plunging axes; the S2 schistosity dips southeast at angles varying from 20° to 70° and the bedding dips steeply towards either the northwest or southeast. The formation is in faulted contact with the North Bay Granite in the west and the St. Alban's Formation in the east. These faults are continuous in outcrop with the Big Rattling Brook Thrust and are therefore considered to be the east dipping extensions of this fault on the west side of the thrust sheets.

Riches Island Formation

Folds. Mesoscopic F2 folds are common in the semipelitic chlorite schist extending through Bois Island and Riches Island to Little River (Pls. 50, 84); they occur further north on both sides of Bay d'Espoir to the northeast of Roti Bay; and they are responsible for the prominent grain in the country between Roti Bay and the North Bay Granite contact. The folds in the schist on Riches Island and along strike are tight or isoclinal and of similar type (Pl. 85); they are well defined by the quartzite and quartz-garnet beds. The axes are subhorizontal trending towards the northeast and the axial planes marked by the S2 schistosity dip at around 40° to the north except where there has been F3 folding (Fig. 9). The F2 folds are overturned and face upwards to the southeast; the lower limbs of the anticlines are longer than the upper limbs.

To the northeast of Roti Bay F2 folding has affected the bedded psammites (Pl. 86). The folds are close to tight and of similar type, although there is only slight thinning on the limbs in the more competent

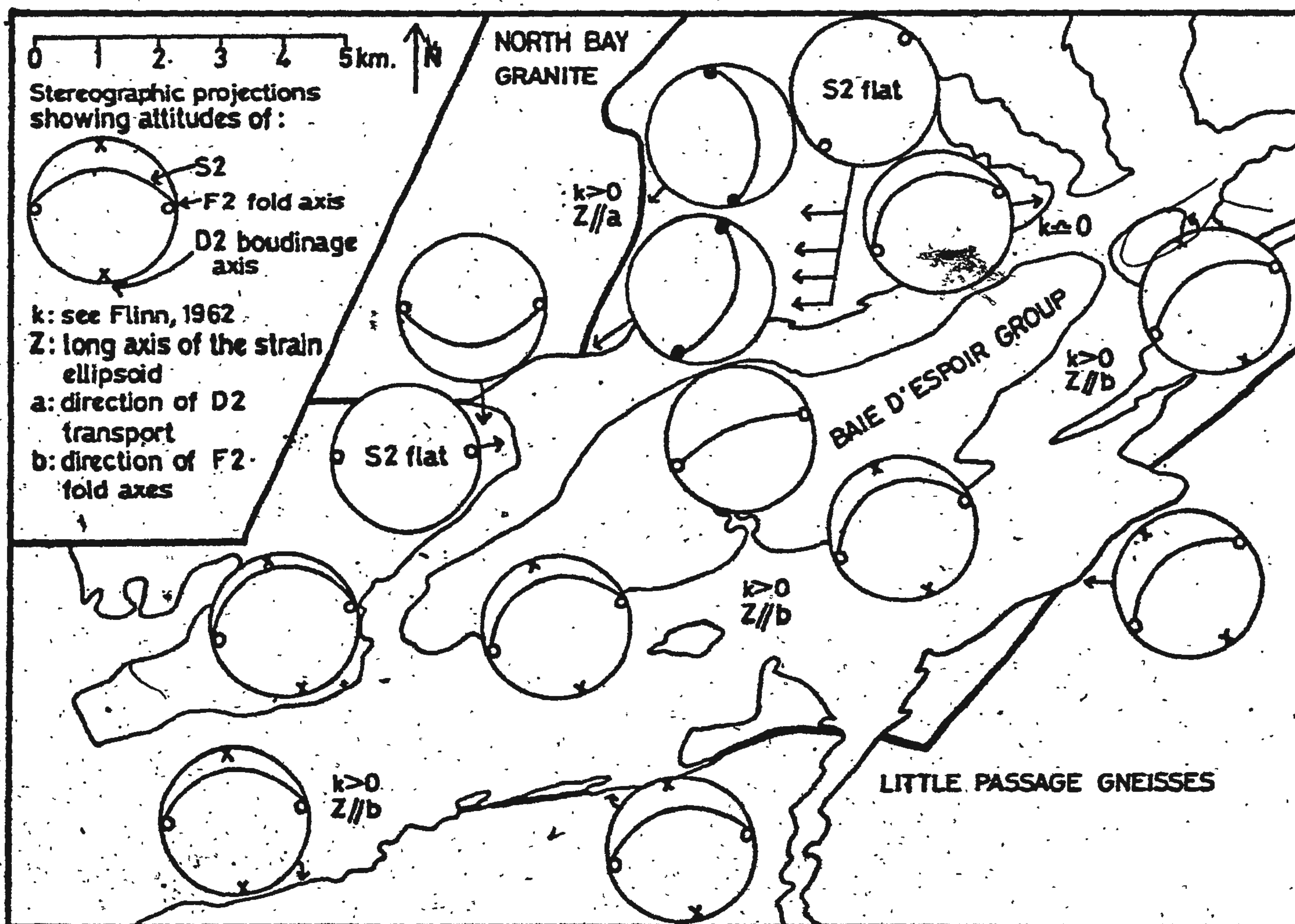


Fig. 9. Variations in the values of k and the attitudes of structures formed during the second deformation of the Baie d'Espoir Group.

psammite beds. The axes are subhorizontal; they generally trend towards the northeast, although on the coast 2 km. south of the Big Rattling Brook Thrust the trend changes to northerly for 200 m. and then reverts to northeasterly again. The axial planes are subhorizontal or gently north dipping and the folds are recumbent. They have both senses of vergence with either the lower or upper limb on the anticlines being longer; the former type is predominant however.

In the country between Roti Bay and the North Bay Granite, the subhorizontal F2 fold axes trend north-northeast parallel to the granite margin; they are discordant to the general trend of F2 axes and the strike of S2 to the south and east. The axial planes of the F2 folds, which further south at the mouth of Roti Bay are north dipping, flatten out to horizontal around the northern part of Roti Bay and then become east-southeast dipping close to the granite (Pls. 32, 33) (Fig. 9). The F2 folds which are of similar type, close or tight, and asymmetric have the same sense of vergence as those on Bois and Riches Islands. The upward facing anticlinal structures with shorter upper than lower limbs become downward facing synformal structures as the attitude of the axial planes changes towards the granite; the facing directions in the rocks around the granite are extrapolated from less metamorphosed areas, and it is assumed that there are no major F1 structures. These F2 folds which involve the marginal granite sills are best exposed in the cliff face northeast of Pomley Cove at the very edge of the main granite body. In this exposure the axial planes of the folds have a maximum dip of 70° towards the east; they can be traced along the north shore of Lampidoes Passage towards Roti Bay as they become flat and then assume a northwest dip (Fig. 9). Along this same section the trend of the fold axes changes from north-northeast parallel to the granite contact to east-northeast parallel to the regional trend.

A similar change in dip of the F2 axial planes is present in the southern part of Pomley Cove. Graphitic schist of the Isle Galet Formation occurs adjacent to the assumed fault at the edge of the granite. The axial planes which are subparallel to bedding dip south away from the granite. Semipelitic schist of the Riches Island Formation which lies above the graphitic schist forms the headland south of Pomley Cove where the axial planes flatten out. As the dip becomes northward further south the graphitic schist reappears.

Schistosity. The axial planes of the F2 folds are marked by S2, which is generally penetrative or crenulation schistosity, although in some of the psammitic beds it is a fracture cleavage. The fabric is also present in the outer parts of the North Bay Granite. S2 has been used as the principal indicator of vergence in the Riches Island Formation; it generally has a gentler dip to the northwest or a steeper dip to the southeast than the bedding.

Boudinage. D2 boudinage is common in the granite sills at the margins of the North Bay Granite (Pl. 34). The boudin axes are parallel to the F2 fold axes and as the trend of the fold axes changes away from the granite contact so does that of the boudins. Elsewhere in the Riches Island Formation boudinage is rare, but where present its orientation is different (Fig. 9); the boudinage axes are formed at right angles to the F2 fold axes (Pl. 87).

<u>Strain ellipsoid</u>. Strain indicators within the Riches Island Formation were found at two localities. At the mouth of Roti Bay, an intraformational conglomerate occurs with pebbles of psammite. Using the strain ellipsoid of Flinn (1962), the Y and Z axes are approximately equal and the X axis normal to S2 (and bedding) is one eighth to one half the length of Y and Z. The original shape of the pebbles is uncertain; some of them may have been flat when they were deposited. The equivalence of Y and Z however implies a k-value approaching zero (Fig. 9).

On the east coast of Riches Island an amygdaloidal metabasalt occurs (Pl. 62). The shape of the amygdales before deformation is again, uncertain. They now have approximate axial ratios of X = 1, Y = 1.2, and Z = 3, where X is the direction of flattening normal to S2 and Z is the direction of maximum extension parallel to the F2 fold axes.

<u>Major structure</u>. The mesoscopic folds, the S2 bedding intersections, and the facing directions in the Riches Island Formation indicate major recumbent anticline closing upwards to the southeast (sections C-D, E-F). The rocks presently exposed belong to the lower limb of this fold; the psammitic rocks northeast of Roti Bay have a varying sense of vergence and this may indicate that the core of the fold is being approached. This core is cut out by the Big Rattling Brook Thrust west of Bay d'Espoir; on the east side of the bay the Riches Island Formation grades into the St. Alban's Formation whose structure has already been interpreted as close to the central part of a recumbent anticline. The axial planes of the minor folds dip southeast

north of Conne River, so that the core of the major structure is nowhere below the level of erosion.

In the margins of the North Bay Granite the metasedimentary sheets are near vertical and the minor folds suggest that there is a downward facing antiform (the facing direction is extrapolated from less metamorphosed areas). This antiform is complementary to the main recumbent anticline forming part of the Bay d'Espoir Nappe.

Isle Galet Formation

Folds. Close to tight F2 folds are exposed in the thick graphitic schist sequence in Lampidoes Passage, where they also affect pegmatite and aplite veins of leucocratic garnetiferous granite. The folds are of similar type and may be up to 100 m. in amplitude; the axes are subhorizontal and the axial planes are horizontal to north dipping. The incompetence of the schist has given rise to considerable complexity in the folding, and the sense of vergence is generally obscure; where granite veins are involved, however, on the west side of the passage, these define antiforms with shorter upper limbs than lower.

To the east of Bois Island, northeast from Cape Mark, mesoscopic F2 folds affect metagraywackes. The folds are tight, of similar type, and have wavelengths of about 10 m. The fold axes are subhorizontal and the axial planes dip north at about 50°. The upper limbs of the folds are shorter than the lower. Tops can be determined from graded and cross bedding; they ~~indicate that the~~ folds face upwards to the southeast.

Minor dismembered F2 tight to isoclinal folds occur in quartz segregations in acid crystal tuffs and graphitic schists near the Day

Cove Thrust (Pl. 88); along the north shore of Simmond's Barasway there are tight F2 folds up to 30 cm. in wavelength in amphibolite and metagraywacke (Pl. 89). No consistent sense of vergence is indicated by these folds and at Simmond's Barasway the axes plunge in various directions in the plane of S2.

At two localities F2 folds affect entire sheets of crystal tuff. About 100 m. southwest of Raymond Point there is an isoclinal recumbent fold in a sheet over 10 m. thick. The fold axis and axial plane are subhorizontal although the S2 schistosity is north dipping both north of the fold and to the south. The upper limb of the south closing fold is shorter than the lower. The crystal tuff in the core of this fold is almost unaffected by D2 and has been used for the earlier petrographic descriptions.

A large recumbent fold in both acid and basic volcanic rocks forms Isle Galet. The southward closing hinge is exposed along the southern shore and the northward closing hinge is seen in the cove on the northwest side of the island. The hill in the centre of the island is capped by crystal tuff forming the upper limb of the north closing fold. The fold limbs as presently preserved are not long enough to give a sense of vergence but stratigraphic tops have been determined from grading in bedded tuff on the southern shore and indicate that the folds face upwards to the south.

<u>Schistosity</u>. The S2 fabric is developed throughout the Isle Galet Formation. Away from the Day Cove Thrust, on Bois Island and around Barasway de Cerf, the bedding consistantly dips more steeply to the north than S2. Close to the thrust on the southern side of Bay

d'Espoir, the bedding and S2 are subparallel; in the acid crystal tuffs there has been minor mylonitization whilst in the graphitic schists there are numerous anastomosing shear surfaces. A lineation, subhorizontal and parallel to that in the mylonitic rocks of the Little Passage Gneisses, occurs on this side of the bay.

Thrust faults. The graphitic schists that separate the sheets of volcanic rocks on the southern side of Bay d'Espoir have been tectonically disrupted during the second deformation. They are fragmented by a network of shear surfaces, and at their margins may include pieces of the surrounding volcanic rocks (Pl. 69); they generally contain numerous rolled quartz segregations. It appears that some of the movement associated with the Day Cove Thrust has been taken up in these schists.

Similar tectonically disrupted zones occur in the acid crystal tuffs north of Dolland Bight and at Patrick's Harbour. The rock has been reduced to a coarse quartz-muscovite schist with rolled quartz segregations.

The tectonic zones vary from 5 to 100 m. thick in the graphitic schist, but are not less than 20 m. thick in the volcanic rocks.

Boudinage. Second deformation boudinage is common along the south coast of Bois Island and east of Cape Mark into Simmond's Barasway. The boudins are generally formed in bands of basic igneous rock in semipelitic or graphitic schist (Pl. 90); however they are best developed in the bed of siliceous marble that occurs about 3 km. east of Snook's Harbour (Pl. 91). The predominant trend of the boudin axes is approximately southeast normal to the F2 fold axes (Fig. 9); boudins have also formed, however, with axes parallel to the F2 fold axes, and where the two directions interfere with each other the competent horizons are divided into disc shaped fragments.

Boudinage is rare along the southern shore of Bay d'Espoir, but where it does occur the boudin axes are normal to the F2 fold axes.

Strain ellipsoid. A partial estimate of the dimensions of the strain ellipsoid in the Isle Galet Formation can be made from the lapilli occurring in acid volcanic tuff at Flobber Cove on Bois Island and near Raymond Point (Pl. 64). In both cases S2 is subparallel to bedding and the original flatness of the lapilli is unknown; thus the X dimension is not a reliable indicator of flattening. At Flobber Cove the ratio X: Y: Z (Flinn, 1962) is 1: 2: 4 and at Raymond Point it is 1: 2: 6. In both instances there is definite extension along Z parallel to the F2 fold axes; this agrees with the main direction of extension indicated by the boudinage axes and by the mineral lineation (Fig. 9).

Major structure. Bedding tops and the sense of vergence derived from folds and the S2 bedding intersections in the Isle Galet Formation indicate that the rocks presently exposed form the lower limb of an anticline facing upwards to the south (sections A-B, C-D, E-F). This interpretation agrees with that for the Riches Island Formation which forms the northern part of the structure and with which the Isle Galet Formation is conformable. This anticline, the Bay d'Espoir Nappe, lies in contact with the basement along the Day Cove Thrust, and the tectonic disruption in the graphitic schists and volcanic rocks along the southern shore of Bay d'Espoir reflects the proximity of these rocks to the thrust. The basement-cover contact and the fold axes in the nappe have an arcuate trace forming part of the Hermitage Flexure (Williams, Kennedy and Neale, 1970). The boudinage, growth lineation, and stretched lapilli in the southern part of Bay d'Espoir indicate extension parallel to F2; this is consistent with the nappe having moved out from its root along a front that was convex to the southeast.

Major Thrust Faults

There are two major thrust faults in the Bay d'Espoir area. Both are associated with the formation of the Bay d'Espoir Nappe and are of D2 age. The most fundamental of these is the Day Cove Thrust which forms the sole of the nappe and brings cover rocks into tectonic contact with the basement. Metamorphic and structural convergence caused by the reconstitution of the basement obscures the contrast between the rocks on each side of the fault; a useful aid in recognizing it is the common occurrence of garnetiferous leucocratic granite veins in the basement rocks and their absence in the cover. The granite veins are of MP1 age, and so confirm the age of movement as D2. The fault is well exposed north of Dolland Bight, at Hatcher and Day Coves, and at Patrick's Harbour, with poorer exposure at Harbour le Gallais. It probably extends westwards north of Great Jervis Harbour to Facheux Bay but the nature of the contact in this area is uncertain. The fault is marked by a mélange up to 20 m. thick; it contains slices of blastomylonite derived from the Stickland Cove Zone of the basement in a matrix of graphitic schist. The schist is cut up into lenses 1 to 2 cm. thick by anastomosing shear surfaces; there is a lineation on the surfaces caused by crinkling parallel to the F2 fold axes. The blastomylonite slices are generally less than 10 cm. thick and 2 m. long and may have the superficial appearance of psammite beds; they are oriented parallel to S2. Southwards there is a gradation from the mélange into the mylonitic rocks of the basement and northwards the mélange is everywhere overlain by acid crystal tuff.

The second major fault in the area is the Big Rattling Brook Thrust which underlies the St. Alban's and Roti Steady Formations. The fault crops out along the southern edge of the St. Alban's Formation. Northwards through Roti Steady it probably bifurcates, separating the Roti Steady Formation from the North Bay Granite and the St. Alban's Formation from the Roti Steady Formation. The fault zone is only exposed in two places, on both sides of Bay d'Espoir. On the west shore the zone of faulting lies just south of Frenchman Cove. Garnetiferous semipelitic schist, typical of the Riches Island Formation is overlain by a graphitic schist unit, 10 m. thick; the graphitic schist has been fragmented into numerous flakes and lenses less than a centimetre thick by a fine network of shear surfaces. Above the schist are pelites and siltstones that have been tightly folded by D2 and contain rare MP1 garnet grains. On the north side of Frenchman Cove are typical interbedded siltstones and pelites of the St. Alban's Formation; metamorphism is at biotite grade and the F2 folds are open.

The Big Rattling Brook Thrust on the east side of Bay d'Espoir occurs in biotite grade pelitic rocks with rare siltstone beds. The D2 fabric is a penetrative schistosity and the F2 folds are close to tight. The rocks grade southwards into garnetiferous semipelitic schist, but across the fault zone there is no change in lithology, metamorphic grade, or structural style. The two major faults in the zone crop out about 30 m. apart; in both cases there is a breccia 2 to 10 m. thick consisting of lense shaped boulders up to 1 m. across in a brecciated pelitic matrix (Pl. 92). The boulders have a pre-existing cleavage which does not appear to have been formed by transposition of an earlier fabric. Beneath the breccia there are polished fault planes dipping approximately 20° to the north at slightly steeper dips than S2 in the immediately surrounding rocks. Slickensides plunge down the dip of the fault planes.

There is a considerable change in the significance of the Big Rattling Brook Thrust from west to east. In the west it brings biotite grade rocks into contact with granite, and sillimanite and kyanite schist (section C-D). Eastwards the contact in the rocks on either side of it diminishes (section E-F) and the fault may fade out altogether east of Conne River. The fault appears to have formed by the breaking of the Bay d'Espoir Nappe on the rigid structural high of the North Bay Granite and enclosed gneisses.

Post D2 Folding

Folds formed after the second deformation fall into three groups, those with east-northeast trending axes, those with north trending axes, and kink bands. Nowhere were two of these sets of folds found together, so their mutual relationships are unknown.

The folds with east-northeast trending axes are close and generally of flexural slip type; they rarely exceed 2 m. in wavelength and the axial planes dip to the south at between 40° and 50° (Pl. 93). One occurrence of these folds has already been noted from the Stickland Cove Zone of the Little Passage Gneisses; in the Baie d'Espoir Group they occur most commonly on the eastern end of Bois Island, on Riches Island, and northwards towards St. Alban's. At one locality opposite Frenchman Gove an axial planar crenulation cleavage is developed (Pl. 94).

The folds with north trending axes occur on Bois Island, west of Snook's Harbour, and are well exposed in the south facing cliffs. They are flexural slip type box folds with conjugate axial planes dipping steeply east and west; synformal structures are more common than antiforms. The limbs of the folds are generally at least 30 m. in length (Pl. 95).

Kink bands a few centimetres wide occur most notably in the acid volcanic tuffs of Raymond Point and Isle Galet (Pl. 96) but are also found in lithologies throughout the Baie d'Espoir Group (Pl. 97). The kink planes strike approximately north-south and dip steeply east and west; the coincidence in orientation with the axial planes of the box folds suggests that they may be related.

SUMMARY AND DISCUSSION

The deformations that affected the rocks of the Bay d'Espoir area can be divided into two groups, those that affected only the Little Passage Gneisses and those that affected both the gneisses and the Baie d'Espoir Group.

The first group was responsible for the folded banding in the amphibolitic and psammitic gneisses, and for the inhomogeneous deformation of the tonalite that intruded them. Zones of intense strain cut through the tonalite and separate areas where primary textures are still recognizable. The style of deformation is similar to that described from basement complexes by Sutton and Watson (1950), Kranck (1957), and many others.

The Little Passage Gneisses were intruded post-tectonically by the Gaultois Granite which pre-dated the second group of deformations, those affecting the Baie d'Espoir Group and causing reworking of the basement. There were two regionally developed deformations, D1 and D2, separated by a metamorphic peak and the intrusion of the North Bay Granite. The first caused minor folding and the formation of a cleavage or schistosity in the cover, and considerable reconstitution of the basement. The second was responsible for the formation of the Bay d'Espoir Nappe, a major southeast facing recumbent fold, and the associated Day Cove and Big Rattling Brook Thrusts; it also caused further reworking of the basement. The style of deformation was similar to that found in, for instance, the Dalradian Series of the Caledonian Belt (e.g. Rast, 1963), or the Fleur de Lys Supergroup in Newfoundland (Kennedy, 1971). The reworking of the basement rocks during the cover deformations is comparable to that described by Sutton (1972a, b) from County Mayo, Ireland and from Kaipokok Bay, Labrador, by De Swardt (1963) from Zambia, and by Haller (1971) from east Greenland.

The description of the structural geology of the Bay d'Espoir area in this study has been mainly concerned with a narrow belt normal to the regional trend (Map 2). The principal object has been to describe the relationships between the Gaultois Granite, the Little Passage Gneisses, the Baie d'Espoir Group, and the North Bay Granite. This approach, however, tends to ignore one of the most notable features of the geology of Bay d'Espoir, which is its position on the axis of the Hermitage Flexure (Williams, Kennedy, and Neale, 1970). The flexure is the marked change in structural trend from northeast around the Head of Bay d'Espoir to east-southeast at Richard's Harbour (Map 1). Williams, Kennedy and Neale proposed that the change was caused by Devonian folding around a northerly trending axial surface. Although this study has confirmed the existence of the curvature in the structural trend, it has become apparent that the curvature is original and not formed by later folding. The following points lead to this conclusion:

1. There is evidence that the axis of the Bay d'Espoir Nappe was originally curved. Boudinage axes, the shape of lapilli in the tuffs, and the growth lineation near the Day Cove Thrust all suggest extension during the second deformation parallel to the F2 axes in the outer parts of the nappe. In the more central parts of the nappe near the North Bay Granite there are no such indications of stretching parallel to F2. This strain configuration is consistent with tectonic transport along a front that was convex to the southeast.

2. If it is maintained that the F2 fold axes were not curved when formed, a complex series of flexures must be proposed (Fig. 10), because the F1 axes have less curvature than the F2 axes; the fold axes are, in general, subhorizontal. The first folds would be formed with straight axes; they would then be flexed so that the curvature was concave to the southeast while the F2 folds were formed likewise with straight axes. Both sets of fold axes would then be flexed in the opposite

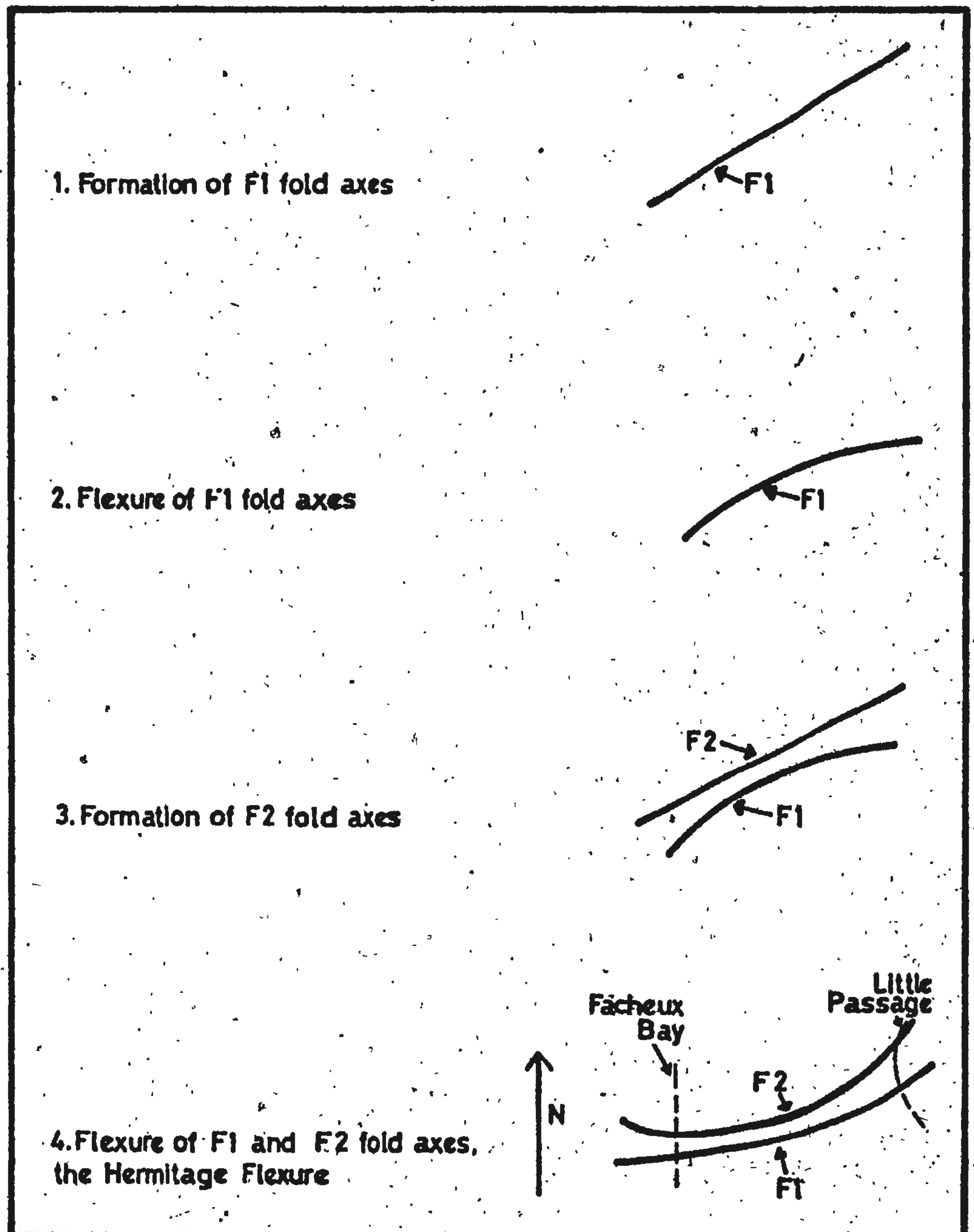


Fig. 10. Illustration of the complexity involved in forming the present curvature of F1 and F2 fold axes in the Bay d'Espoir area by later folding.

direction so that the curvature was convex to the southeast. This is clearly an unnecessarily complex solution to the problem.

3. The fold axes formed during the cover deformations are with few exceptions subhorizontal. This implies either that any axis about which they were folded was vertical, or that the F1 and F2 axes had pre-existing plunges that were exactly compensated for by the plunge and degree of folding on the axis of the Hermitage Flexure. The latter case seems unlikely. If the axis of the Hermitage Flexure was steep or vertical, there would have been major compression of the crust in northwest Newfoundland with folding and thrusting; conversely there would have been major extension of the crust in the southeast with rifting and probably intrusion of basic magma. None of these features have been reported; the only marked extension in the Bay d'Espoir area is of D2 age and is restricted to the cover and the reworked basement; it can be shown that it is centred on the core of the lower part of the Bay d'Espoir Nappe in the North Bay Granite.

4. The principal feature that was noted by Williams, Kennedy and Neale (1970) as describing the curvature of the flexure was the outcrop of basement gneisses, which appeared to form a linear belt from Gander Lake through Bay d'Espoir to Port-aux-Basques. It has since been found (Williams, 1970; J. G. Degrace, pers. comm. 1973) that these gneisses underlie much of central Newfoundland and do not form a linear belt at all.

Thus, although from a cursory examination of the geological map of Newfoundland (Williams, 1967), it would appear that the Central Mobile Belt has been folded around the Hermitage Flexure, more detailed investigation has shown that it is in fact an original outcrop pattern formed by the interaction between basement and cover.

CHAPTER 6

REGIONAL CORRELATIONS AND INTERPRETATION

REGIONAL CORRELATIONS

The rocks of Bay d'Espoir are of uncertain age and therefore must be correlated with those in other areas (Fig. 11) by similarities in lithologies, and structural and metamorphic histories. They consist of four principle components:

1. The basement (Little Passage Gneisses) with older amphibolitic and psammitic gneisses enclosed in younger tonalitic gneisses.

2. A megacrystic granite (Gaultois Granite), that post-dated the gneissic banding in the basement, but pre-dated the deformation of the cover; it is not seen in intrusive contact with the cover.

3. The cover rocks (Baie d'Espoir Group) which consist of flysch and volcanic rocks, and which have suffered two regional deformations and an intervening metamorphism of biotite to sillimanite grade; the second deformation caused the formation of a major southeast facing recumbent fold which over-rides the basement.

4. A synorogenic leucocratic granite (North Bay Granite) which intruded the cover and the basement between the two cover deformations; it is characteristically garnetiferous.

Correlations with the Gander Region

The correlation between the Bay d'Espoir rocks and those around

	Bay d'Espoir	Gander	Central Nfld.	Nfld. SW coast	Nova Scotia
Garnetiferous leucocratic granite	North Bay Granite and others	several leucocratic granites	unnamed leucocratic granites	unnamed leucocratic granites	Coastal Gneisses
Cover	Baie d'Espoir Group	Gander Lake Group	unnamed metasedimentary rocks?	unnamed metasedimentary rocks?	possible correlatives of Fourchu Gp.
Megacrystic granite	Gaultois Granite	Deadman's Bay Granite and others	—	Burgeo Granite?	xenoliths in Coastal Gneisses
Basement	Little Passage Gneisses	unnamed gneissic terrane	unnamed gneiss in leucocratic granite	Port-aux-Basques Gneisses	George River Group?

Fig. 11. Correlations between the Bay d'Espoir area and other parts of Newfoundland and Nova Scotia (see also Fig. 12).

Gander Lake was suggested by Snelgrove (in Jewell, 1939) and Jenness (1963) on the basis of lithology and structural trend; the link between the two areas was confirmed by the mapping of Anderson and Williams (1970). In both areas it was thought that a single conformable succession graded from sediment into gneiss with increasing metamorphism southeastwards.

The radical reinterpretation of the geology of Bay d'Espoir that is proposed in this study is matched by a similar reinterpretation in the Gander region. Kennedy and McGonigal (1972) have divided the Gander Lake Group of Jenness (1958) into three parts:

1. The gneissic terrane on the northwest shore of Bonavista Bay (includes part of the lower unit of the Gander Lake Group and part of the Love Cove Group of Jenness).

2. The Gander Lake Group (previously mainly the lower unit of the Gander Lake Group).

3. The Davidsville Group (previously the middle in part and the upper units of the Gander Lake Group).

The gneissic terrane consists of

> . . . migmatites in which the granitic fraction shows a gneissic banding that has been formed by the transposition of an earlier banding. They contain xenoliths, from a few inches to 4 ft. (> 1.2 m.) across, of even older tectonites. These xenoliths range in composition from mafic to psammitic and semipelitic and contain their own banded fabric, which has been formed by the transposition of an earlier banding. The tectonite fabrics of these xenoliths predate the latest banding of the enclosing granitic gneiss, which forms augen around them.

These rocks can be compared with the Little Passage Gneisses forming the basement in Bay d'Espoir. The granitic gneiss may correspond to the tonalitic gneiss, whilst the older complex represented by the xenoliths may be equivalent to the amphibolitic and psammitic gneisses.

Kennedy and McGonigal describe the Gander Lake Group thus:

> It is at least 10,000 ft. (> 3000 m.) thick and consists predominantly of semipelitic and psammitic schists with minor graphitic and mafic schists. The psammitic schist is locally pebbly. The Gander Lake Group has been subjected to polyphase deformation and greenschist to low amphibolite metamorphism.

The lithologies are similar to those of the Riches Island and Isle Galet Formations of the Baie d'Espoir Group, differing only in the absence of acid volcanics. As in the Baie d'Espoir Group the principle schistosity is S2 and the F2 folds face towards the southeast; there has been growth of garnet porphyroblasts between the first and second deformations.

The granitic rocks of the Gander and Bay d'Espoir regions are as similar as the gneisses and metasediments. On the shores of Bonavista Bay megacrystic granite comparable to the Gaultois Granite intrudes the gneissic terrane but not the metasediments; it post-dates the gneissic banding, although it has locally been deformed by the cover deformations. Garnetiferous leucocratic granites similar to the North Bay Granite intrude both the gneisses and the Gander Lake Group. Their intrusion post-dates the gneissic banding but pre-dates the deformation of the metasediments. They differ from the leucocratic granites of Bay d'Espoir in having an obvious early phase of intrusion before the first deformation of the cover. Later granites in the Gander Lake region and the ultramafic rocks described by Jenness (1958) in the Gander River area have no equivalents around Bay d'Espoir. The ultramafic rocks, however, may be represented farther inland towards the northwest.

Correlations with Central Newfoundland

The area northwest of Bay d'Espoir from which the Bay d'Espoir Nappe was presumably derived has been mapped by Williams (1970), and Anderson and Williams (1970). They suggested correlations between the Baie d'Espoir-Gander Lake Groups and the metasedimentary rocks in central Newfoundland south of Noel Paul's Brook. These rocks have been metamorphosed to garnet, staurolite and sillimanite grades, and have been intruded and migmatized by garnetiferous leucocratic granites. The geological relationships are similar to those found in the margins of the North Bay Granite, north of Lampidoes Passage. Gneisses are present in the granite and like those found in North Bay probably represent a pre-existing basement.

The high grade metasediments, the granite, and the gneisses are overlain by lower grade gray and black slates and siltstones. These may be equivalent to the St. Alban's Formation of the Baie d'Espoir Group, or else they may be correlated with the later Ordovician Davidsville Formation of Kennedy and McGonigal (1972). Occurrences of ultramafic rocks in central Newfoundland may, at least in part, be equated with those in the Gander Lake Group.

Correlations Along the Southwest Coast of Newfoundland.

Williams, Kennedy, and Neale (1970) suggested that the Bay d'Espoir-Gander Lake Belt can be correlated with the rocks cropping out along the south coast of Newfoundland towards Port-aux-Basques. They noted that the regional strike swings through ninety degrees around the Hermitage Flexure between Bay d'Espoir and Facheux Bay so that it has a west-northwest trend; it curves around the Burgeo Granite and continues in a southwesterly direction to the coast near Port-aux-Basques.

Most of the south coast is underlain by the Burgeo Granite which is a megacrystic biotite granite continuous with the Gaultois Granite (Riley, 1959; Williams, 1971); it is similar to the Deadman's Bay and other plutons in the north of the island. West of the Burgeo Granite, the belt of gneisses and metasediments is again exposed on the coast and its outcrop extends as far as the Cape Ray Fault. The fault is considered to be of fundamental significance separating the Western Platform from south and eastern Newfoundland (Brown, 1973).

The rocks between La Poile and Port-aux-Basques have been described by Cooper (1954), Gillis (1971) and Brown (1972). Cooper, working at La Poile, recognized the Devonian Bay du Nord Group and the possibly Devonian La Poile Group. Brown (1972; pers. comm. 1973), working farther west has mapped a series of well banded amphibolitic and psammitic gneisses, the Port-aux-Basques Gneisses, extending from the Cape Ray Fault to Rose Blanche. In the east these gneisses have been reconstituted and at Harbour Le Cou contain infolded semipelitic schists; the schists contain quartz-garnet bands and the garnet grains may have straight inclusion trails oblique to the main schistosity. They are similar in appearance to the higher grade schists of the Riches Island Formation in Bay d'Espoir. Garnetiferous leucocratic granites intrude the schists and gneisses and have been involved in some of the deformation.

Although the Port-aux-Basques Gneisses bear little resemblance to the gneisses of Bay d'Espoir or Bonavista Bay, the similarity of the possible cover rocks at Harbour Le Cou, the cover-basement relationship, and the pre-tectonic intrusion of garnetiferous granite suggest a correlation. The Devonian rocks at La Poile, however, have no known equivalents to the east.

Correlations with Nova Scotia

Rocks similar to those in Bay d'Espoir have been described from northeast Cape Breton Island by Wiebe (1972). A basement gneiss complex is intruded by a number of granite plutons and is overlain by a cover of volcanic rocks. The basement contains much carbonate and is not like that found in Newfoundland; Wiebe tentatively correlated it with the George River Group of southern Cape Breton Island (Weeks, 1954).

Amongst the granites that intrude the basement, but are not in contact with the cover, are the so-called Coastal Gneisses which are similar to the deformed garnetiferous leucocratic granites of Bay d'Espoir (M. J. Kennedy and E. R. W. Neale, pers. comm. 1973). Just to the north of the area mapped by Wiebe, Kennedy and Neale have found previously foliated xenoliths of megacrystic granite within the leucocratic granite; this association is similar to that at the head of Sam Hitches Harbour on Long Island, Bay d'Espoir. The Rb/Sr age determined by R. Cormier from the leucocratic granites of Bay d'Espoir is 573 m.y. ± 40; it compares with an age of 562 m.y. ± 80 from the Coastal Gneisses (Cormier, 1972).

The cover rocks, which Wiebe suggests may be correlatives of Weeks' Fourchu Group, consist of acid and andesitic volcanics intercalated with black slate. They have been penetratively deformed at least twice (M. J. Kennedy and E. R. W. Neale, pers. comm. 1973) and have generally been metamorphosed to garnet or staurolite grade; the metamorphism is spatially related to the intruding granites, and sillimanite and kyanite occur near the granite margins. The cover rocks may be comparable with the Baie d'Espoir Group, especially the Isle Galet Formation.

Regional Setting of the Bay d'Espoir Area

The Baie d'Espoir Group has been correlated with metasedimentary and metavolcanic rocks to the northeast around Gander Lake, to the northwest in central Newfoundland, possibly to the west at Harbour le Cou, and in Nova Scotia on northern Cape Breton Island. In each area these rocks lie on a continental-type basement (Fig. 12). At Port-aux-Basques the basement extends westwards to the Cape Ray Fault which has been interpreted as a cryptic suture and the site of a former ocean basin (Brown, 1973). Here and possibly on the Aspy Fault in Cape Breton Island the basement of the eastern side of the Appalachians is in contact with the basement of the western side.

The line of the suture runs northeastwards (Fig. 12); along Noel Paul's Brook where its position is occupied by a narrow strip of Ordovician and Silurian rocks, it forms the northwest edge of the granitic and gneissic basement in south central Newfoundland. On the western side of these Lower Palaeozoic rocks are granites and gneisses (Riley, 1957; Baird, 1960; J. Degrace, pers. comm. 1973) which may in part represent the northern continuation of the basement on the west side of the Cape Ray Fault.

In northeast Newfoundland the Lower Palaeozoic rocks of Notre Dame Bay separate the marginal metamorphic belts of the Burlington

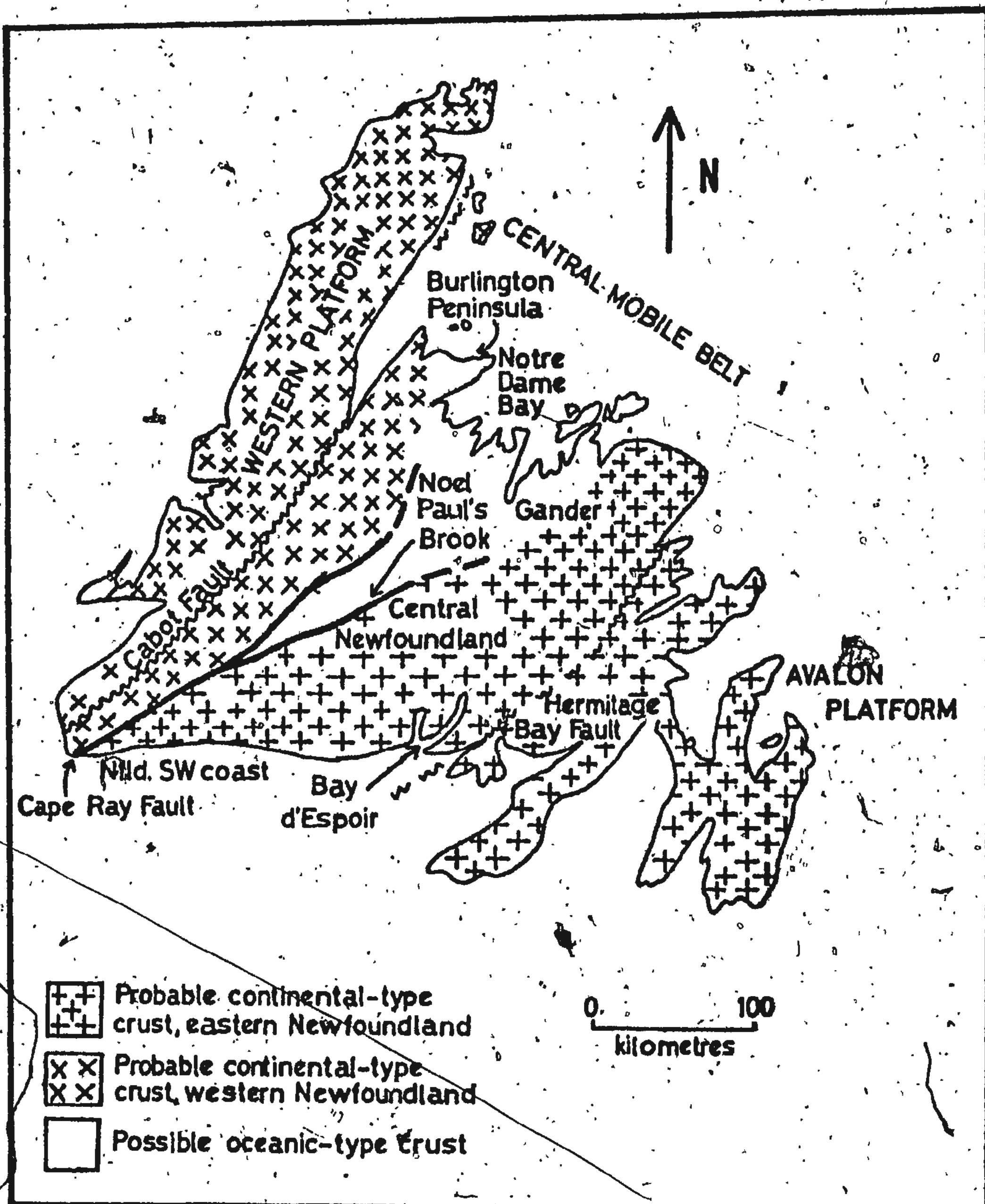


Fig.12. The suspected nature of the basement in Newfoundland.

Peninsula in the west and the Gander Region in the east (Williams, 1964). They form an area of possible oceanic-type crust (e.g. Dewey, 1969; Bird and Dewey, 1970; Strong, 1972) separating two areas which are, at least in part, underlain by granitic gneisses; they may represent the extension and incomplete closure of the Cape Ray Fault, and/or later renewed spreading along the line of the fault.

The Bay d'Espoir area lies about 100 km. from Noel Paul's Brook and the edge of the basement rocks of south central Newfoundland. The direction of tectonic movement has been from the northwest, and the basic influence on the geology of the area has been the interaction of this segment of the continental crust with whatever rocks have from time to time lain immediately to the northwest of it.

The southeastern margin of the Bay d'Espoir area is marked by the Hermitage Bay fault which separates it from the less deformed and metamorphosed rocks of the Avalon Platform. The fault has a marked topographic expression and forms a chloritized shear zone through the granite at the head of the bay. The fault line is represented on Bonavista Bay by a mylonitic zone from 300-500 m. across (F. Blackwood, pers. comm. 1973). No certain correlation can be made across the fault because there is a marked change in sedimentary facies, and structural and metamorphic histories. Wiebe's (1972) tentative correlation of the deformed volcanic rocks of northern Cape Breton Island with the Fourchu Group farther south is tantamount to matching the Isle Galet Formation with the Musgravetown Formation of the Avalon Platform. Whereas these volcanic rocks may be time equivalents and even due to the same megatectonic process, the uncertain age of the Baie d'Espoir Group and the lack of continuity across the fault make such a correlation extremely tenuous.

AN INTERPRETATION OF THE GEOLOGY OF BAY D'ESPOIR

Pre-Orogenic History

The history of the Bay d'Espoir area before the deformation and metamorphism of the cover rocks involves three stages. Firstly, the formation of the basement gneisses about which no interpretation will be made, secondly, the deposition of the Baie d'Espoir Group, and thirdly, the intrusion of the Gaultois Granite.

Deposition of the Baie d'Espoir Group

Two principal facies have been recognized, the flysch-type deposits of the St. Alban's, Riches Island, and Roti Steady Formations, and the volcanic rocks of the Isle Galet Formation. Both facies were deposited on or close to continental-type basement, since the flysch is rich in quartz, and fragments of granite and gneiss occur in the Isle Galet Formation.

The flysch succession, consisting of compositionally mature turbidites, is most indicative of deposition on an Atlantic-type plate margin (Reading, 1972). The presence of acid and basic volcanic rocks lying stratigraphically above the flysch suggests the development of a subduction zone under the continent and the change to an Andean-type margin. The probable tuffaceous beds in the St. Alban's Formation may indicate the start of volcanism during the deposition of these rocks, but not necessarily in the immediate vicinity. Since the only apparent major suture that has been identified in Newfoundland lies to the northwest of Bay d'Espoir, a subduction zone beneath this area is assumed to have been east dipping. It should be noted that the above interpretation of the origin of the Isle Galet Formation volcanic rocks is based entirely on non-chemical information; a consideration of the chemistry of the rocks is necessary to reach any final conclusions.

The Gaultois Granite

This granite was intruded into the Little Passage Gneisses before the deformations of the Baie d'Espoir Group. Neither it nor the megacrystic granites around Bonavista Bay are seen intruding the cover rocks. The granite is therefore thought to be earlier than or synchronous with the deposition of the Baie d'Espoir Group.

W. L. Dickson (pers. comm. 1973) considers the megacrystic granites of the Gander Lake Belt to be due to partial melting of oceanic crust above a subduction zone; the evidence for this theory is the low Sr 87/86 initial ratio of 0.704 ± 0.003 (R. Cormier, pers. comm. 1973). Although this has been taken as indicative of a probable oceanic crust origin in the Mesozoic Sierra Nevada batholiths (e.g. Kistler and Peterman, 1973), it does not necessarily apply to the Precambrian or Lower Palaeozoic Gander Lake area; therefore any interpretation must be tentative.

Orogenic History

The Bay d'Espoir area underwent two major deformations and an intervening metamorphic climax associated with synorogenic granite intrusion.

Metamorphism and the North Bay Granite Intrusion

The regional metamorphism of the Baie d'Espoir Group belongs to a slightly lower pressure facies series than the kyanite-sillimanite series of Miyashiro (1961). It is the type of metamorphism expected in the high temperature metamorphic belt of a cordilleran orogeny (Dewey and Bird, 1970).

The intrusion of the garnetiferous leucocratic North Bay Granite was spatially and chronologically related to the metamorphism; near Gander Lake however similar granites were intruded earlier, before the first deformation. W. L. Dickson (pers. comm. 1973) considers the leucocratic granites to be the product of partial melting of the continental crust. He cites as evidence their enrichment in potassium, rubidium and silicon, and depletion in strontium, calcium, magnesium and iron; they also have a low potassium : rubidium ratio. Their Sr 87/86 initial ratio of 0.706 ± 0.002 (R. Cormier, pers. comm. 1973) is higher than that from the megacrystic granites; the difference is so slight, however, that it is not considered to be significant.

Deformation

There is a difference between the relative importance of D1 and D2 structures in the basement and in the cover. The first deformation caused no recognizable major structure in the Baie d'Espoir Group, whereas the second deformation caused the formation of a major recumbent fold, the Bay d'Espoir Nappe. In contrast, in the Little Passage Gneisses and Gaultois Granite, the effects of the first deformation are more widespread than those of the second. The zone of D1 reworking in Little

Passage extends farther south than that of D2, and the fabric in much of the Gaultois Granite is attributed to the first deformation.

Within the map area of eastern Bay d'Espoir, the spatial relationship between the D2 basement reworking and the Day Cove Thrust implies that it is simply the result of cover-basement interaction, as opposed to the more pervasive deformation of the basement during D1. However the second deformation cataclastic zone northwest of Muddy Hole is 3 km. from the outcrop of the Baie d'Espoir Group and indicates that major strain did take place within the basement complex away from the cover.

The deformation that is observed within the Bay d'Espoir area implies major compression of the continental crust. This may be due to either a cordilleran or collision-type orogeny (Dewey and Bird, 1970). In the case of a cordilleran orogeny, igneous intrusion would be expected to pre-date D1; leucocratic granites of this age do occur in the Gander region and may well be present to the northwest of Bay d'Espoir.

Plate Tectonic Setting

The geology of the metamorphic belt of which Bay d'Espoir is a part, and the presence of a major suture, the Cape Ray Fault, to the west, suggest an eastward dipping subduction zone. Such a subduction zone was proposed by Strong et al. (1974) from the variation in the potassium content of the granitic rocks of Newfoundland. They claim, although it is not clearly shown by their diagram, that there is a general increase in potassium eastwards. This they compare with the increase of potassium away from the coast in the Western Cordillera of the United States (Bateman and Dodge, 1970).

This subduction zone could have caused most or all of the geological relationships in the Bay d'Espoir area. However it seems likely that much of the deformation was the result of continental collision between eastern and western Newfoundland along the line of the Cape Ray Fault. Such a collision would be expected to produce structures comparable to those in the Alps or the Himalayas; the recumbent folds and basement reconstitution in the Bay d'Espoir metamorphic belt make this area a prime candidate for such a comparison.

The date of closure along the suture has not been determined on the Cape Ray Fault itself. Assuming that all of the deformation in the Bay d'Espoir area was caused by continental collision, the radiometric age of the leucocratic granites would place it at about the beginning of the Cambrian. This conflicts, however, with other lines of evidence, for instance the end of faunal provinciality in the Middle and Upper Ordovician (Wilson, 1966; A. Williams, 1969), or the Middle Ordovician emplacement of the Taconic klippe on the west coast of Newfoundland (Rodgers and Neale, 1963). The only definite limit that can be placed on the deformation of the Bay d'Espoir-Gander Lake metamorphic rocks themselves is an upper one; the inclusion of deformed Gander Lake Group fragments in the Davidsville Formation (Kennedy and McGonigal, 1972) indicates deformation before the end of the Middle Ordovician.

CONCLUSION

The rocks of Bay d'Espoir were formed at a continental margin, and are in part the volcanic and plutonic products of an east dipping subduction zone. Both cover and basement were penetratively deformed twice, forming, during the second deformation, a major recumbent fold, the Bay d'Espoir Nappe. Much of the deformation was probably caused by compression of the crust during continental collision. Synorogenic granite intrusion and related Barrovian-type regional metamorphism can be attributed to the high heat flow of this kind of plate tectonic régime.

Correlations can be made with rocks that have similar depositional, intrusive, metamorphic, and structural histories; these occur in the Gander region, south central Newfoundland, along the southwest coast of Newfoundland and in northern Cape Breton Island. It is likely that all these areas formed one west facing continental margin that underwent a unified geological evolution during the late Precambrian and early Palaeozoic.

REFERENCES

Anderson, F. D. 1965. Belleoram, Newfoundland. Canada Geol. Survey Map. 8-1965, with descriptive notes.

Anderson, F. D. 1967. Structural studies in the Baie d'Espoir Group, Newfoundland. in Geol. Assoc. Canada Spec. Pap. No. 4, Hugh Lilly Memorial Volume, ed. E. R. W. Neale and H. Williams, pp. 193-200.

Anderson, F. D. and Williams, H. 1970. Gander Lake (west half), Newfoundland. Canada Geol. Survey Map 1195 A, with descriptive notes.

Baird, D. M. 1960. Sandy Lake (west half), Newfoundland. Canada Geol. Survey Map 47-1959, with descriptive notes.

Barrow, G. 1893. On an intrusion of muscovite biotite gneiss in the S.E. Highlands of Scotland and its accompanying metamorphism. Quart. Jour. Geol. Soc. London, v. 49, pp. 330-55.

Barrow, G. 1912. On the geology of Lower Dee-side and the southern Highland border. Proc. Geol. Assoc. London, v. 23, pp. 274-90.

Bateman, P. C. and Dodge, F. C. W. 1970. Variations of major chemical constituents across the central Sierra Nevada batholith. Geol. Soc. America Bull., v. 81, pp. 409-20.

Bird, J. M. and Dewey, J. F. 1970. Lithosphere plate-continental margin tectonics and the evolution of the Appalachian orogen. Geol. Soc. America Bull., v. 81, pp. 1031-60.

Bouma, A. H. 1962. Sedimentology of some flysch deposits. A graphic approach to facies interpretation. Elsevier, Amsterdam, 168 pp.

Brown, P. A. 1972. Structural and metamorphic history of the gneisses of the Port-aux-Basques region, Newfoundland. Unpub. M.Sc. thesis, Memorial University of Newfoundland, 112 pp.

Brown, P. A. 1973. Possible cryptic suture in south-west Newfoundland. Nature Phys. Sci., v. 245, pp. 9-10.

Chinner, G. A. 1961. The origin of sillimanite in Glen Clova, Angus. Jour. Pet., v. 2, pp. 312-23.

Cooper, J. R. 1954. La Poile-Cinq Cerf map area, Newfoundland. Canada Geol. Survey Mem. 276, 62 pp.

Cormier, R. F. 1972. Radiometric ages of granitic rocks, Cape Breton Island, Nova Scotia. Canadian Jour. Earth Sci., v. 9, pp. 1074-86.

Dainty, A. M., Keen, C. E., Keen, K. J. and Blanchard, J. E. 1966. Review of geophysical evidence on crust and upper-mantle structure on the eastern seaboard of Canada. in, The earth beneath the continents, ed. J. S. Steinhart, and T. J. Smith, Geophysical Monograph 10, American Geophys. Union, pp. 349-69.

Deer, W. A., Howie, R. A. and Zussman, J. 1962-64. Rock-forming minerals. vols. 1-5, Longmans, London.

Deer, W. A., Howie, R. A. and Zussman, J. 1966. An introduction to the rock-forming minerals. Longmans, London, 528 pp.

De Swardt, A. M. J. 1963. Deformation of the Basement Complex associated with Lufilian folding south of Mapanza Mission, Northern Rhodesia. Trans. Geol. Soc. South Africa, v. 66, pp. 76-89.

Dewey, J. F. 1969. Evolution of the Appalachian/Caledonian orogen. Nature, v. 222, pp. 124-129.

Dewey, J. F. and Bird, J. M. 1970. Mountain belts and the new global tectonics. Jour. Geophys. Res., v. 75, pp. 2625-47.

Dunlop, W. B. 1954. Exploration of the Bay d'Espoir area, Newfoundland and Labrador Corp., unpub. company report.

Dzulynski, S., Ksiazkiewicz, M. and Kuenen, P. H. 1959. Turbidites in flysch of the Polish Carpathian Mountains. Geol. Soc. America Bull., v. 70, pp. 1089-1118.

Fiske, R. S. 1963. Subaqueous pyroclastic flows in the Ohanapecosh Formation, Washington. Geol. Soc. America Bull., v. 74, pp. 391-406.

Fiske, R. S. and Matsuda, T. 1964. Submarine equivalents of ash flows in the Tokiwa Formation, Japan. American Jour. Sci., v. 262, pp. 76-106.

Fleuty, M. J. 1964. The description of folds. Proc. Geol. Assoc. London, v. 75, pp. 461-92.

Flinn, D. 1962. On folding during three-dimensional progressive deformation. Quart. Jour. Geol. Soc. London, v. 118, pp. 385-433.

Gillis, J. W. 1971. Geology of Port-aux-Basques map area, Newfoundland. Canada Geol. Survey report and map 00-1971.

Haller, J. 1971. Geology of the east Greenland Caledonides. Interscience Publishers, London, 413 pp.

Higgins, M. W. 1971. Cataclastic rocks. Prof. Pap. U. S. Geol. Survey 687, 97 pp.

Holmes, A. 1920. The nomenclature of petrology. Allen and Unwin, London, 284 pp.

Howley, J. P. 1907. Geologic map of Newfoundland. Newfoundland Geol. Survey.

Jenness, S. E. 1958. Geology of the Gander River ultrabasic belt, Newfoundland. Newfoundland Geol. Survey report 11.

Jenness, S. E. 1960. Late Pleistocene glaciation of eastern Newfoundland. Geol. Soc. America Bull., v. 71, pp. 161-80.

Jenness, S. E. 1963. Terra Nova and Bonavista map areas, Newfoundland (2 DE ½ and 2c). Canada Geol. Survey Mem. 327, 184 pp.

Jewell, W. B. 1939. Geology and mineral deposits of the Baie d'Espoir area. Newfoundland Geol. Survey Bull. 17, 29 pp.

Johnson, M. R. W. 1961. Polymetamorphism in movement zones in the Caledonian thrust belt of northwest Scotland. Jour. Geol., v. 69, pp. 417-32.

Johnson, M. R. W. 1967. Mylonite zones and mylonite banding. Nature, v. 213, pp. 246-47.

Kennedy, M. J. 1971. Structure and stratigraphy of the Fleur de Lys Supergroup in the Fleur de Lys area, Burlington Peninsula, Newfoundland. Proc. Geol. Assoc. Canada, v. 24, pp. 59-71.

Kennedy, M. J. and McGonigal, M. H. 1972. The Gander Lake and Davidsville Groups of northeastern Newfoundland. New data and geotectonic implications. Canadian Jour. Earth Sci., v. 9, pp. 452-59.

Kerr, P. F. 1959. Optical mineralogy. McGraw-Hill, New York, 442 pp.

Kinkel, A. R. Jr. 1962. Observations on the pyrite deposits of the Huelva district, Spain, and their relation to volcanism. Econ. Geol., v. 57, pp. 1071-80.

Kinkel, A. R. Jr. 1966. Massive pyritic deposits related to volcanism, and possible methods of emplacement. Econ. Geol., v. 61, pp. 673-694.

Kistler, R. W. and Peterman, Z. E. 1973. Variations in Sr, Rb, K, Na, and initial Sr 87/Sr 86 in Mesozoic granitic rocks and intruded wall rocks in central California. Geol. Soc. America Bull., v. 84, pp. 3489-3512.

Kranck, E. H. 1957. On folding-movements in the zone of the basement. Geol. Rund., v. 46, pp. 261-282.

Maxwell, J. C. 1962. Origin of slaty and fracture cleavage in the Delaware Water Gap area, New Jersey and Pennsylvania. in, Petrologic Studies - a volume in honor of A. F. Buddington, Geol. Soc. America, pp. 281-311.

Miyashiro, A. 1961. Evolution of metamorphic belts. Jour. Pet., v. 2, pp. 277-311.

Moore, J. C. 1973. Cretaceous continental margin sedimentation, southwestern Alaska. Geol. Soc. America Bull., v. 84, pp. 595-613.

Murray, A. 1871. Report upon the Geological Survey of Newfoundland for the year 1870.

Pettijohn, F. J. 1957. Sedimentary rocks, 2nd. edition. Harper and Row, New York, 718 pp.

Piper, D. J. W. and Normark, W. R. 1971. Re-examination of a Miocene deep-sea fan and fan valley, southern California. Geol. Soc. America Bull., v. 82, pp. 1823-30.

Powell, C. McA. 1972. Tectonic dewatering and strain in the Michigamme Slate, Michigan. Geol. Soc. America Bull., v. 83, pp. 2149-58.

Ramsay, J. G. 1967. Folding and fracturing of rocks. McGraw-Hill, New York, 525 pp.

Rast, N. 1963. Structure and metamorphism of the Dalradian rocks of Scotland. in, The British Caledonides, ed. M. R. W. Johnson, and F. H. Stewart, Oliver and Boyd, Edinburgh, pp. 123-142.

Rast, N. 1965. Nucleation and growth of metamorphic minerals. in, Controls of metamorphism, ed. W. S. Pitcher, and G. S. Flinn, Oliver and Boyd, Edinburgh, pp. 73-102.

Reading, H. G. 1972. Global tectonics and the genesis of flysch successions. 24th Internat. Geol. Congress, Sect. 6, pp. 59-66.

Riley, G. C. 1957. Red Indian Lake (west half), Newfoundland. Canada Geol. Survey Map 8-1957, with descriptive notes.

Riley, G. C. 1959. Burgeo-Ramea, Newfoundland. Canada Geol. Survey Map 22-1959, with descriptive notes.

Rodgers, J. and Neale, E. R. W. 1963. Possible "Taconic" klippen in western Newfoundland. American Jour. Sci., v. 261, pp. 713-730.

Schermerhorn, L. J. G. 1970. The deposition of volcanics and pyritite in the Iberian Pyrite Belt. Mineral. Deposita, v. 5, pp. 273-79.

Shackleton, R. M. 1958. Downward-facing structures of the Highland Border. Quart. Jour. Geol. Soc. London, v. 113 (for 1957), pp. 361-92.

Stauffer, P. H. 1967. Grain flow deposits and their implications, Santa Ynez Mountains, California. Jour. Sed. Pet., v. 37, pp. 487-508.

Strong, D. F. 1972. Sheeted diabases of central Newfoundland: new evidence for Ordovician seafloor spreading. Nature, v. 235, pp. 102-104.

Strong, D. F., Dickson, W. L., O'Driscoll, C. F., Kean, B. F. and Stevens, R. K. 1974. Geochemical evidence for an east-dipping Appalachian subduction zone in Newfoundland. Nature, in press.

Sturt, B. A. and Harris, A. L. 1961. Metamorphic history of the Loch Tummel area, central Perthshire. L'pool Manchr. Geol. Jour., v. 2, pp. 689-711.

Sutton, J. and Watson, J. 1950. The pre-Torridonian metamorphic history of the Loch Torridon and Scourie areas in the North-West Highlands, and its bearing on the chronological classication of the Lewisian. Quart. Jour. Geol. Soc. London, v. 106, pp. 241-307.

Sutton, J. S. 1972a. The pre-Caledonian rocks of the Mullet Peninsula, County Mayo, Ireland. Sci. Proc. Royal Dublin Soc., Ser. A., v. 4, pp. 121-36.

Sutton, J. S. 1972b. The Precambrian gneisses and supracrustal rocks of the western shore of Kaipokok Bay, Labrador, Newfoundland. Canadian Jour. Earth Sci., v. 9, pp. 1677-1692.

Turner, F. J. and Verhoogen, J. 1960. Igneous and metamorphic petrology, 2nd edition. McGraw-Hill, New York, 694 pp.

Twenhofel, W. H. and MacClintock, P. 1940. Surfaces of Newfoundland. Geol. Soc. America Bull., v. 54, pp. 1665-1728.

Van Hise, C. R. 1904. A treatise on metamorphism. U. S. Geol. Survey, Monograph 47.

Walker, R. G. 1965. The origin and significance of the internal sedimentary structures of turbidites. Yorkshire Geol. Soc. Proc., v. 35, pp. 1-32.

Walker, R. G. 1967. Turbidite sedimentary structures and their relationship to proximal and distal depositional environments. Jour. Sed. Pet., v. 37, pp. 25-43.

Walker, R. G. 1970. Review of the geometry and facies organization of turbidites and turbidite-bearing basins. in, Flysch sedimentology in North America, ed. J. Lajoie, Geol. Assoc. Canada Spec. Pap. 7, pp. 219-252.

Weaver, D. F. 1967. A geological interpretation of the Bouguer anomaly field of Newfoundland. Pub. Dominion. Observ. Ottawa, v. 35, pp. 223-51.

Weeks, L. J. 1954. Southeast Cape Breton Island, Nova Scotia. Canada Geol. Survey Mem. 277, 112 pp.

Widmer, K. 1952. The geology of the Hermitage Bay area, Newfoundland. Unpub. Ph.D. thesis, Princeton University, 459 pp.

Wiebe, R. A. 1972. Igneous and tectonic events in northeastern Cape Breton Island, Nova Scotia. Canadian Jour. Earth Sci., v. 9, pp. 1262-77.

Williams, A. 1969. Ordovician of British Isles. in, North Atlantic - geology and continental drift, ed. M. Kay, American Assoc. Petr. Geol. Mem. 12, pp. 236-66.

Williams, H. 1964. The Appalachians in northeastern Newfoundland - a two-sided symmetrical system. American Jour. Sci., v. 262, pp. 1137-58.

Williams, H. 1967. Island of Newfoundland. Canada Geol. Survey Map 1231 A.

Williams, H. 1970. Red Indian Lake (east half), Newfoundland. Canada Geol. Survey Map 1196 A, with descriptive notes.

Williams, H. 1971. Burgeo (east half), Newfoundland. Canada Geol. Survey Map 1280 A, with descriptive notes.

Williams, H., Kennedy, M. J., and Neale, E. R. W. 1970. The Hermitage Flexure, the Cabot Fault, and the disappearance of the Newfoundland Central Mobile Belt. Geol. Soc. America Bull., v. 81, pp. 1563-68.

Williams, P. F. 1972. Development of metamorphic layering and cleavage in low grade metamorphic rocks at Bermagui, Australia. American Jour. Sci., v. 272, pp. 1-47.

Wilson, G. 1953. Mullion and rodding structures in the Moine Series of Scotland. Proc. Geol. Assoc. London, v. 64, pp. 118-151.

Wilson, G. 1961. The tectonic significance of small scale structures and their importance to the geologist in the field. Annals. Soc. Geol. Belg., v. 84, pp. 423-58.

Wilson, J. T. 1966. Did the Atlantic close and then re-open? Nature, v. 211, pp. 676-681.

Zwart, H. J. 1960. Relations between folding and metamorphism in the Central Pyrenees and their chronological succession. Geol. en Mijnb., v. 39, pp. 163-80.

APPENDIX 1

HYDROMUSCOVITE

The presence of hydromuscovite (Pls. 16, 17) in the quartz-plagioclase-mica gneiss at Maria Cove Point is so unusual that it warrants further discussion. The mineral was found in only one hand specimen. It forms xenoblastic, equidimensional grains up to 1 mm. across and occurs with quartz and plagioclase grains of similar shape and size. It is particularly associated with plagioclase with which it has curved or embayed grain boundaries marked by sericitic fringes. It appears to have formed preferentially at the margins of biotite and sillimanite rich bands.

Under plane polarized light its colour varies within the space of 10 cm. from very pale yellow to olive green; it is not pleochroic. No cleavage was observed in thin section. Its refractive index was not measured precisely but is distinctly lower than that of the ordinary ray of quartz; it has slightly higher relief than quartz or oligoclase. Birefringence is very weak giving interference colours up to first order white; the variation in birefringence gives the mineral an agate-like zoned appearance. No interference figures have been obtained. Veins of sericite extend radially into the grains from the sericite fringes at the edges; the style of alteration strongly resembles the pinitization of cordierite.

A grain of the mineral was extracted from a thin section and an X-ray diffraction photograph was made. Although the quality of the photograph was very poor the following lines were observed:

dÅ	I/II
4.46	
3.39	100
2.58	50
2.28	
2.16	
1.67	
1.50	30

The closest comparison in the ASTM index is with card 9-334 for illite or hydromuscovite.

An analysis by J. Malpas using the Cambridge Geoscan 500 electron microprobe at the Department of Geology, Manchester University, England, gave the following result:

	Weight per cent
SiO_2	46.28
TiO_2	0.01
Al_2O_3	40.22
FeO, Fe_2O_3	3.73
MgO	2.75
CaO	0.18
Na_2O	0.26
K_2O	2.11
	95.53

This corresponds more closely to the analysis of hydromuscovite than to those of any other mineral described by Deer, Howie, and Zussman (1962-4).

REFERENCES

Deer, W. A., Howie, R. A., and Zussman, J. 1962-64. Rock-forming minerals. vols. 1-5. Longmans, London.

APPENDIX 2

RADIOMETRIC AGES

Fifteen samples were sent to R. Cormier of St. Francis Xavier University for radiometric age determination using the Rb/Sr method. Five samples were collected from the tonalite of the Little Passage Gneisses, five from the Gaultois Granite, and five from the North Bay Granite and associated intrusions. The results are given in Fig. 13 and plotted in Fig. 14.

One sample from the Gaultois Granite (GG 4) plots away from all the other samples and its significance is not known. An isochron for all the other fourteen samples, which are not readily distinguishable, was plotted and gave an age of 565 ± 80 m.y. with an initial ratio of 0.707 ± 0.004 (errors are given at the 95 per cent confidence level; decay constant used was 1.39 x 10^{-11} $yr.^{-1}$). A geologically more realistic isochron was plotted for just the samples from the North Bay Granite and associated intrusions; it gave an age of 573 ± 40 m.y. with an initial ratio of 0.706 ± 0.002. It seems likely that the values from the Little Passage Gneisses have been rejuvenated, but the age of the Gaultois Granite could well be within the experimental error.

Samples from the outcrop area of the Gaultois Granite were collected by F. D. Anderson for K-Ar dating of biotite by the Geological Survey of Canada (Wanless et al., 1968). The first sample (GSC 66-170) came "from augen gneiss, 4 miles west northwest of Gaultois"; this is the lithology described as foliated Gaultois Granite in this study.

Sample	Rb ppm	Sr ppm	Rb 87/Sr 86	Sr 87/ Sr 86
TON-1	232	120	5.6	0.7529
TON-2	190	155	3.6	0.7354
TON-3	121	196	1.8	0.7308
TON-4	151	303	1.4	0.7225
TON-5	157	392	1.2	0.7168
Leuco-1	172	92	5.4	0.7512
Leuco-2	128	529	0.7	0.7128
Leuco-3	205	134	4.4	0.7396
Leuco-4	184	358	1.5	0.7172
Leuco-5	105	582	0.5	0.7099
GG-1	228	233	2.8	0.7313
GG-2	240	229	3.0	0.7284
GG-3	302	177	4.9	0.7401
GG-4	264	34	23.1	0.8567
GG-5	144	197	2.1	0.7210

Fig. 13. Analyses and isotope ratios for Rb/Sr age determination.

TON = Little Passage Gneisses tonalite. Leuco = North Bay Granite and associated intrusions. GG = Gaultois Granite.

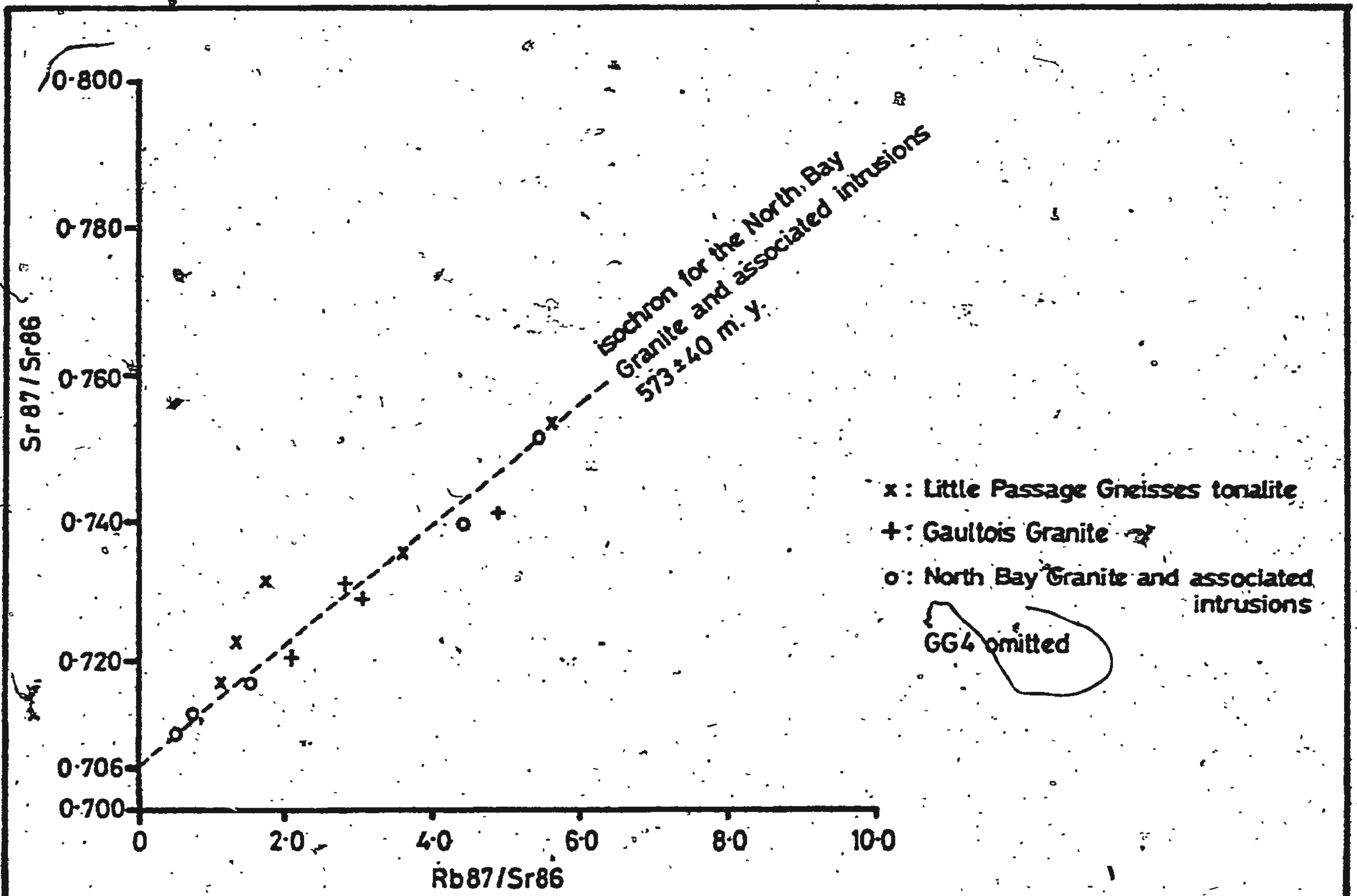


Fig.14. Plot of isotope ratios for Rb/Sr age determinations.

The age derived was 393 ± 16 m.y.

The second sample (GSC 66-171) was collected in Piccaire Harbour from a rock only rarely exposed during exceptionally low tides (F. D. Anderson, pers. comm. 1974), and not observed by the author. It was reported to be a "grey, medium to coarse grained massive biotite granite", somewhat similar in description to the equigranular variety of the Gaultois Granite mentioned in this study (p. 38). However the rock from which the dated sample was taken was reported to cut the foliated Gaultois Granite. Its age was determined as 316 ± 14 m.y.

It is probable that sample GSC 66-170 has a K-Ar age rejuvenated during the Acadian orogeny since it conflicts with all available geological evidence. The age of sample GSC 66-171 may be either rejuvenated or original. If original, it implies the presence of an Upper Carboniferous granite intrusion not seen elsewhere in the area mapped.

REFERENCES

Wanless, R. K., Stevens, R. D., Lachance, G. R. and Edmonds, C. M. 1968. Age determinations and geological studies. K-Ar isotopic ages, Report 8. Canada Geol. Survey Paper 67-2, Part A, 141 p.

APPENDIX 3

MP2 STAUROLITE

Appendix 3 is included on the recommendation of R. St. J. Lambert.

The staurolite occurring in muscovite schist around Snook's Harbour indicates an apparent metamorphic peak after the second deformation (p. 85; Fig. 7; Pl. 74). This is later than the metamorphic peak anywhere else in the Baie d'Espoir Group, and is separated from the MP1 growth of garnet in the same rock by an interval of time during which the Bay d'Espoir Nappe was formed. For the purposes of general description the schist in which the MP2 staurolite occurs has been included with the graphitic schist common in the Isle Galet Formation; as was previously noted (p. 85), however, at this particular locality graphite is less common and in places is completely absent.

Miyashiro (1964) drew attention to the important role of graphite in metamorphic rocks as a buffer of the partial pressure of oxygen approximately equivalent to the FMQ (fayalite-magnetite-quartz) buffer used in experimental work (French, 1966; Hoschek, 1969; Ganguly, 1972). In graphite-free rocks PO_2 may be unusually high and this can have a substantial effect on metamorphic reactions, in particular those involving iron. Ganguly (1968) compared analyses of almandine garnet and staurolite, and came to the conclusion that the distribution of ferric iron is very strongly biased towards staurolite. Thus increasing PO_2 must favour the formation of staurolite relative to almandine and as suggested by Ganguly the staurolite isograd may reflect increasing PO_2 rather than increasing temperature.

It is also of significance that the staurolite at Snook's Harbour has apparently formed by replacement of muscovite and iron oxide; it occurs in rocks where the only chlorite is a late-stage product of the retrogression of garnet, and no chloritoid has been found. This paragenesis compares with that reported by Chakraborty and Sen (1967) from the Iron Ore Series, Bihar, India. They found that the almandine and staurolite isograds were approximately isothermal as measured by the partitioning of ferrous iron and magnesium between garnet and biotite. Ganguly (1972) suggested the possible reaction:

$$\text{Musc} + \text{Mt} + \text{Qtz} + H_2O \rightleftharpoons \text{St} + \text{Bio} + O_2$$

for the first appearance of staurolite at a temperature below those of the more usual reactions involving chlorite or chloritoid.

Thus the MP2 staurolite at Snook's Harbour may not indicate metamorphic temperatures above those generally prevailing at the garnet isograd in graphite-bearing rocks; it may be merely the result of a rise in PO_2 brought about by the complete oxidation of graphite in the rock. It remains to be explained, however, why even this grade of metamorphism should occur at Snook's Harbour after the second deformation when the highest grade elsewhere was reached during the MP1 and MS2 growth stages. Two explanations present themselves. First, the temperature throughout the area may have reached a maximum during MP1 and MS2 and porphyroblast growth was completed at these times; the temperature continued at the same levels until after the second deformation, when further porphyroblast growth (of staurolite) took place locally where equilibrium was disturbed by a rise in PO_2 upon complete oxidation of graphite in the rock.

The second possibility is that the presence of staurolite indicates a second metamorphic event resulting perhaps from strain energy accumulated during D2 or from the intrusion of an unexposed MP2 granite body. These explanations seem less likely because, although there has been intense tectonic deformation in the Snook's Harbour area, significant MP2 growth of any minerals is lacking in equally or more tectonized rocks elsewhere, and there is no evidence anywhere in the Bay d'Espoir area for granite intrusion after the second deformation.

REFERENCES

Chakraborty, K. and Sen, S. 1967. Regional metamorphism around Kandra, Singhbhum, Bihar. Contr. Mineral. Pet., V. 16, pp. 210-32.

French, B. M. 1966. Some geological implications of equilibrium between graphite and a C - H - O gas at high temperatures and pressures. Rev. Geophys., V. 4, pp. 223-53.

Ganguly, J. 1968. Analysis of the stabilities of chloritoid and staurolite and some equilibria in the system FeO - Al_2O_3 - SiO_2 - H_2O - O_2. American Jour. Sci., V. 266, pp. 277-98.

Ganguly, J. 1972. Staurolite stability and related parageneses: theory, experiments, and applications. Jour. Pet., V. 13, pp. 335-65.

Hoschek, G. 1969. The stability of staurolite and chloritoid and their significance in metamorphism of pelitic rocks. Contr. Mineral. Pet., V. 22, pp. 208-32.

Miyashiro, A. 1964. Oxidation and reduction in the Earth's crust with special reference to the role of graphite. Geochim. cosmochim. Acta, V. 28, pp. 717-20.

PLATES

Plate 1

Gneisses intruded by veins of North Bay Granite, North Bay. Width of photograph 10 m.

Plate 2

Tightly folded amphibolitic gneiss intruded by veins of tonalite, Seal Cove Zone, Little Passage Gneisses, Northwest Arm, Piccaire.

Plate 3

Poikiloblastic hornblende in amphibolitic gneiss, Seal Cove Zone, Little Passage Gneisses, Grip Cove, Little Passage. Width of photograph 8 mm.

Plate 4

Biotite with plagioclase lenses between cleavage planes and inclusions of zircon with pleochroic haloes, amphibolitic gneiss, Seal Cove Zone, Little Passage Gneisses, west of Middle Island, Little Passage. Width of photograph 1 mm.

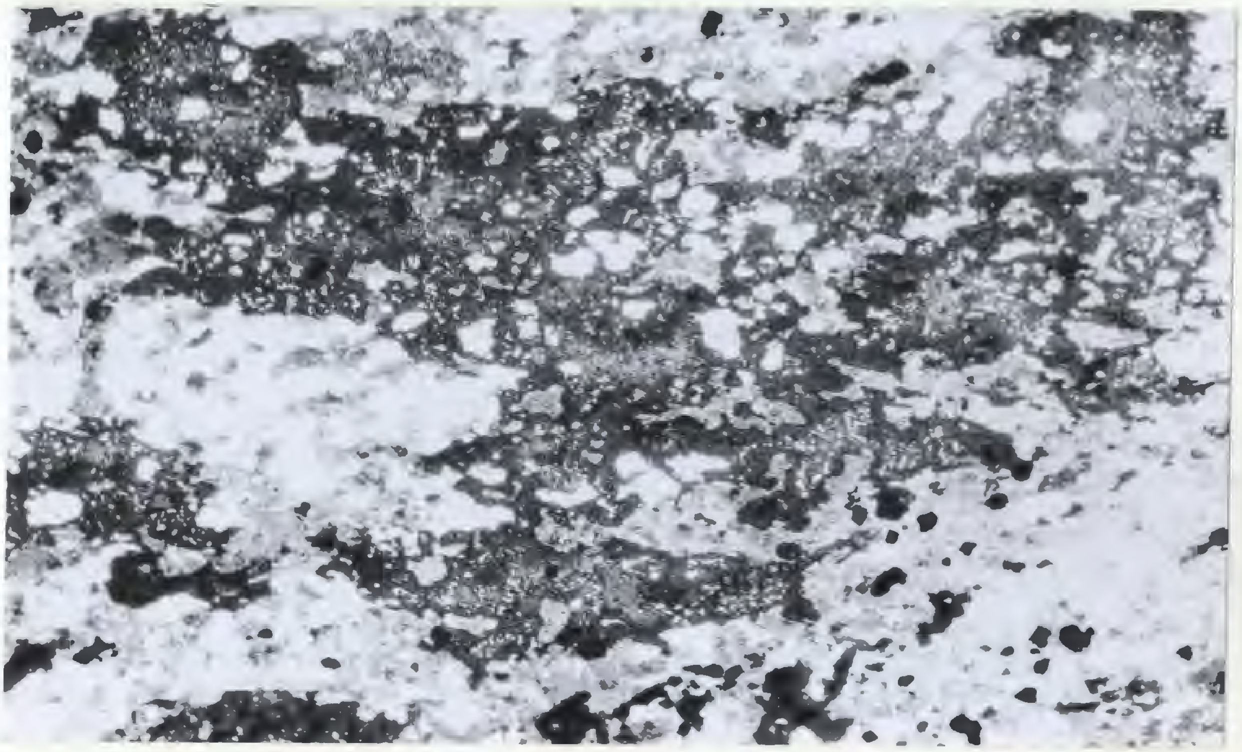


Plate 5

Banding and intrafolial folds in psammitic gneiss, Seal Cove Zone, Little Passage Gneisses, Northwest Arm, Piccaire.

Plate 6

Folded gneissic banding in xenolith of amphibolitic gneiss enclosed in mildly deformed tonalite, Seal Cove Zone, Little Passage Gneisses, southwest of Middle Island, Little Passage.

Plate 7

Isoclinally folded xenolith of amphibolitic gneiss enclosed in intensely deformed tonalitic gneiss, Seal Cove Zone, Little Passage Gneisses, southwest of Middle Island, Little Passage.

Plate 8

Gaultois Granite pegmatite cutting tonalitic gneiss in the Seal Cove Zone of the Little Passage Gneisses, Seal Cove, Little Passage.

Plate 9

Folded gneissic banding in intensely deformed tonalitic gneiss, Seal Cove Zone, Little Passage Gneisses, east of Middle Island, Little Passage.

Plate 10

Relict gneissic banding in zone of massive anatectically remobilised tonalitic gneiss, Seal Cove Zone, Little Passage Gneisses, east of Middle Island, Little Passage.


MILLIMETRES
CENTIMETRES

Plate 11

Fibrolitic sillimanite formed by alteration of biotite in tonalite, Seal Cove Zone, Little Passage Gneisses, north of Seal Cove, Little Passage. Width of photograph 2 mm.

Plate 12

Open F1 folds in quartz-plagioclase-mica gneiss at the southern edge of the Stickland Cove Zone, Little Passage Gneisses, south of Stickland Cove, Little Passage.

Plate 13

Kink bands formed during D1 in a muscovite grain in quartz-plagioclase-mica gneiss at the southern edge of the Stickland Cove Zone, Little Passage Gneisses, just north of Seal Nest Cove, Little Passage. Width of photograph 3 mm.

Plate 14

F1 folds in a Gaultois Granite pegmatite vein intruding quartz-plagioclase-mica gneiss, Stickland Cove Zone, Little Passage Gneisses, Stickland Cove, Little Passage. Width of photograph 2 m.

Plate 15.

F2 fold closure in a biotite and fibrolitic sillimanite band in quartz-plagioclase-mica gneiss, Stickland Cove Zone, Little Passage Gneisses, Maria Cove Point, Little Passage. Width of photograph 3 mm.

Plate 16

Hydromuscovite in quartz-plagioclase-mica gneiss, Stickland Cove Zone, Little Passage Gneisses, Maria Cove Point, Little Passage. Width of photograph 3 mm.

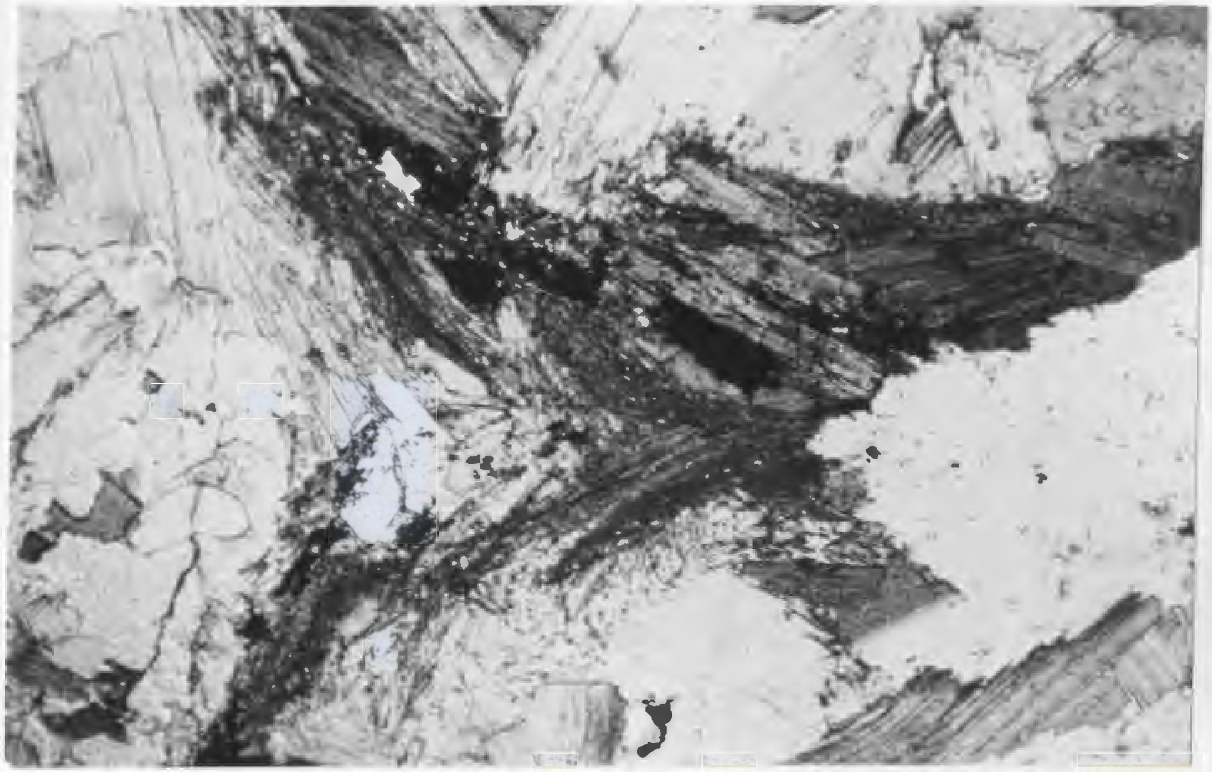


Plate 17

Hydromuscovite in quartz-plagioclase-mica gneiss, Stickland Cove Zone, Little Passage Gneisses, Maria Cove Point, Little Passage. Width of photograph 1 mm.

Plate 18

Poikiloblastic MP1 plagioclase with an included D1 fabric; S1 has been openly folded and the plagioclase fractured during D2. Amphibolitic gneiss, Stickland Cove Zone, Little Passage Gneisses, Deer Cove, Little Passage. Width of photograph 3 mm.

Plate 19

Augen formed by S2 around poikiloblastic MP1 plagioclase containing straight discordant inclusion trails of S1. Quartz-plagioclase-mica gneiss, Stickland Cove Zone, Little Passage Gneisses, southwest of Grip Island, north coast of Long Island. Width of photograph 3 mm.

Plate 20

D2 cataclastic fabric in quartz-plagioclase-mica gneiss adjacent to the Day Cove Thrust, Stickland Cove Zone, Little Passage Gneisses, Day Cove, Little Passage. Width of photograph 3 mm.

Plate 21

F2 fold closures in D2 mylonite formed from quartz-plagioclase-mica gneiss, Stickland Cove Zone, Little Passage Gneisses, south of Grip Island, north coast of Long Island.

Plate 22

F2 folds in gneissic banding, amphibolitic gneiss, Stickland Cove Zone, Little Passage Gneisses, just north of Maria Cove, Little Passage.

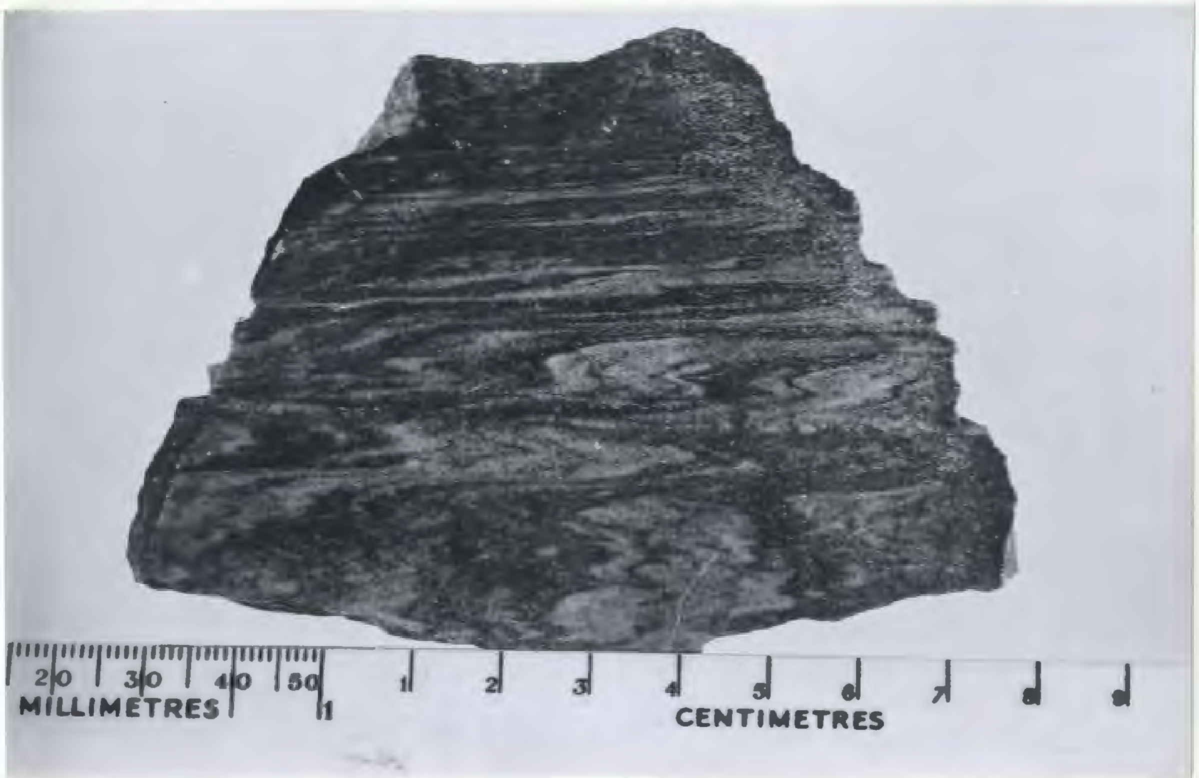

MILLIMETRES
CENTIMETRES

Plate 23

Zoned plagioclase phenocryst in the Seal Nest Cove Tonalite, Seal Nest Cove, Little Passage. Width of photograph 2 mm.

Plate 24

Porphyroblasts of potassium feldspar in tonalitic gneiss of the Little Passage Gneisses, near the outcrop of the Gaultois Granite, northeast of L'Anse à Flamme, Little Passage.

Plate 25

Aplite vein cutting porphyritic Gaultois Granite; the trace of S1 runs across the photograph. Northwest Arm, Piccaire.

Plate 26

Xenoliths of amphibolitic gneiss in the Gaultois Granite, first island opposite L'Anse à Flamme, Little Passage.

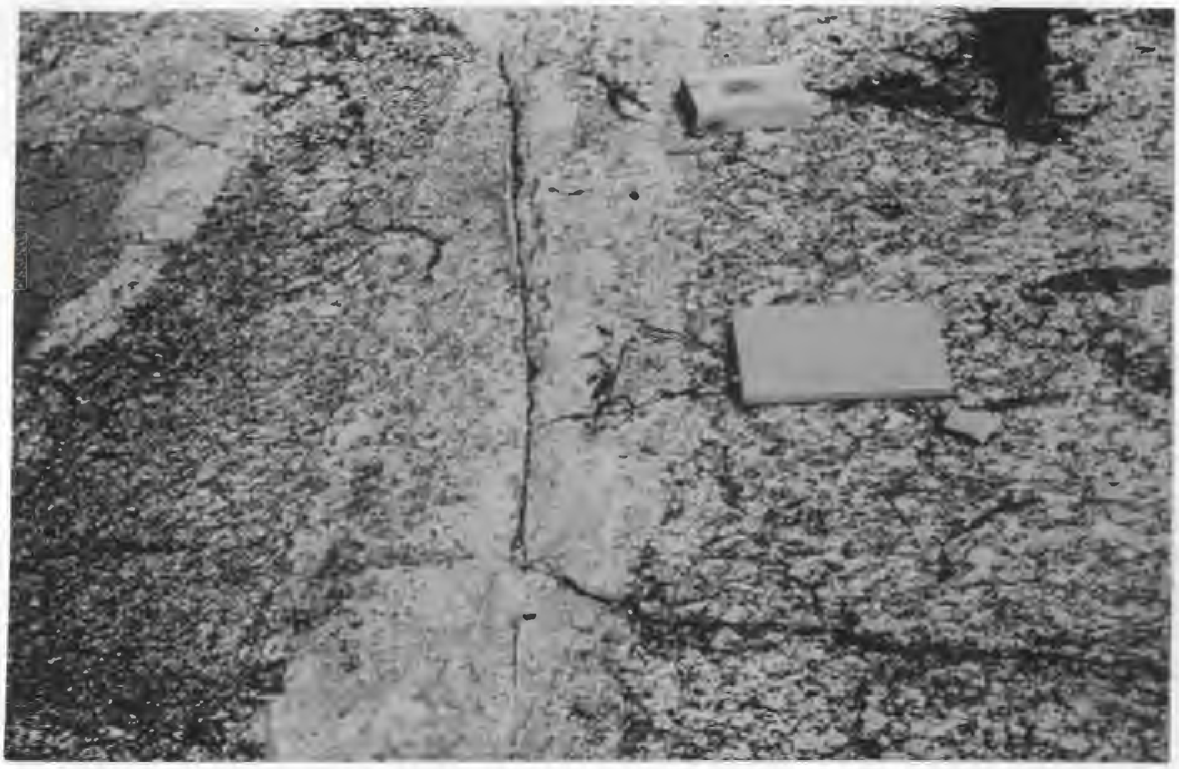


Plate 27

Xenolith of foliated (D1) Gaultois Granite cut by a vein of leucocratic granite which has been injected between foliation planes; the leucocratic granite has a D2 tectonic fabric. Head of Sam Hitches Harbour, Long Island.

Plate 28

Dacite (top) intruded into tonalitic gneiss (bottom), Middle Island, Little Passage.

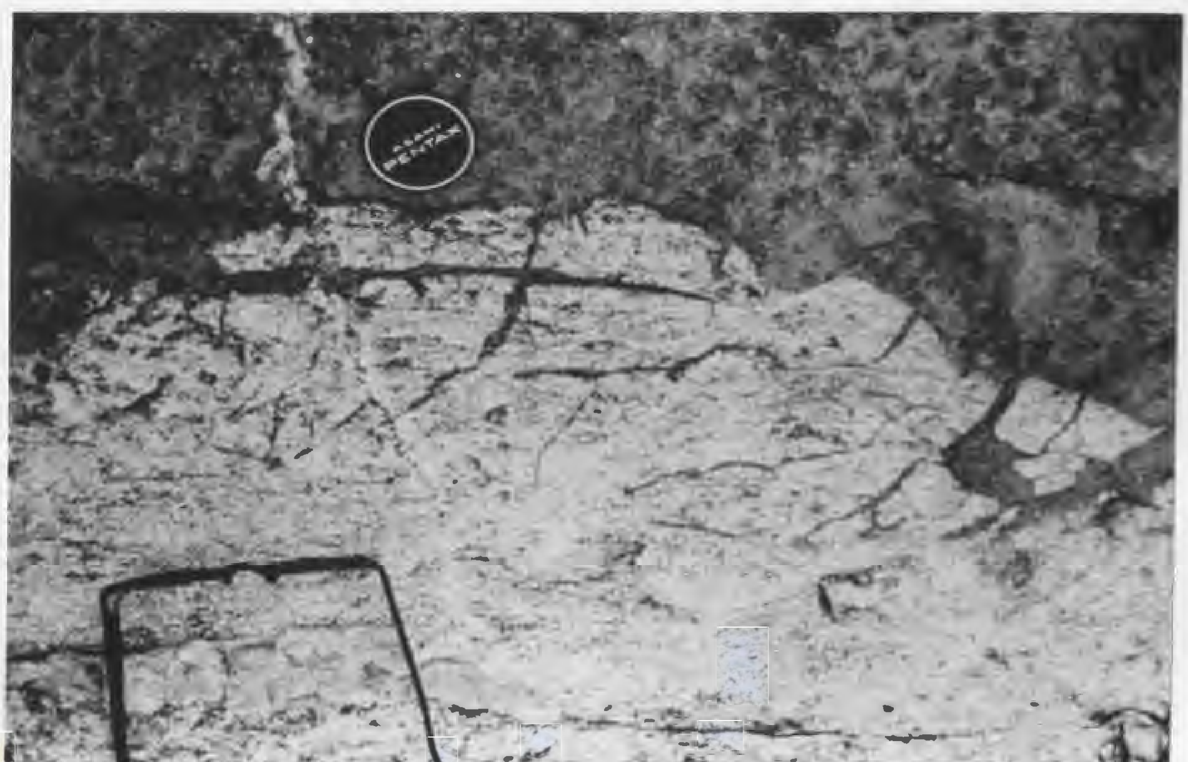
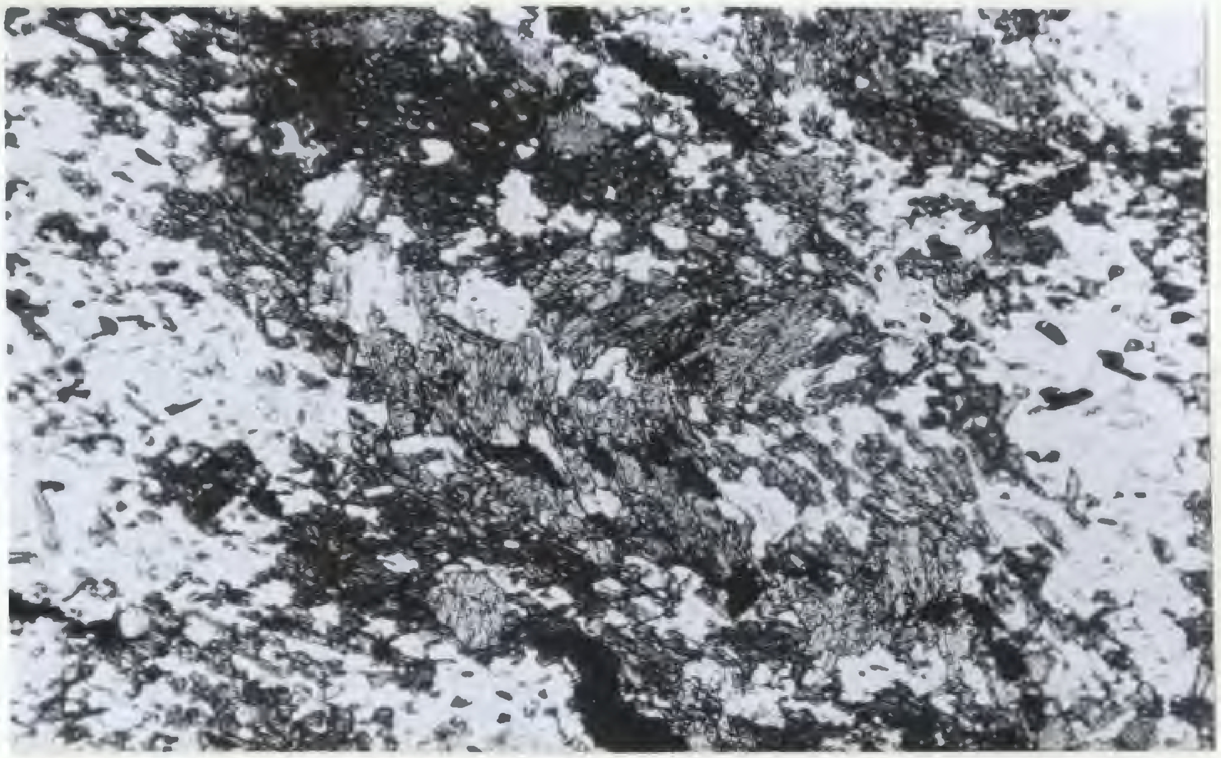

PENTAX

Plate 29

F2 fold in the D1 fabric defined by hornblende needles, amphibolite dyke intrusive into the Little Passage Gneisses of the Stickland Cove Zone, east of Hatcher Cove. Width of photograph 3 mm.

Plate 30

Plagioclase phenocryst in the dacite dyke on Middle Island, Little Passage; the preferred orientation of the biotite grains from the NW of the photograph to the SE defines S1. Width of photograph 3 mm.



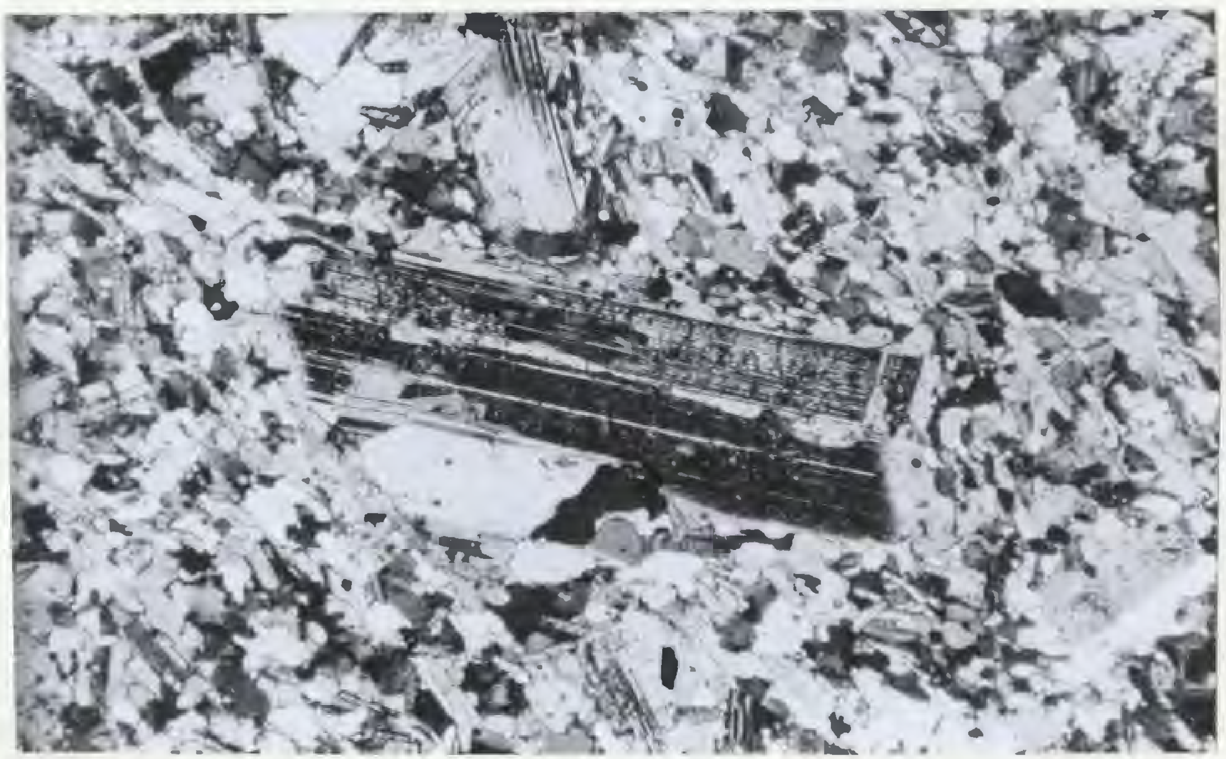


Plate 31

Sills of North Bay Granite in semipelitic schist of the Riches Island Formation, Pomley Cove, Lampidoes Passage. Width of photograph 30 m.

Plate 32

F2 folds in North Bay Granite sills intruding the Riches Island Formation at the edge of the North Bay Granite, Pomley Cove, Lampidoes Passage. Width of photograph 30 m.

Plate 33

F2 folds in North Bay Granite sills intruding the Riches Island Formation at the edge of the North Bay Granite, Pomley Cove, Lampidoes Passage.

Plate 34

D2 boudinage in a North Bay Granite sill intruding the Riches Island Formation, Northwest Cove, Lampidoes Passage. Width of photograph 5 m.

Plate 35

Isoclinal F2 fold in garnetiferous leucocratic granite sill intruding the Little Passage Gneisses of the Stickland Cove Zone, southwest of Grip Island, north coast of Long Island.

Plate 36

Veins of garnetiferous leucocratic granite flattened parallel to the mylonitic banding in the Little Passage Gneisses of the Stickland Cove Zone, Dolland Bight.

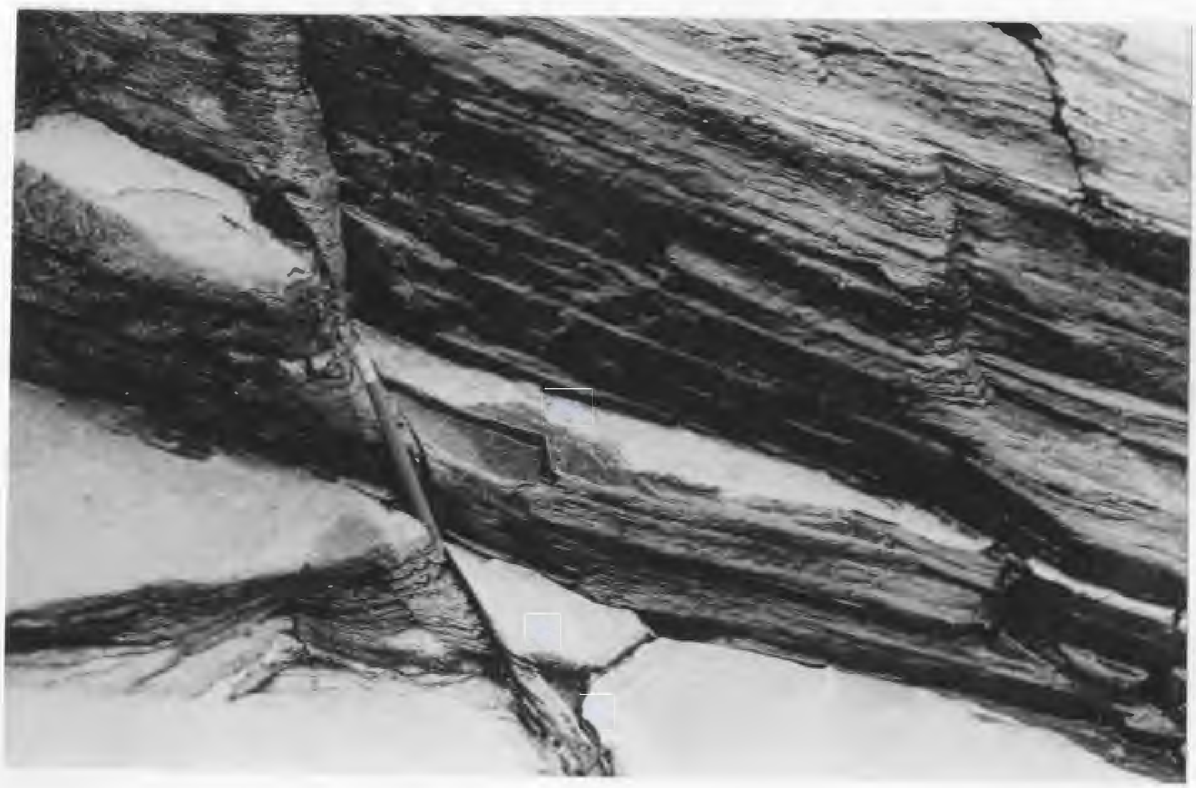


Plate 37

D2 stretching lineation in garnetiferous leucocratic granite vein, southwest of Grip Island, north coast of Long Island.

Plate 38

Garnetiferous leucocratic granite veins intruding the Little Passage Gneisses of the Seal Cove Zone, near Dolland Bight.

Plate 39

Oscillatory zoning and simple twinning in plagioclase, North Bay Granite, North Bay. Width of photograph 8 mm.

Plate 40

Quartz vein cutting acid volcanic tuff of the Isle Galet Formation with a well developed S2 schistosity, near Raymond Point, Long Island.

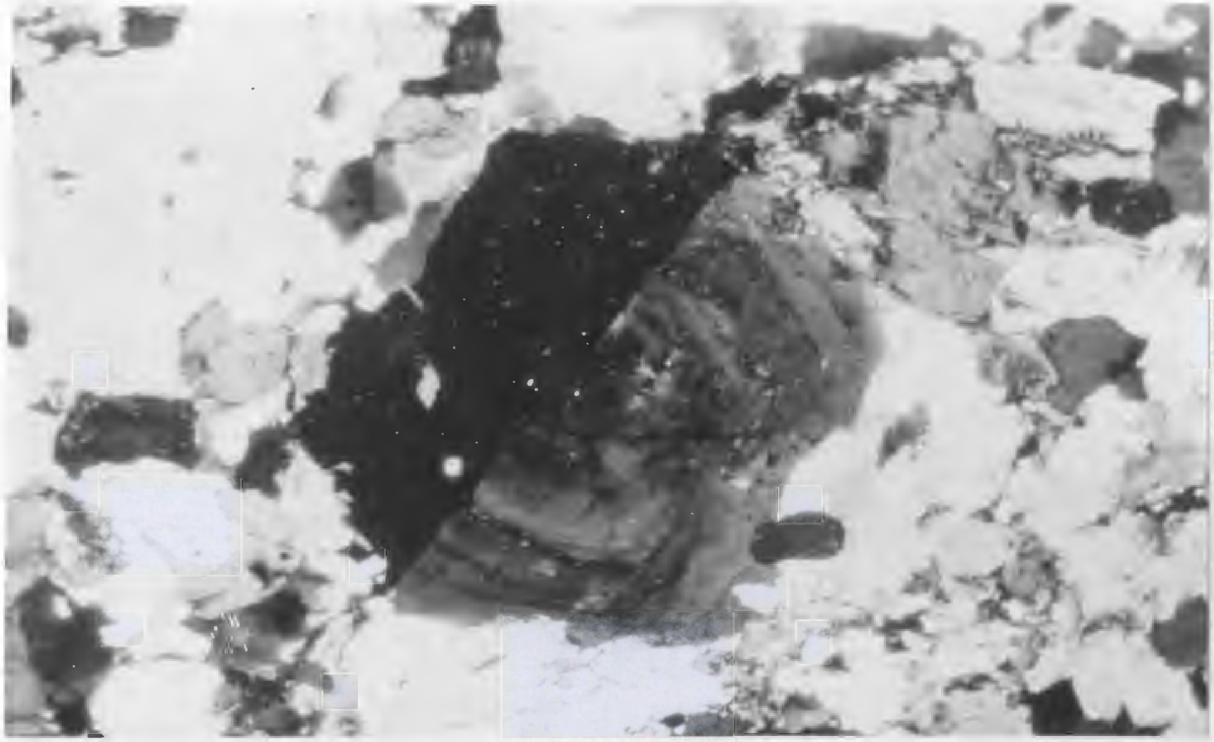


Plate 41

Mineralized quartz vein cutting foliated Gaultois Granite, Blunder Cove, Long Island.

Plate 42

Interbedded siltstone and pelite cut by the S2 cleavage, St. Alban's Formation, St. Joseph's.

Plate 43

Cross and parallel lamination in siltstone overlain by pelite, St. Alban's Formation, Head of Bay D'Espoir.

Plate 44

Parallel lamination in siltstone bed, St. Alban's Formation, St. Joseph's.


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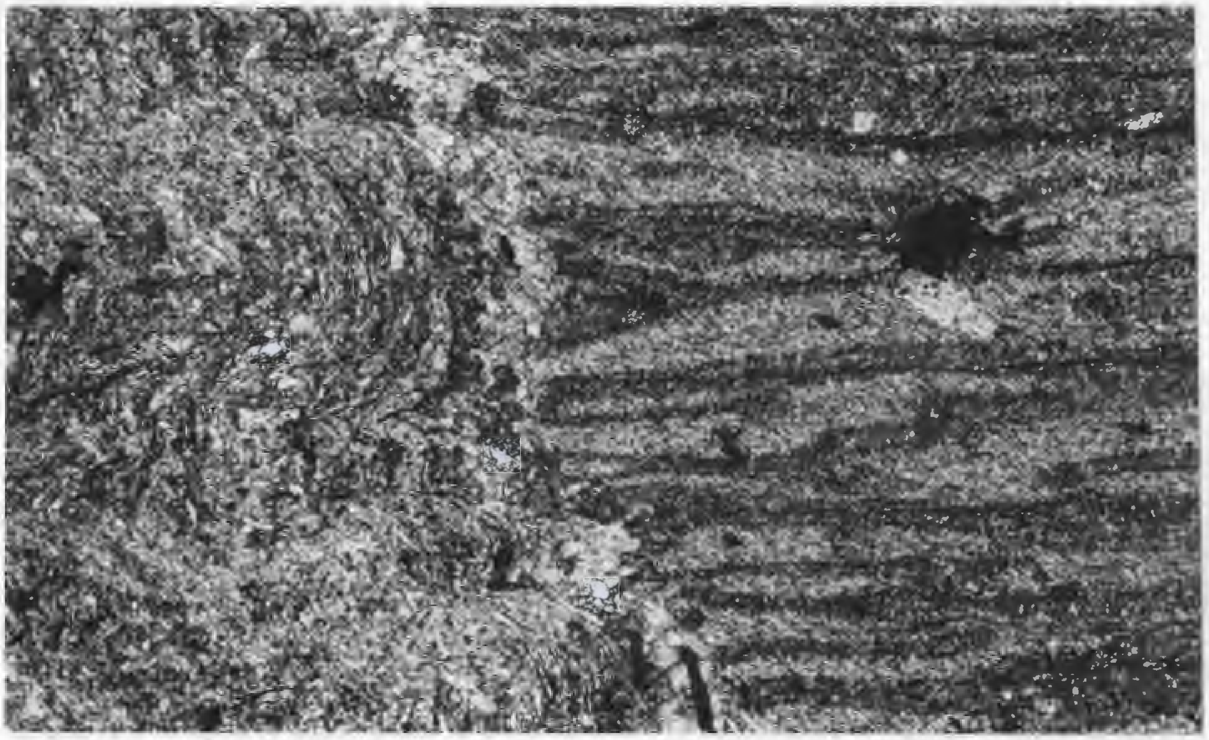
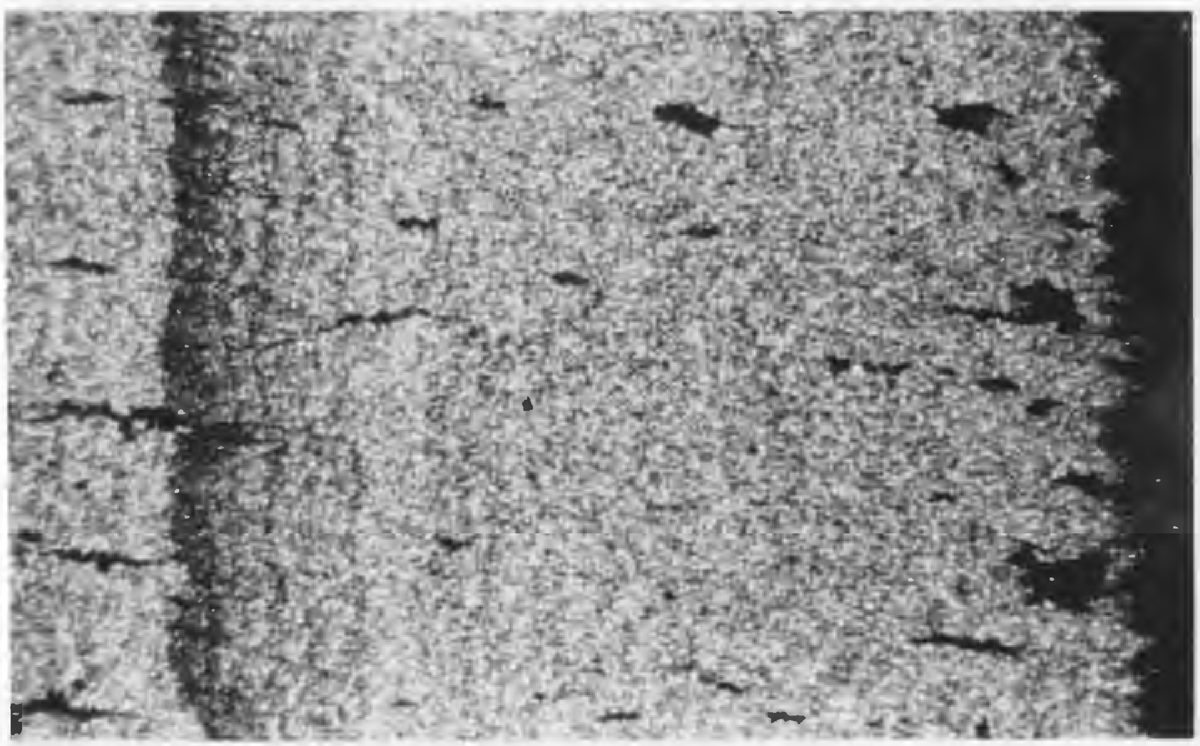
Plate 45

Microscopic grading in a siltstone bed, St. Alban's Formation, Brant Cove. Length of photograph 6 mm.

Plate 46

S2 crenulation cleavage formed by deformation of S1 penetrative cleavage in pelite beds; F2 crinkling of S1 in overlying siltstone bed; St. Alban's Formation, St. Alban's. Length of photograph 3 mm.





Plates 47 and 48

Injection of siltstone along slaty cleavage planes during F1 folding and dewatering; St. Alban's Formation, Man of War Head, St. Alban's.

Plate 49

MP1 biotite (dark patch) overgrowing a penetrative S1 cleavage; the biotite has undulose extinction due to F2 crinkling and is cut by D2 microfaults; St. Alban's Formation, St. Alban's. Width of photograph 2 mm.

Plate 50

Quartz-garnet beds in semipelitic chlorite schist, folded by F2 folds, Riches Island Formation, Riches Island.

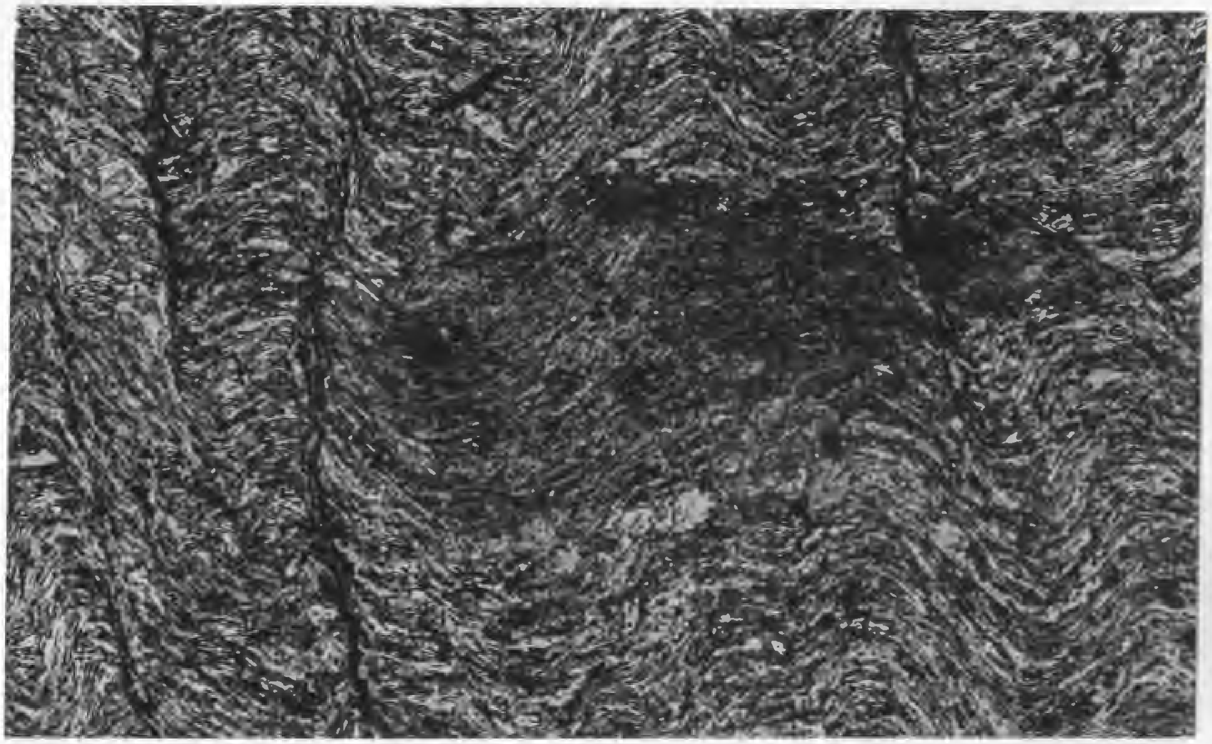


Plate 51

MP1 garnet with a straight inclusion trail of the S1 schistosity and an inclusion-free rim; S2 defined by biotite forms an augen around the garnet; Riches Island Formation, 2 km. south of Frenchman Cove. Width of photograph 3 mm.

Plate 52

MP1 chlorite porphyroblast deformed by D2, Riches Island Formation, east end of Lampidoes Passage. Width of photograph 1.5 mm.

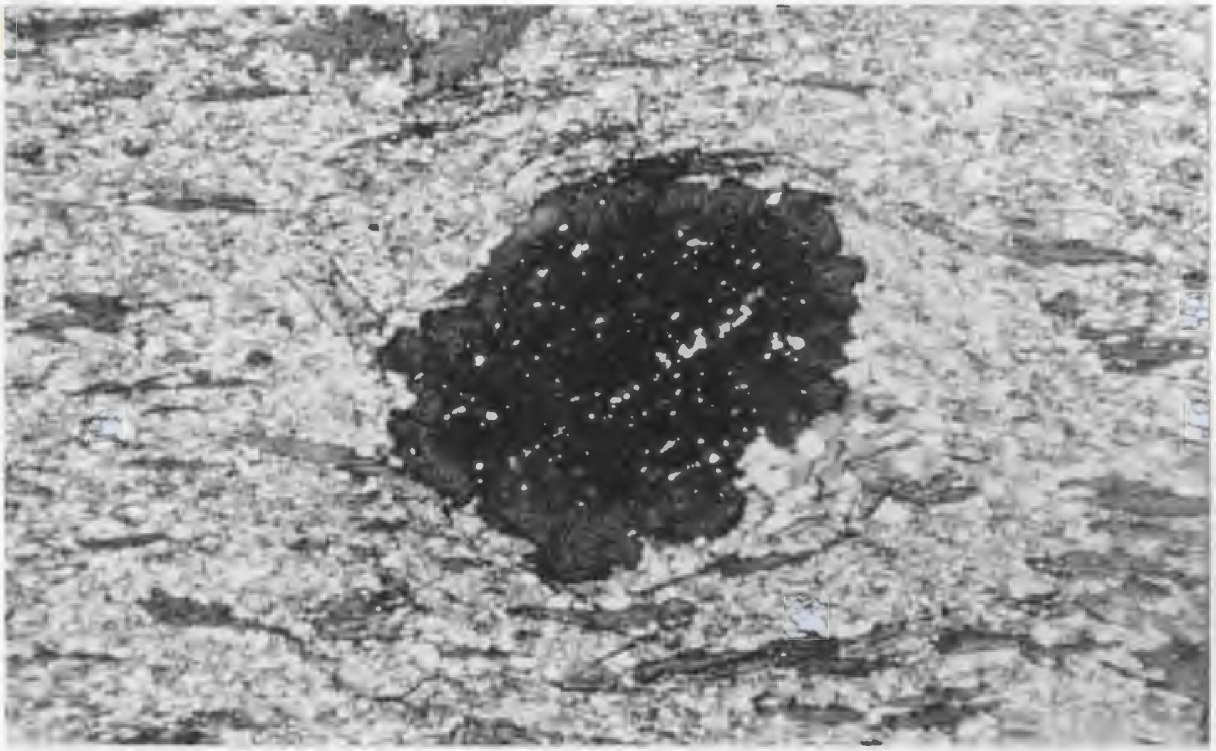
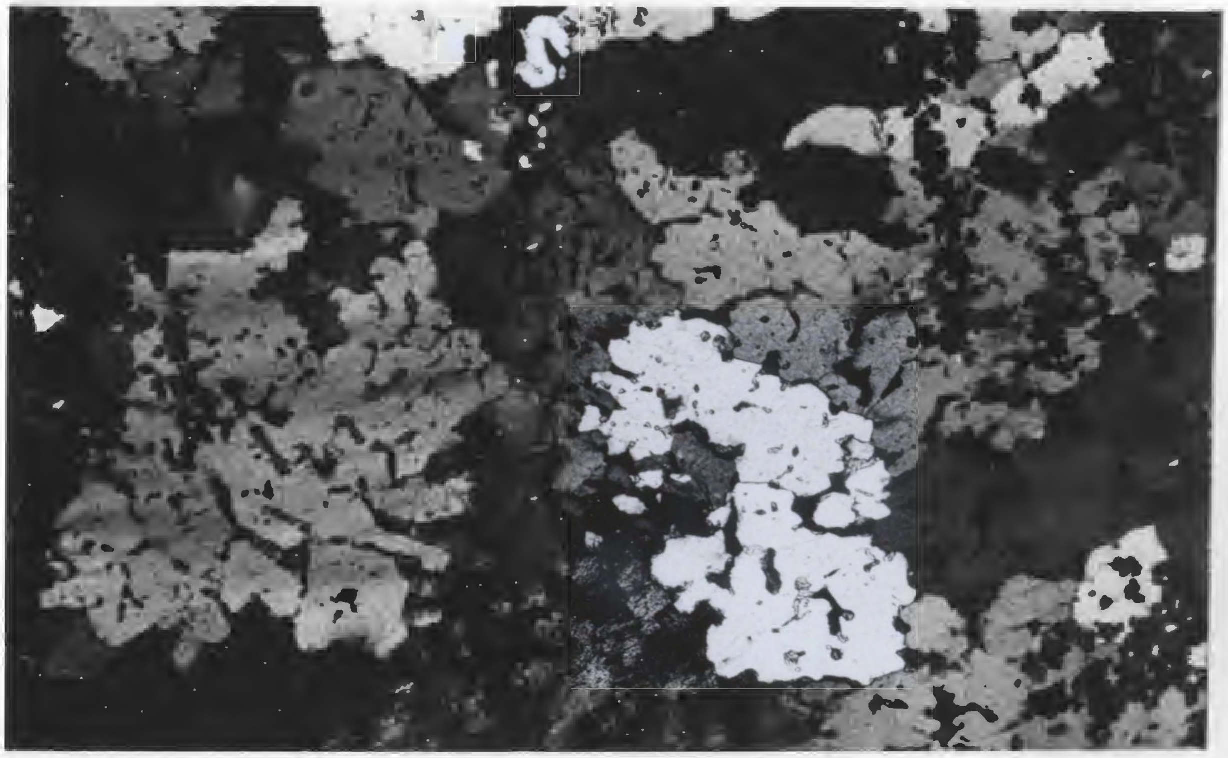


Plate 53

MP2 annealed quartz grains with inclusions of chlorite and garnet defining the polygonal texture developed after D1, Riches Island Formation, Riches Island. Width of photograph 3 mm.

Plate 54

MP1 staurolite with straight inclusion trails of the S1 fabric; a crenulation schistosity has formed in S1 during D2 and forms an augen around the staurolite, Riches Island Formation, northeast Pomley Cove, Lampidoes Passage. Width of photograph 6 mm.



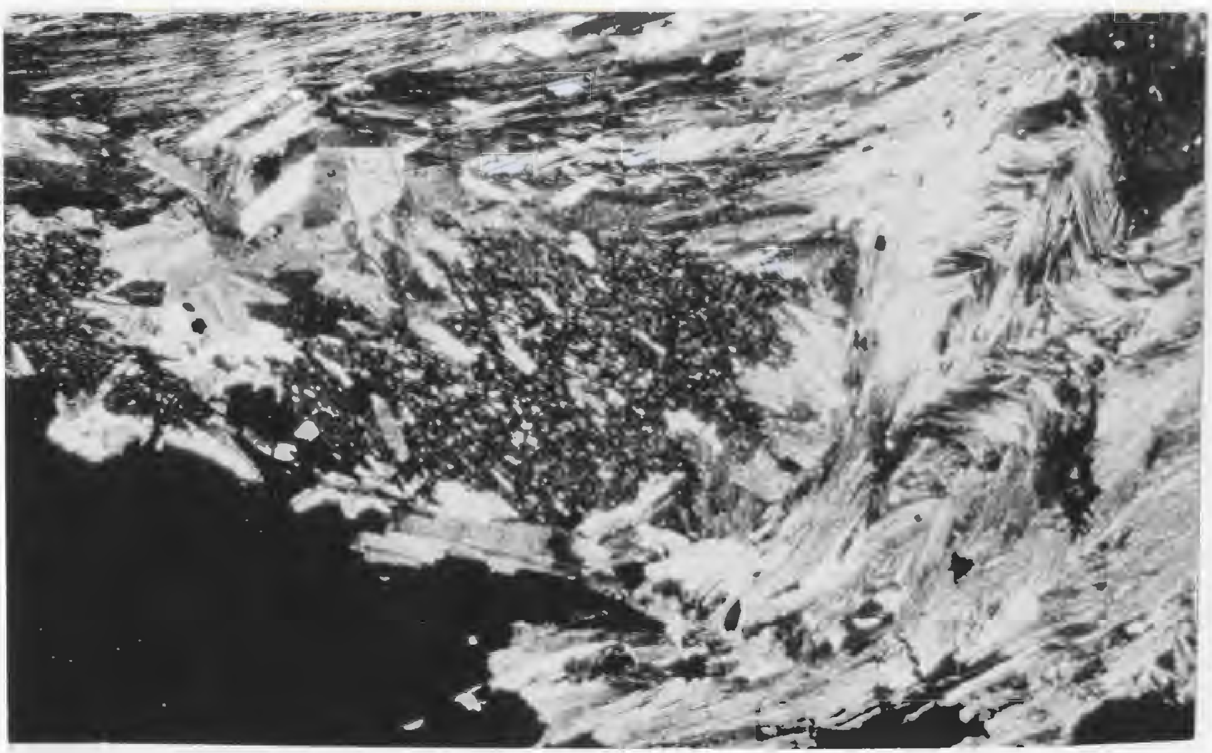


Plate 55

Fibrolitic sillimanite formed from biotite, Riches Island Formation, northeast Pomley Cove, Lampidoes Passage. Width of photograph 1 mm.

Plate 56

MS2 kyanite defining S2 in semipelitic schist, Riches Island Formation(?), southeast of Rocky Hill. Width of photograph 3 mm.

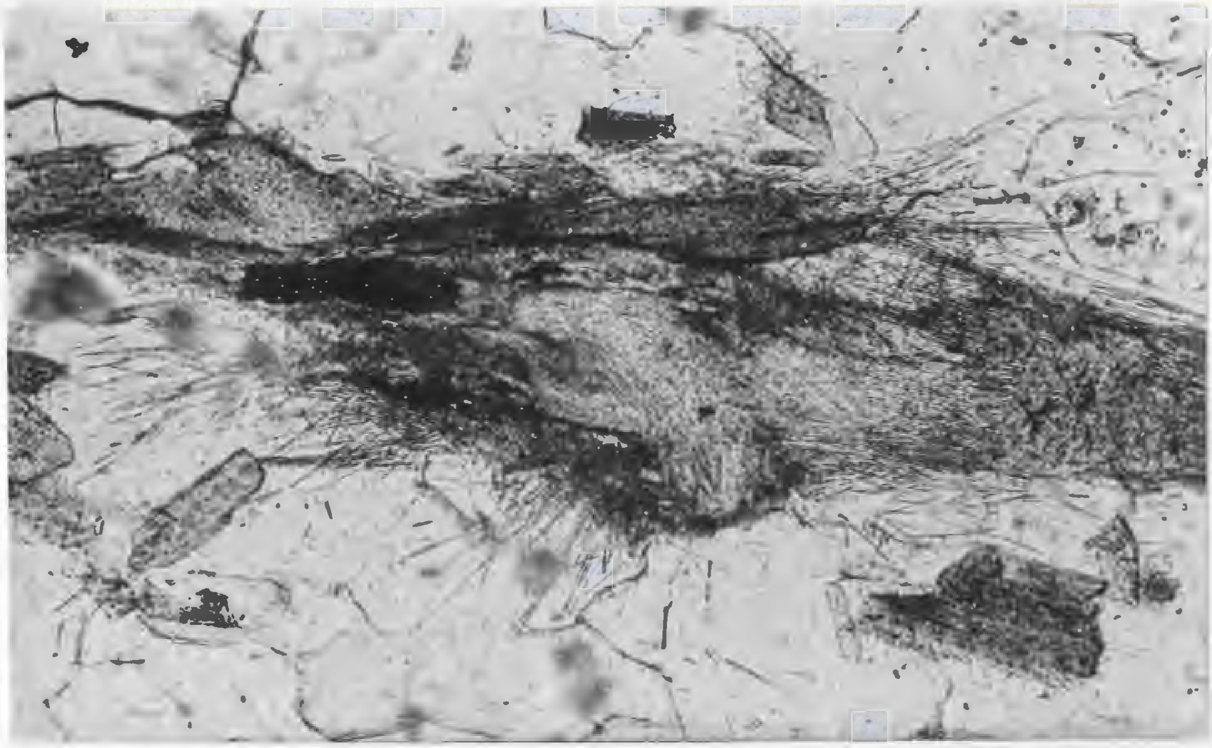


Plate 57

Graphitic inclusions forming a six-rayed star in garnet, Riches Island Formation, Riches Island. Width of photograph 1 mm.

Plate 58

Biotite occupying the cores of garnet grains, northeast Pomley Cove, Lampidoes Passage. Width of photograph 1 mm.

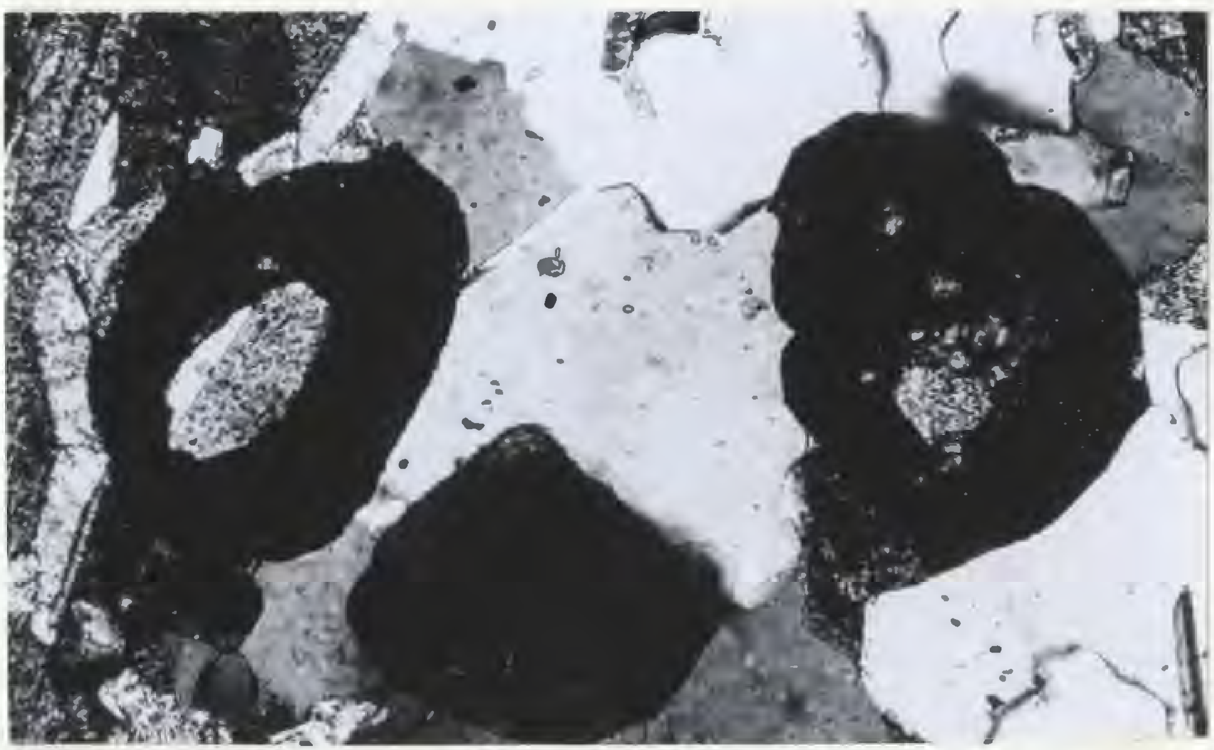


Plate 59

S2 cleavage intersecting psammite beds in semipelitic mica schist, Riches Island Formation, Roti Bay. North is to the right of the photograph.

Plate 60

Polygonal texture formed in quartz after D1, Riches Island Formation, 2 km. south of Frenchman Cove. Width of photograph 3 mm.

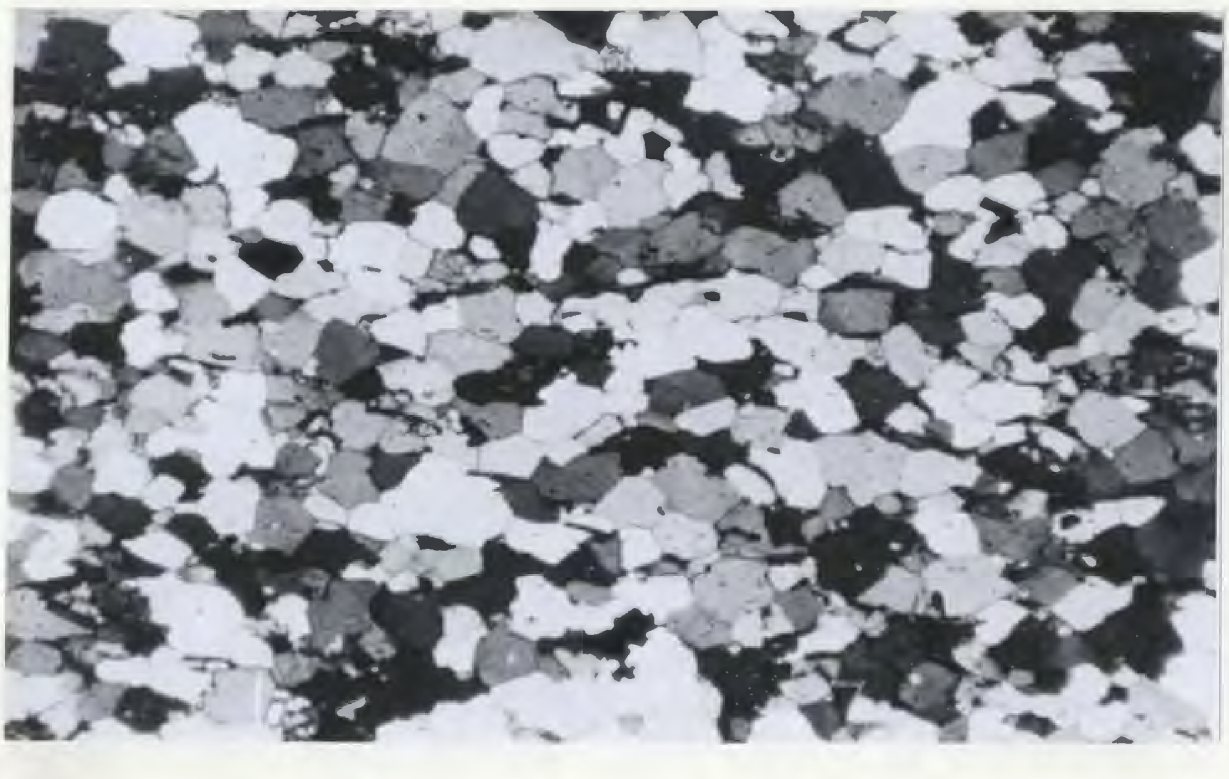
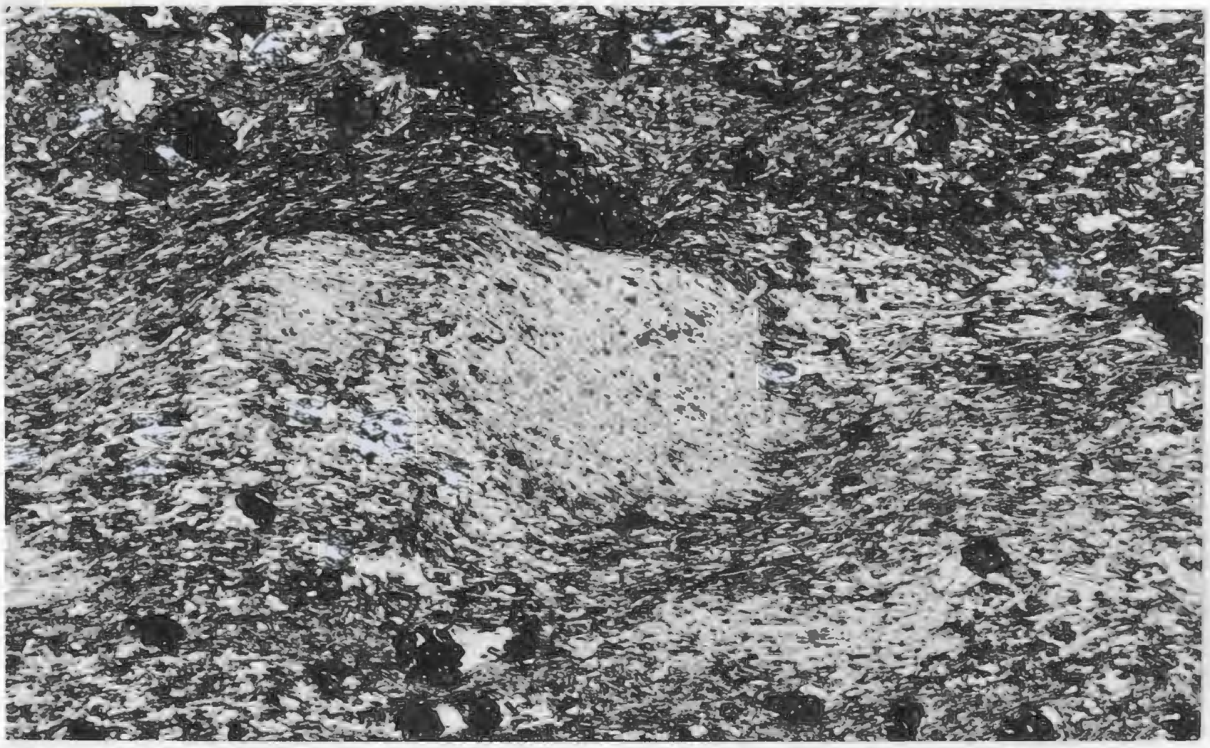


Plate 61

Aggregates of muscovite containing S1 inclusion trails and with augen formed around them by S2, Riches Island Formation, Roti Point. Width of photograph 3 mm.

Plate 62

Flattened amygdales in metabasalt, Riches Island Formation, Riches Island.



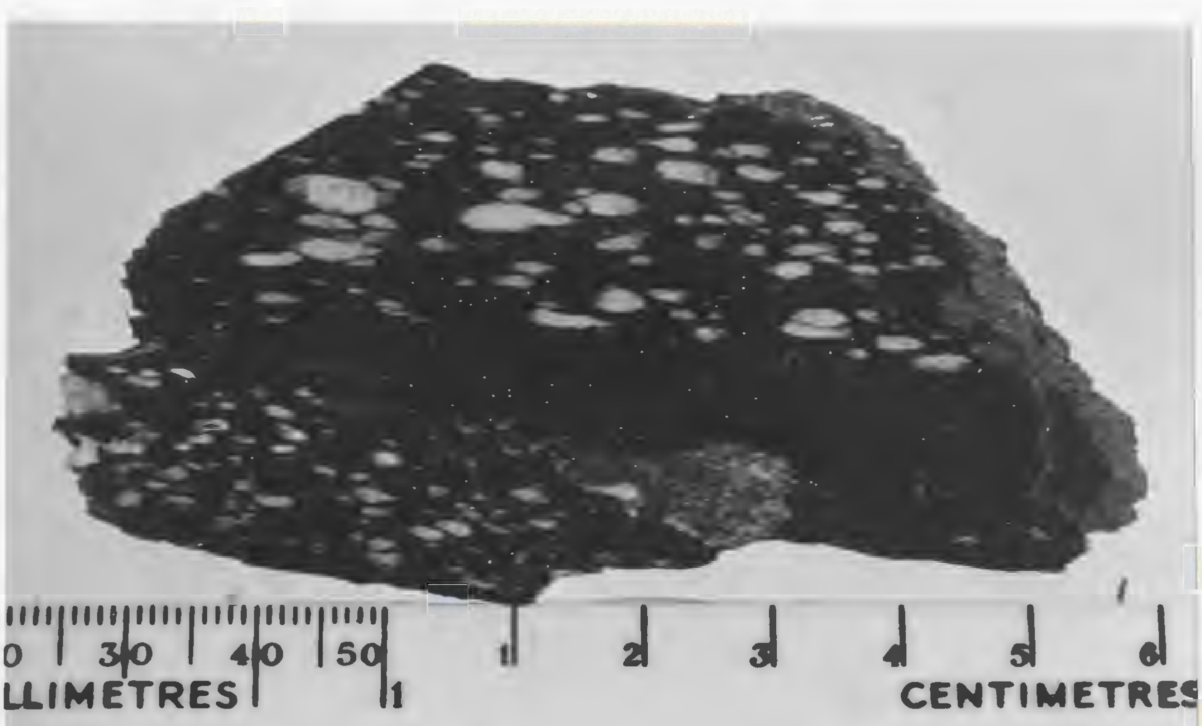

0 30 40 50 1 2 3 4 5 6
LLIMETRES 1 CENTIMETRES

Plate 63

A sheet of unbedded quartzo-feldspathic acid crystal tuff overlying bedded tuff, Isle Galet Formation, Isle Galet. Width of photograph 50 m.

Plate 64

Lapilli tuff with flattened lapilli, Isle Gallet Formation, Flobber Cove, Bois Island.

Plate 65

Phenocryst of microcline in a fragment in lapilli tuff, Isle Galet Formation, Flobber Cove, Bois Island. Width of photograph 3 mm.

Plate 66

S2 schistosity in acid crystal tuff, Isle Galet Formation, northeast of Cape Mark.

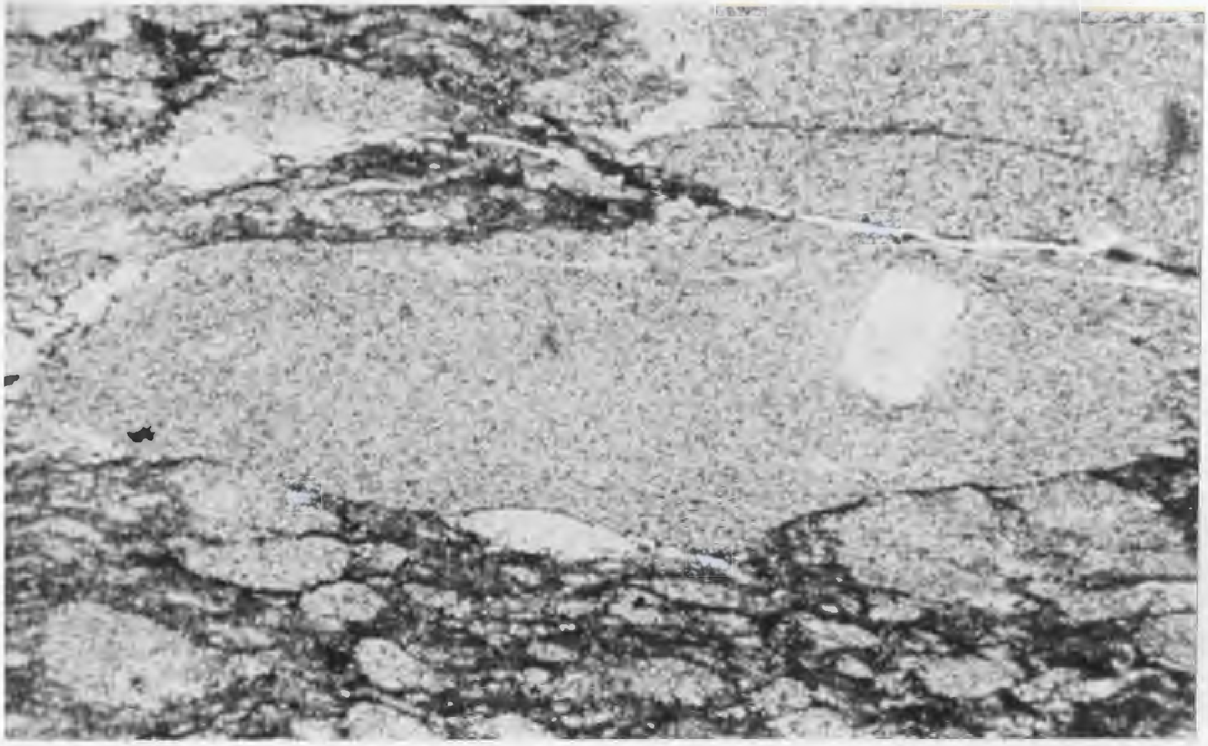



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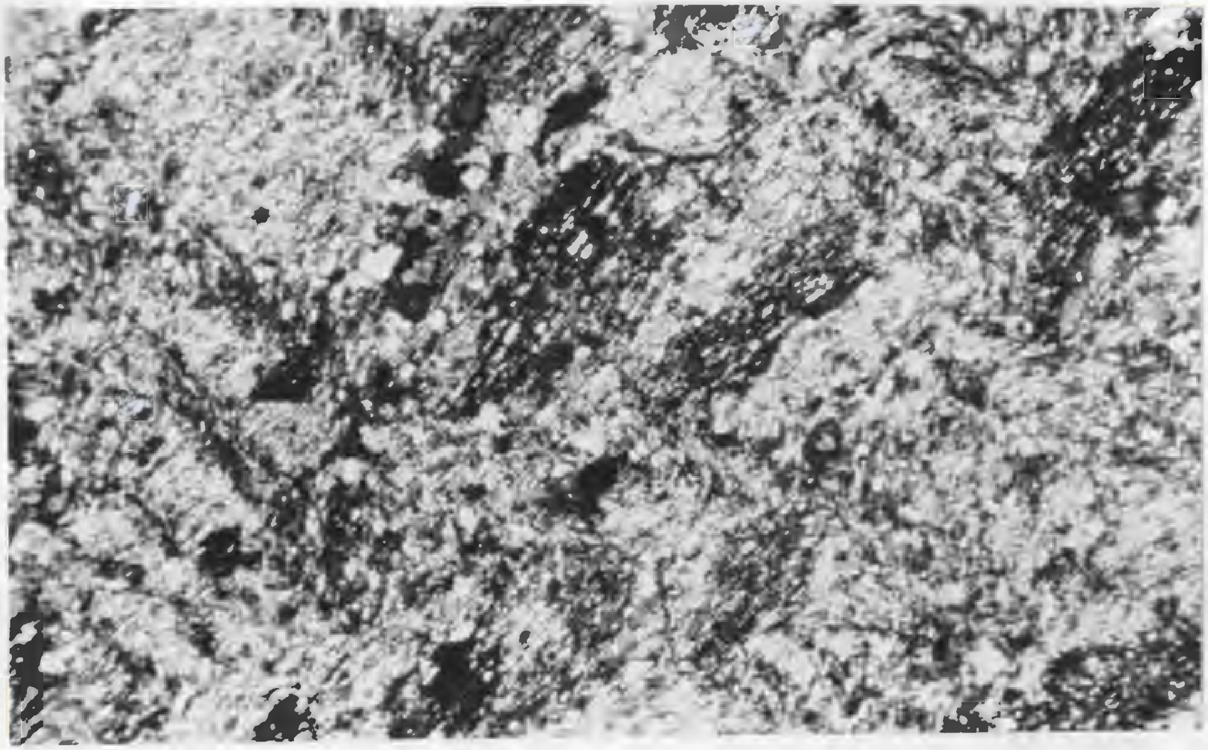
Plate 67

MP1 albite (black) with straight inclusion trails of S1; S1 is crenulated by F2; Isle Galet Formation, Flobber Cove, Bois Island. Width of photograph 3 mm.

Plate 68

Hexagonal cross section of high quartz crystal in acid crystal tuff, Isle Galet Formation, Raymond Point, Long Island. Width of photograph 1 mm.



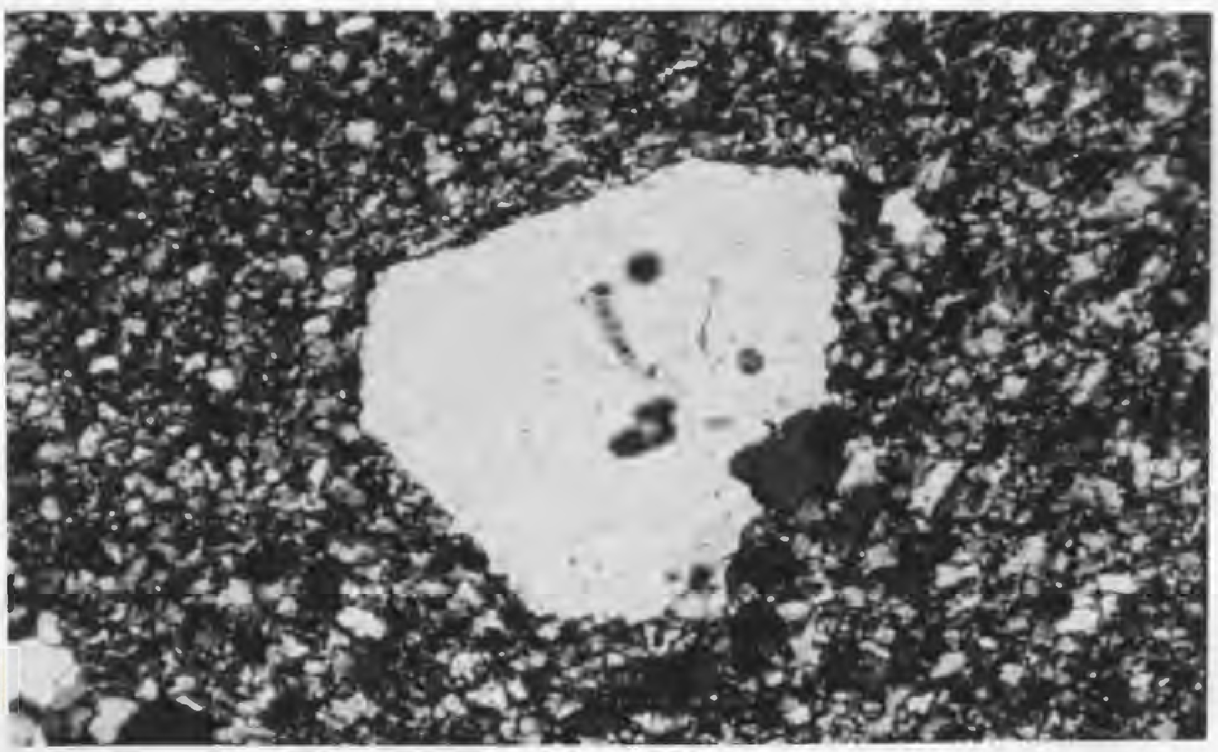
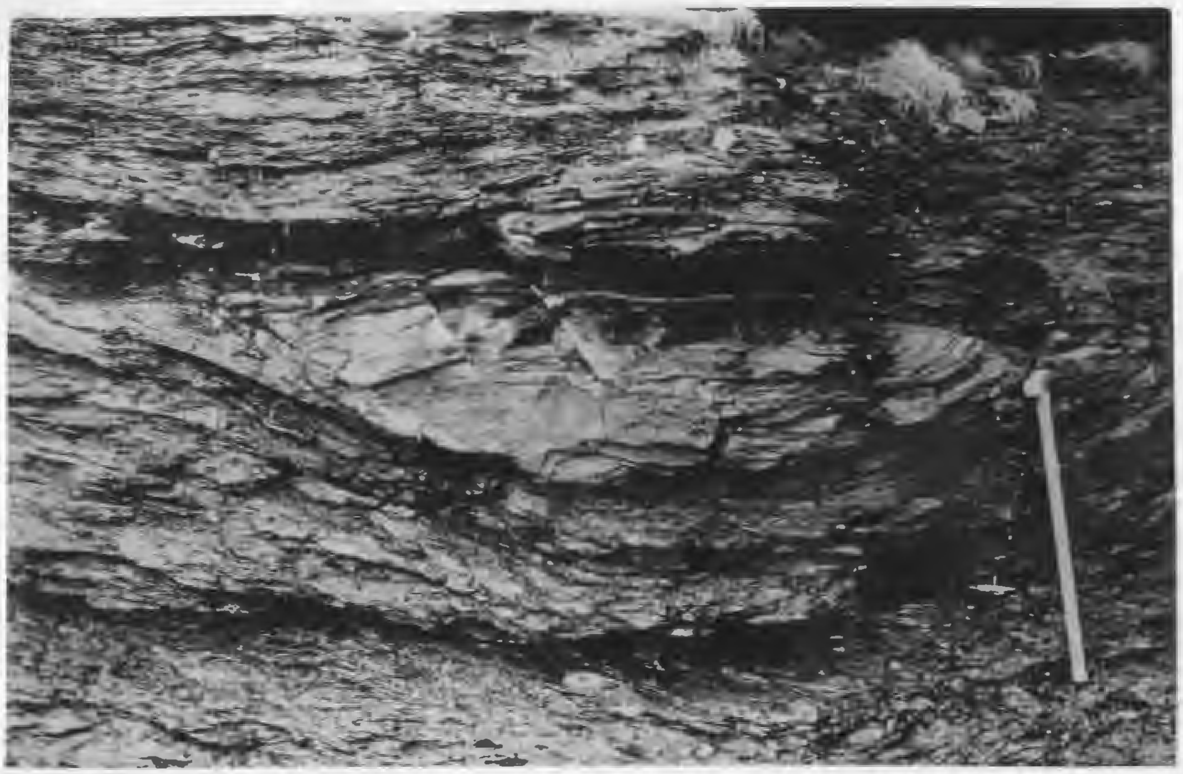


Plate 69

A slice of amphibolite within tectonically disrupted graphitic schist, Isle Galet Formation, Raymond Point, Long Island.

Plate 70

F2 fold in the S1 schistosity defined by hornblende needles, amphibolitic tuff, Isle Galet Formation, Simmond's Barasway. Width of photograph 8 mm.



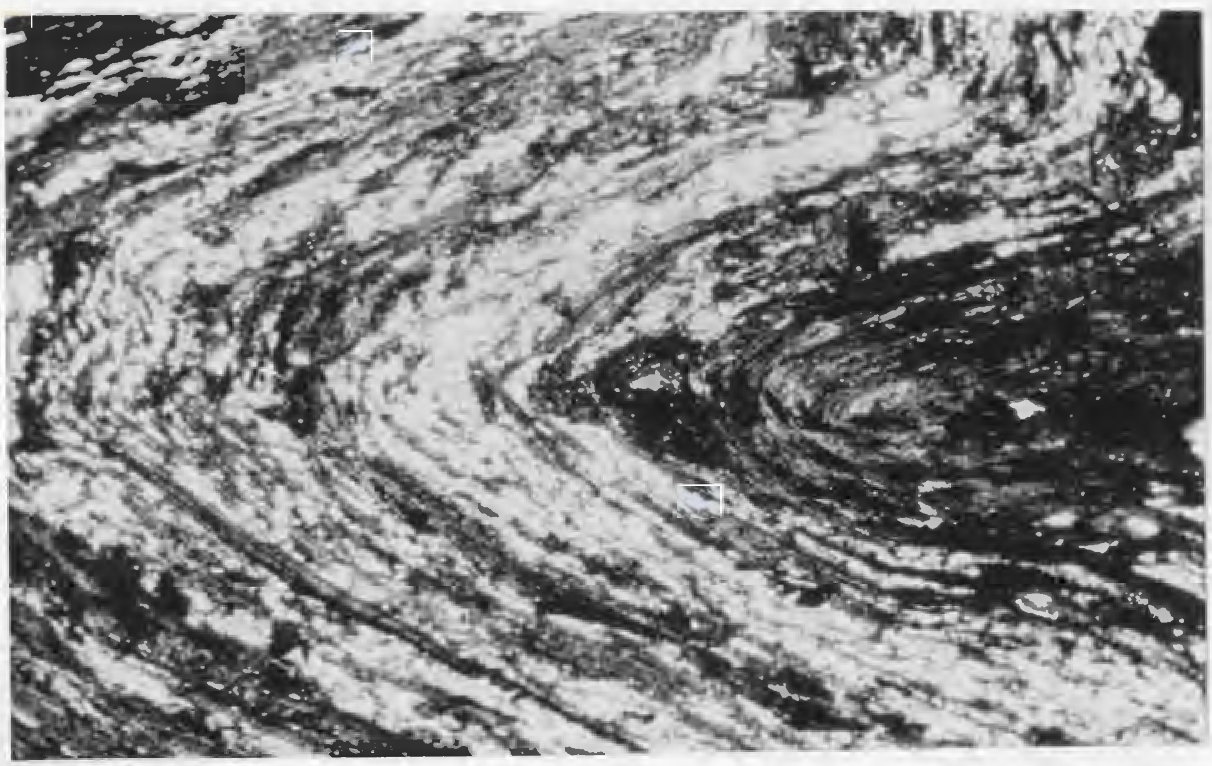
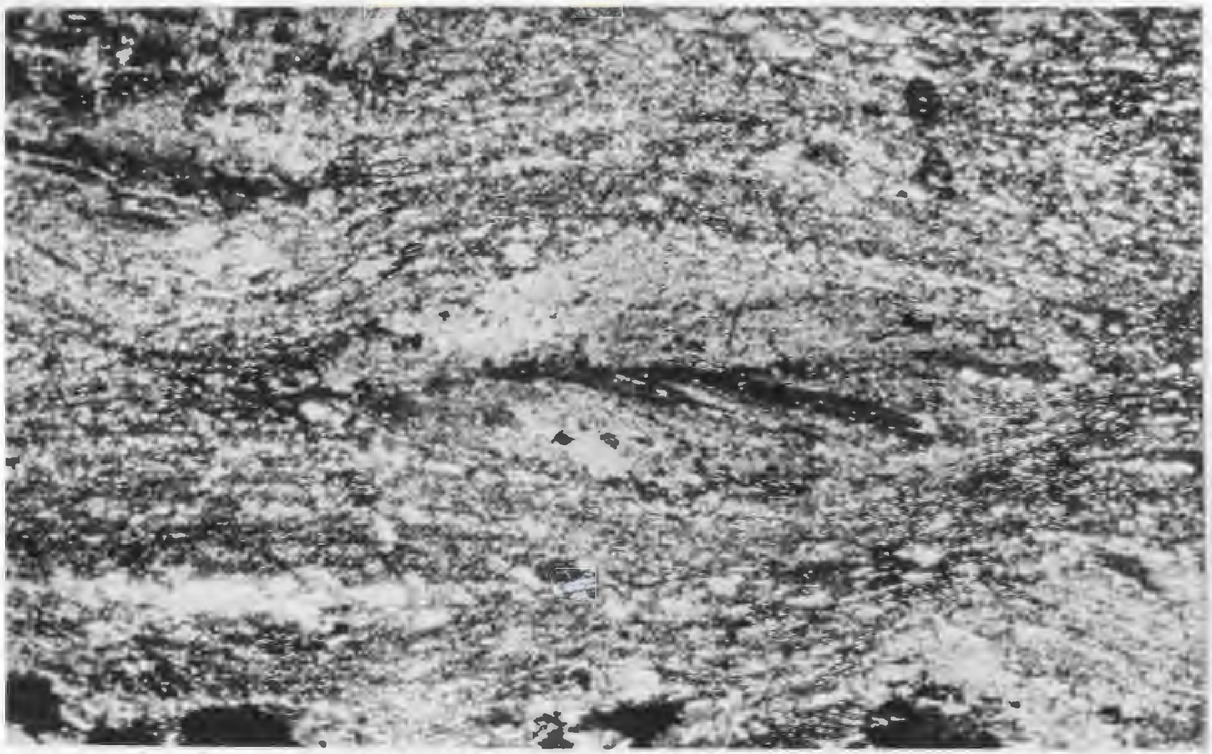


Plate 71

Augen formed by S2 around hornblende in amphibolitic tuff, Isle Galet Formation, Flobber Cove, Bois Island. Width of photograph 8 mm.

Plate 72

Hornblende rosette overgrowing the S1 fabric defined by iron oxide in amphibolite, Isle Galet Formation, Barasway de Cerf. Width of photograph 8 mm.



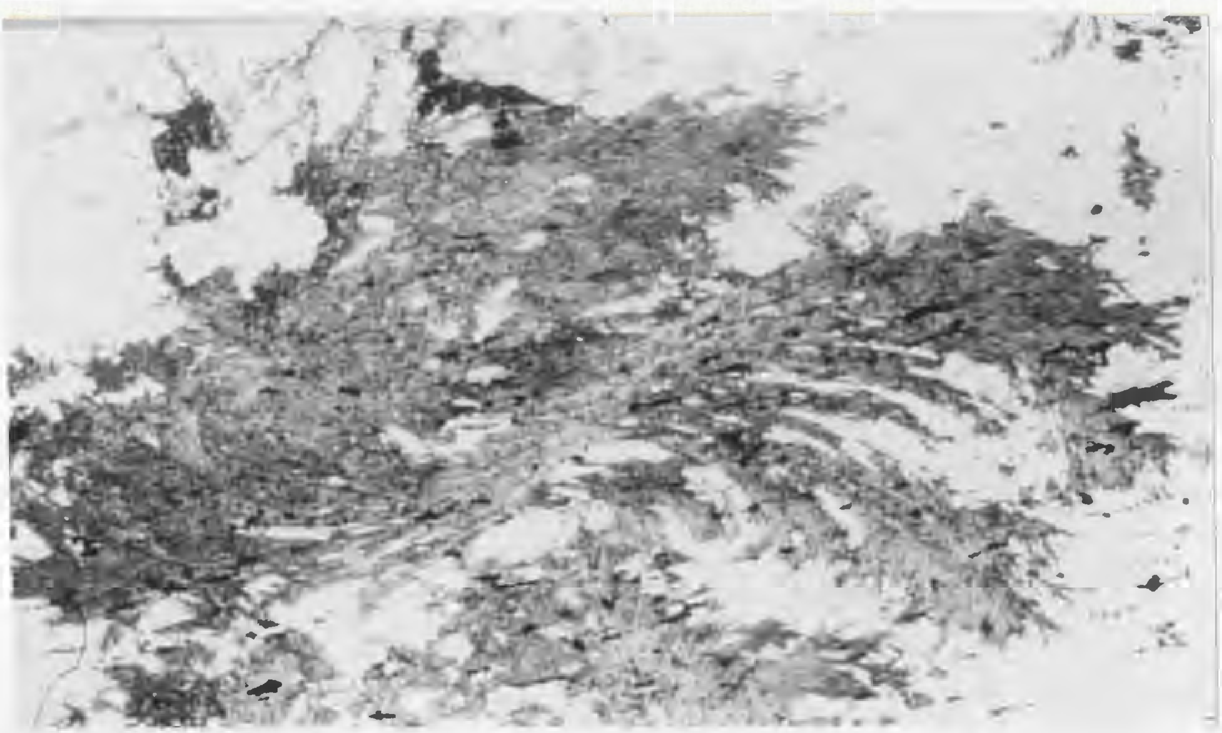
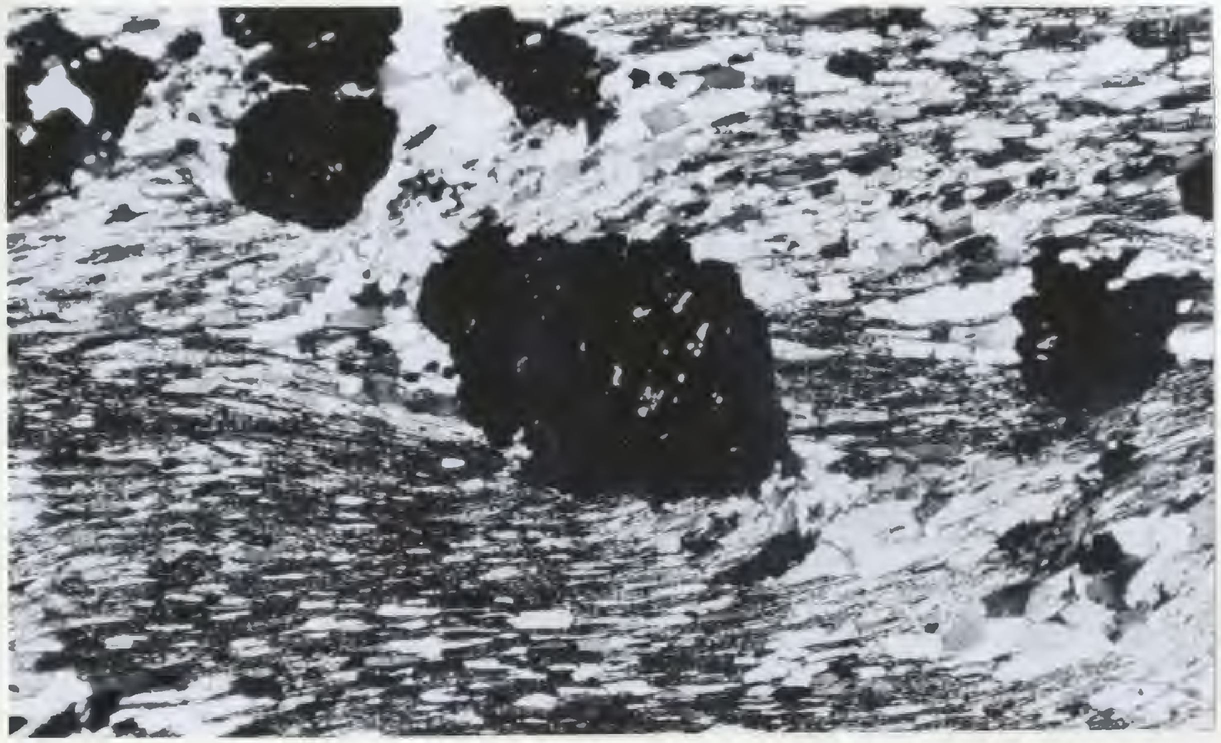


Plate 73

MP1 garnet containing an inclusion trail of S1 and with an augen formed by S2, graphitic schist, Isle Galet Formation, Snook's Harbour, Bois Island. Width of photograph 3 mm.

Plate 74

MP2 staurolite overgrowing S2 schistosity which forms augen around MP1 garnet, graphitic schist, Isle Galet Formation, Snook's Harbour, Bois Island. Width of photograph 3 mm.



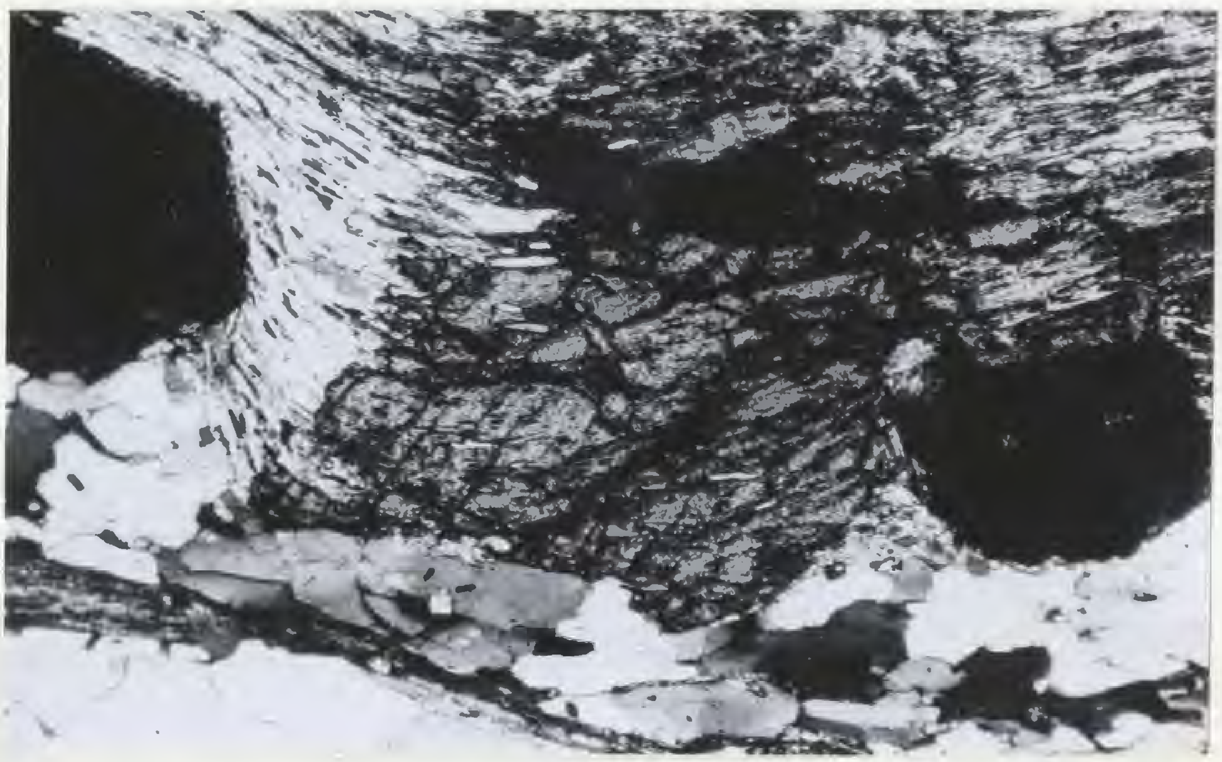


Plate 75

MP1-MS2 biotite with inclusion trails of S1 and surrounded by D2 augen, graphitic schist, Isle Galet Formation, Snook's Harbour, Bois Island. Width of photograph 3 mm.

Plate 76

MS2 garnet with S-shaped inclusion trails and augen formed by S2, semipelitic schist, Isle Galet Formation, Simmond's Barasway. Width of photograph 1.5mm.

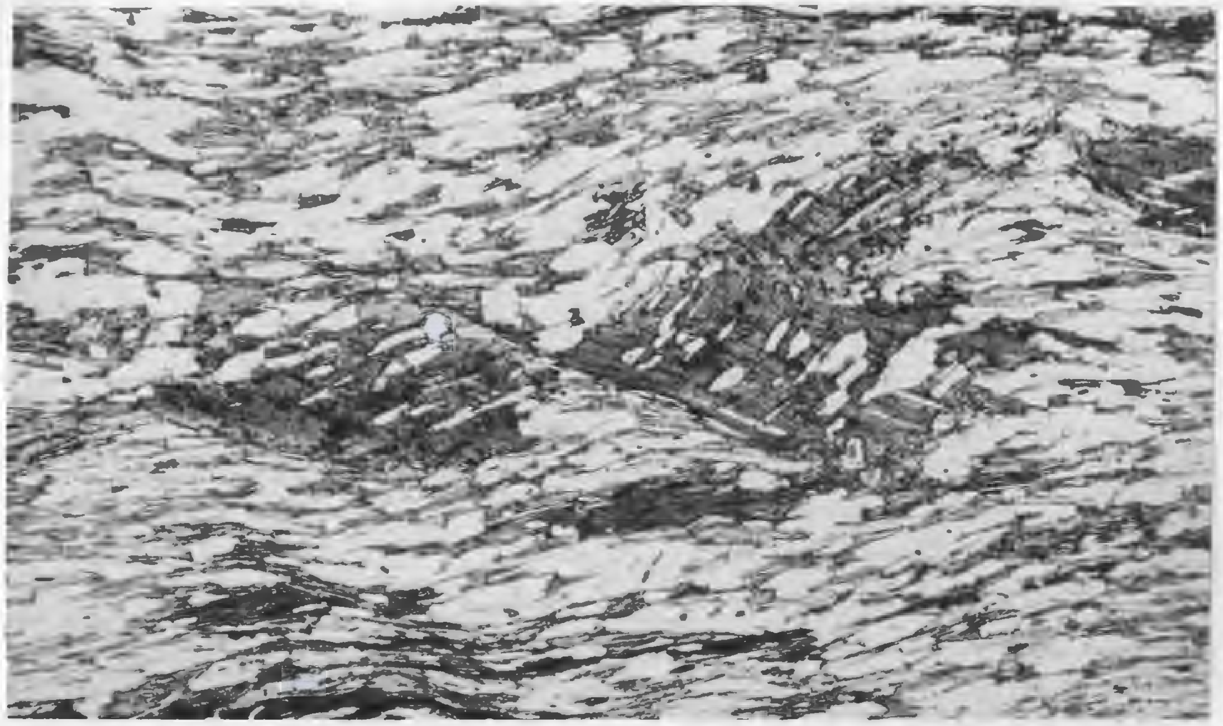
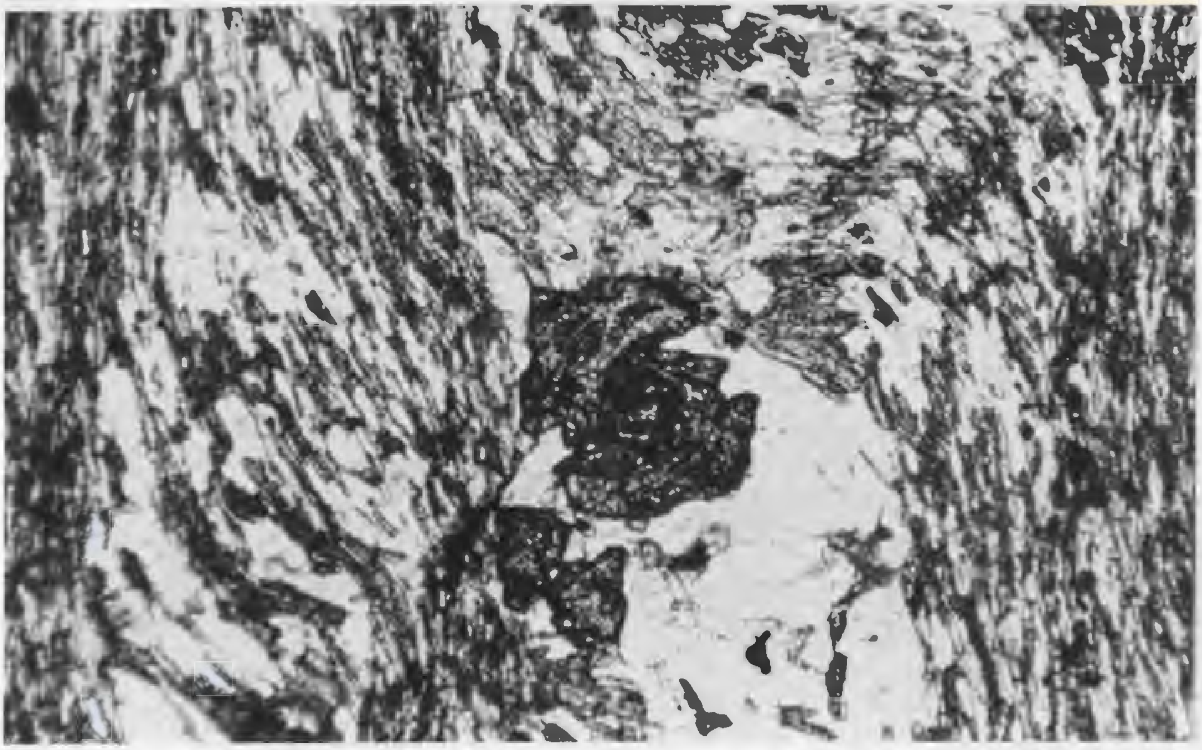


Plate 77

MS2 garnet with curved inclusion trail; S2 (vertical) is a differentiated crenulation schistosity in S1 (centre of photograph); Isle Galet Formation, Simmond's Barasway. Width of photograph 1 mm.

Plate 78

MS2 garnet with a partially included D2 augen, semipelitic schist, Isle Galet Formation, Simmond's Barasway. Width of photograph 5 mm.



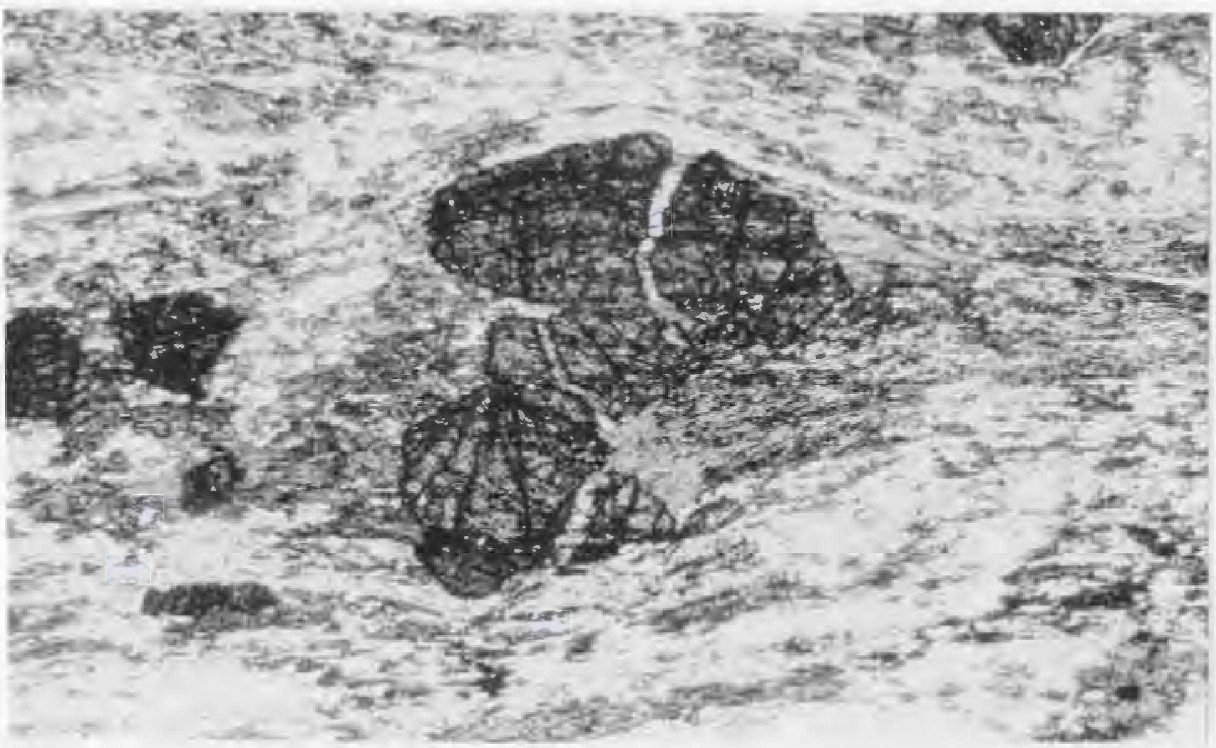


Plate 79

Pebbles of quartz in metagraywacke with augen formed around them by the S2 schistosity, Isle Galet Formation, west of Baraway de Cerf.

Plate 80

Thrust fault in the Gaultois Granite, just north of Wreck Cove, Long Island. Width of photograph 60 m.


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Plate 81

South facing escarpment formed along the line of a thrust fault in gneisses of the Stickland Cove Zone, Little Passage Gneisses, western end of Long Island.

Plate 82

Tight F1 fold refolded by F2 folds, St. Alban's Formation, Man of War Head, St. Alban's.

Plate 83

F2 fold in interbedded siltstone and pelite of the St. Alban's Formation, Brant Cove. Width of photograph 20 m.

Plate 84

F2 folds with an axial planar schistosity in quartzite beds within semipelitic chlorite schist, Riches Island Formation, opposite the east coast of Riches Island.

Plate 85

Closure of an isoclinal fold in semipelitic chlorite schist, Riches Island Formation, north side of Lampidoes Passage. Width of photograph 3 m.

Plate 86

F2 fold in psammite bed, Riches Island Formation, southeast of Frenchman Cove; north is to the left of the photograph.

Plate 87

D2 boudinage in F2 fold core, semipelitic chlorite schist, Riches Island Formation; the fold axis is in the plane of photograph, the axial plane is horizontal, and the boudinage axis is normal to the plane of photograph.

Plate 88

Tight F2 folds in intensely deformed acid crystal tuff, Isle Galet Formation, just north of the Day Cove Thrust, Dolland Bight.

Plate 89

F2 fold in bedded amphibolite, Isle Galet Formation, Simmond's Barasway.

Plate 90

D2 necking in an amphibolite band in semipelitic schist, Isle Galet Formation, south of May Head, Bois Island.

Plate 91

D2 boudinage in siliceous marble, Isle Galet Formation, east of Snook's Harbour, Bois Island.

Plate 92

Fault breccia on the Big Rattling Brook Thrust, southwest of Conne River. Width of photograph 2 m.

Plate 93

Post D2 fold with east-northeast trending axis, Riches Island Formation, south of Frenchman Cove; south is to the left of photograph.

Plate 94

Crenulation cleavage (dipping south to the right of photograph) axial planar to post D2 folds in semi-pelitic chlorite schist, Riches Island Formation, opposite Frenchman Cove.

Plate 95

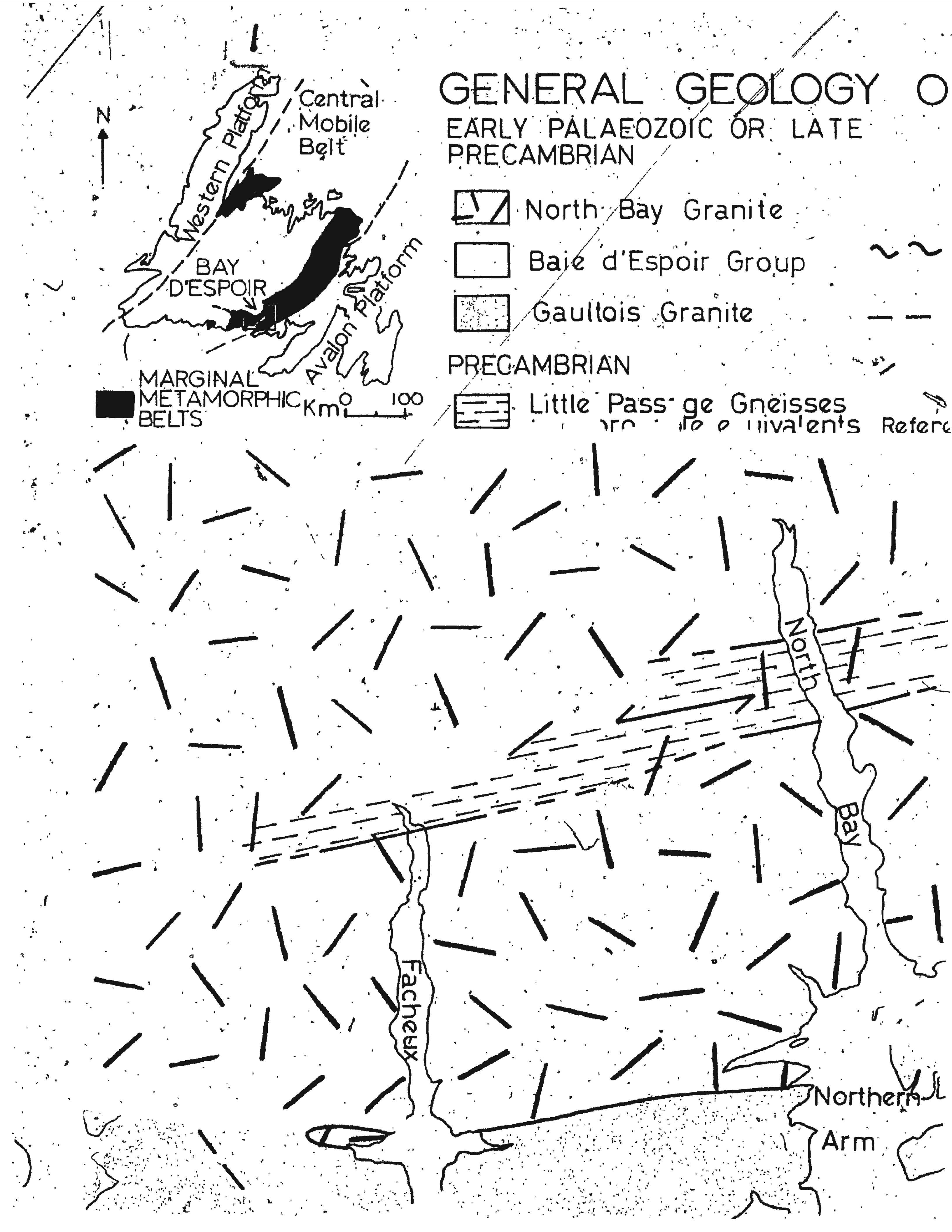
Post D2 fold with north trending axis, Isle Galet Formation, Bois Island at the southern end of Lampidoes Passage.

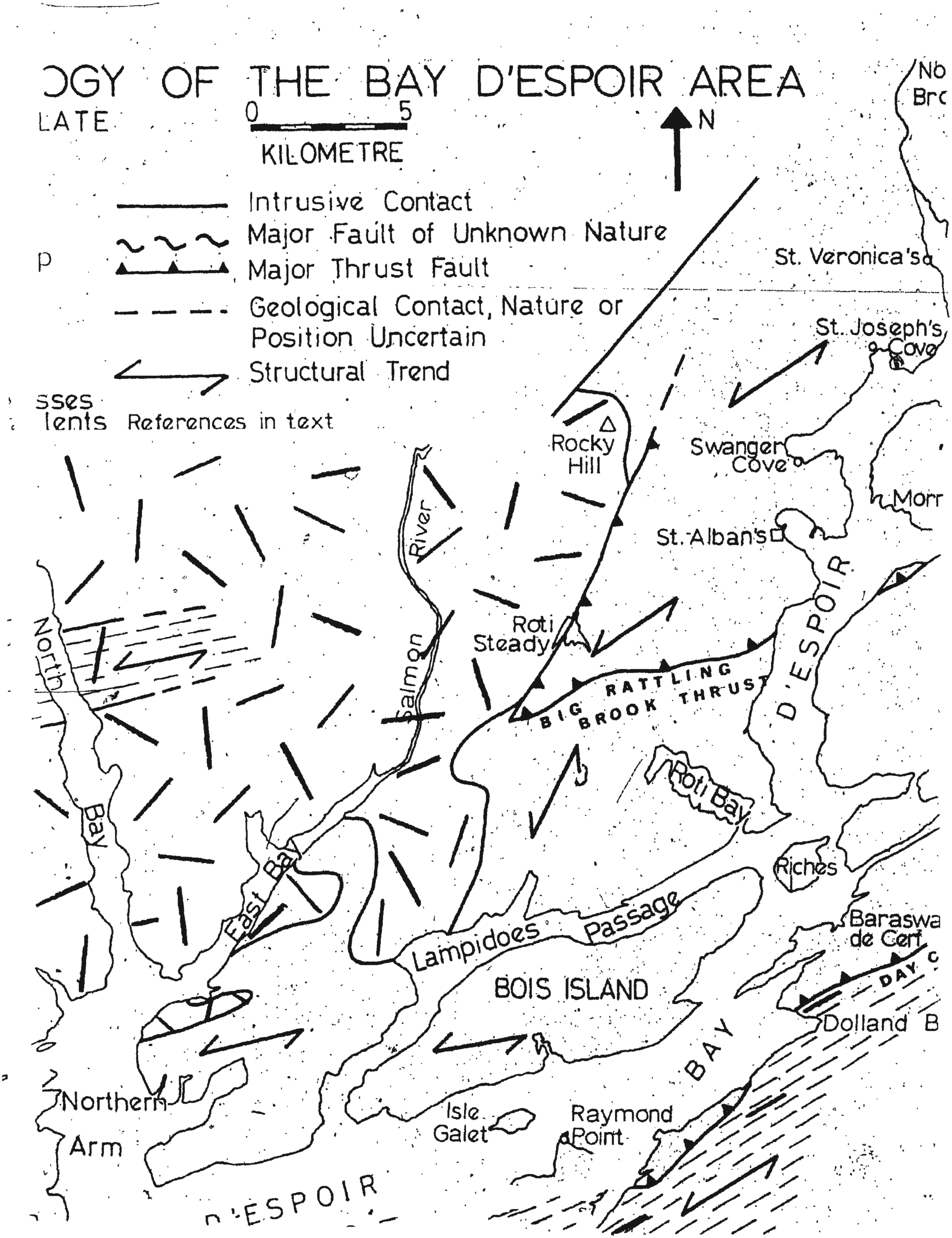
Plate 96

Post D2 kinks in micaceous acid crystal tuff, Isle Galet Formation, Raymond Point, Long Island.

Plate 97

Post D2 kink bands in semipelitic mica schist, Riches Island Formation, Roti Bay.


GENERAL GEOLOGY O
EARLY PALAEOZOIC OR LATE PRECAMBRIAN
North Bay Granite
Baie d'Espoir Group
Gaultois Granite
PRECAMBRIAN
Little Pass ge Gneisses
N
Central Mobile Belt
Western Platform
BAY D'ESPOIR
Avalon Platform
MARGINAL METAMORPHIC BELTS
Km 0 100
North Bay
Facheux
Northern Arm



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KILOMETRE
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Intrusive Contact
Major Fault of Unknown Nature
Major Thrust Fault
Geological Contact, Nature or Position Uncertain
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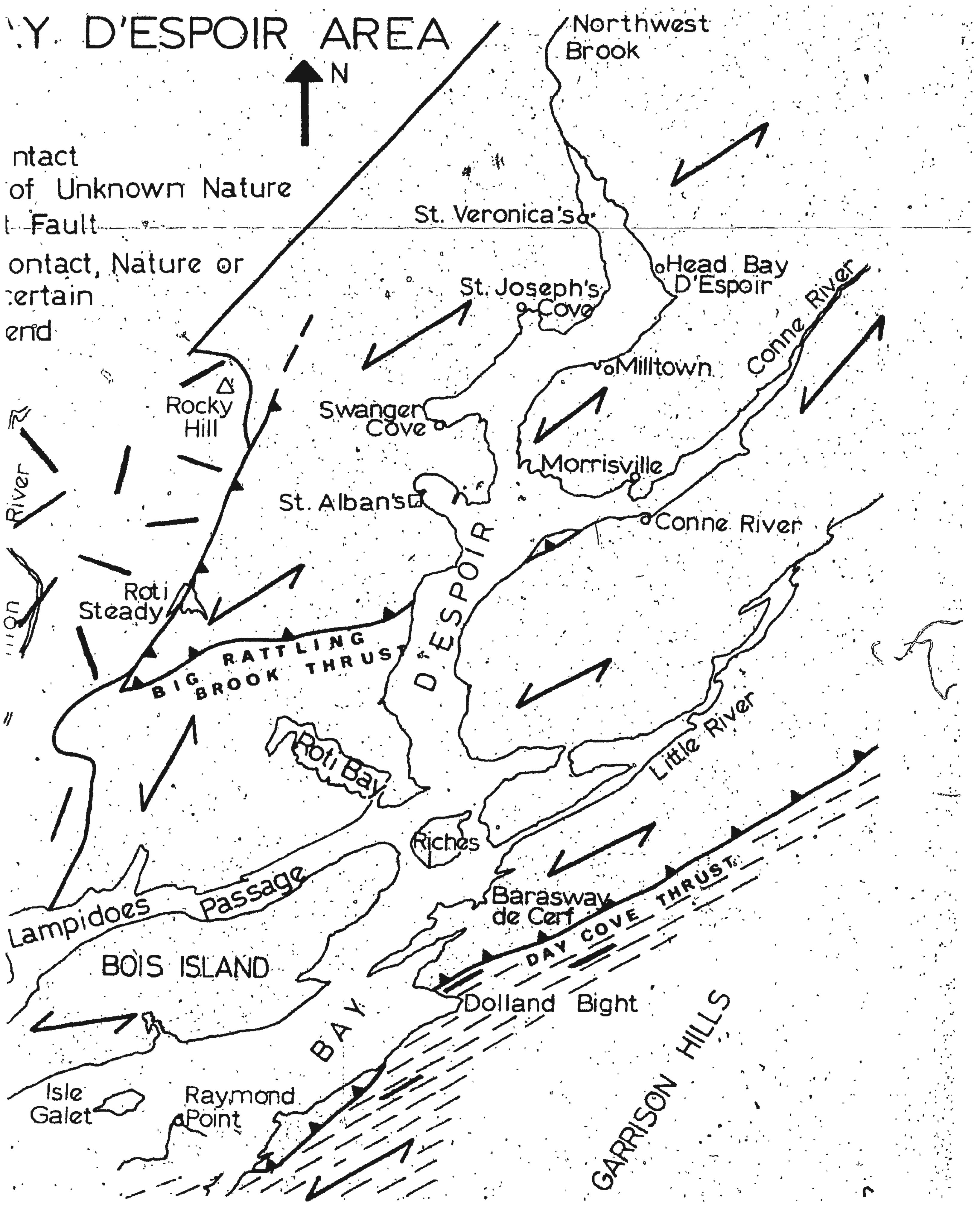
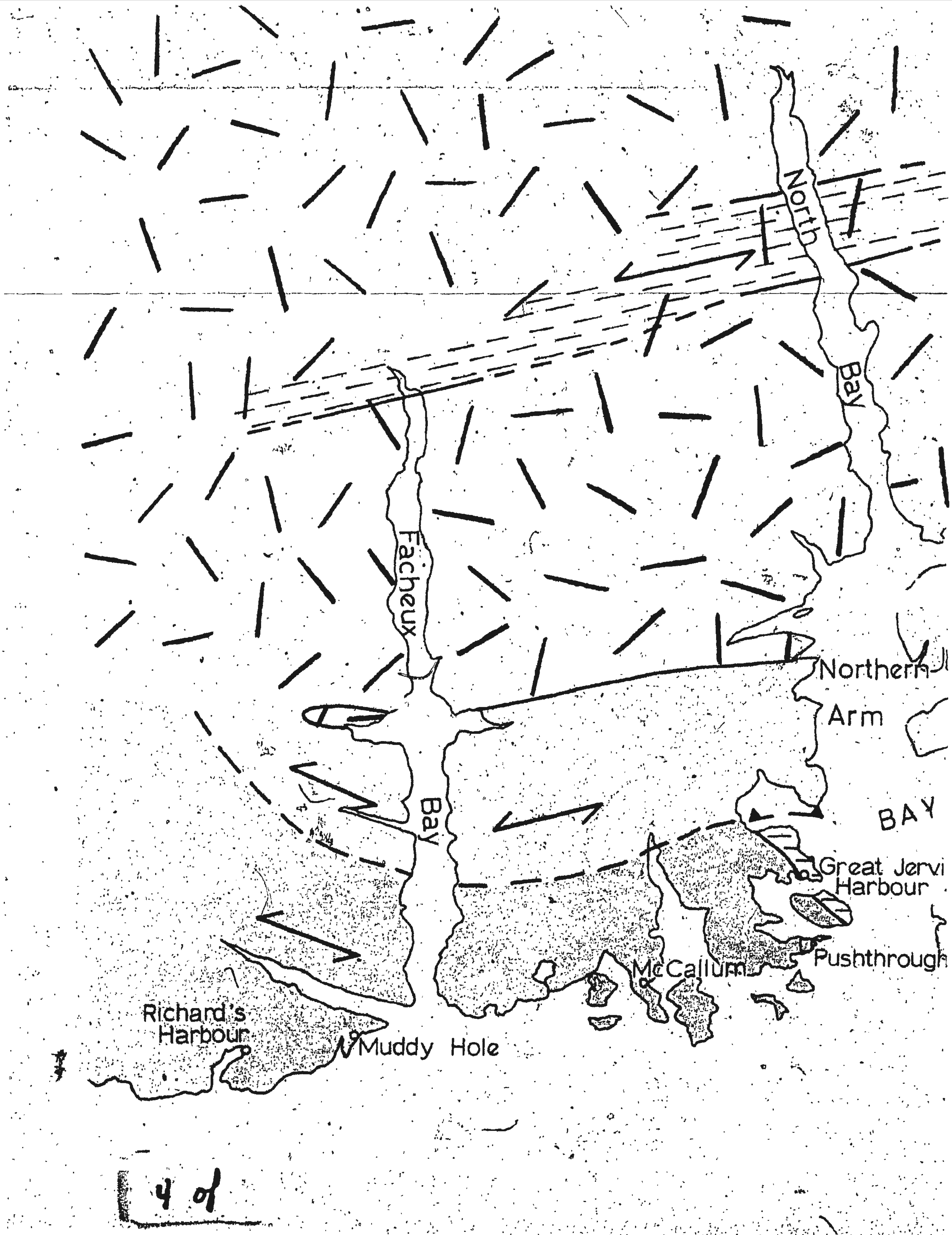
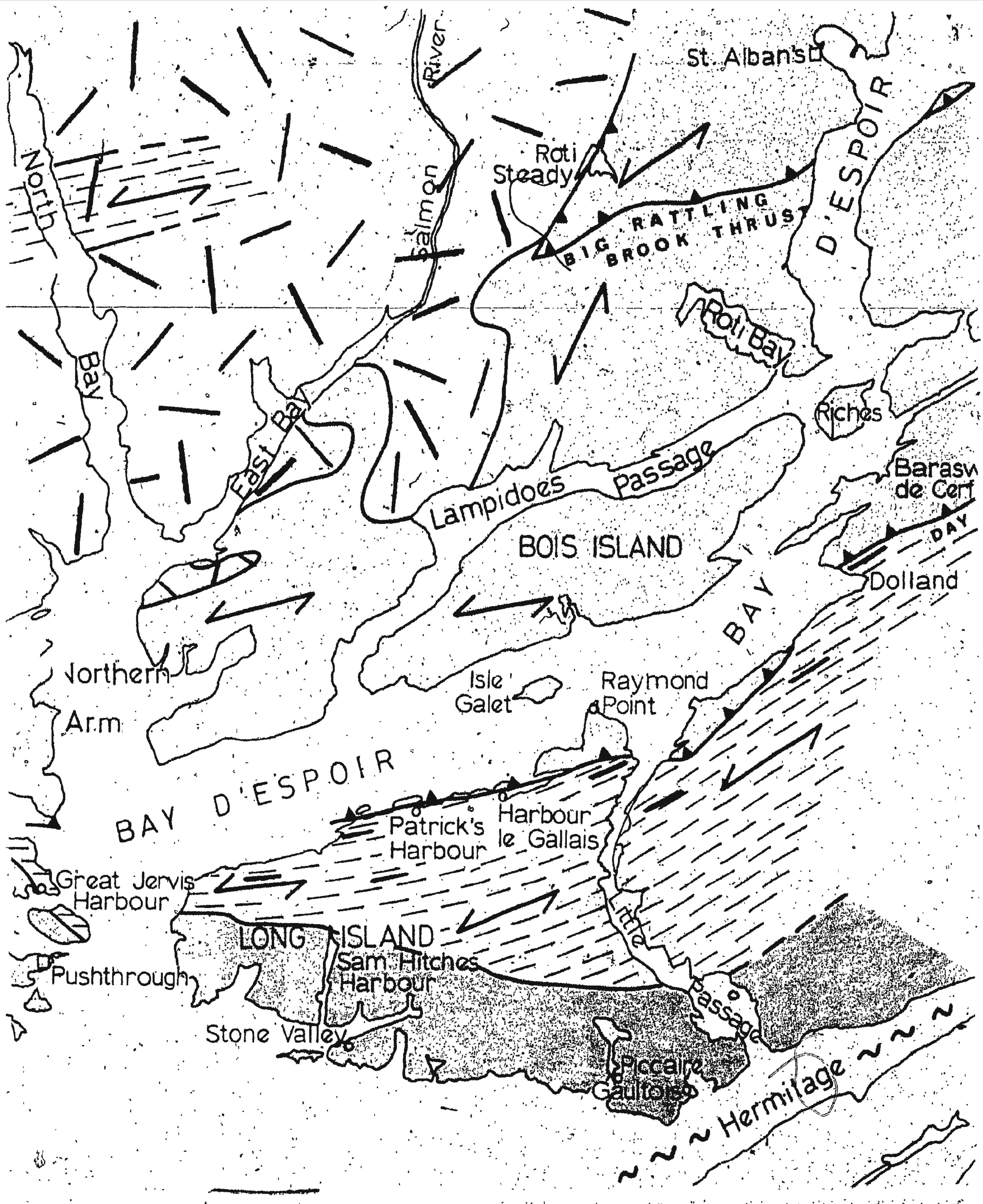
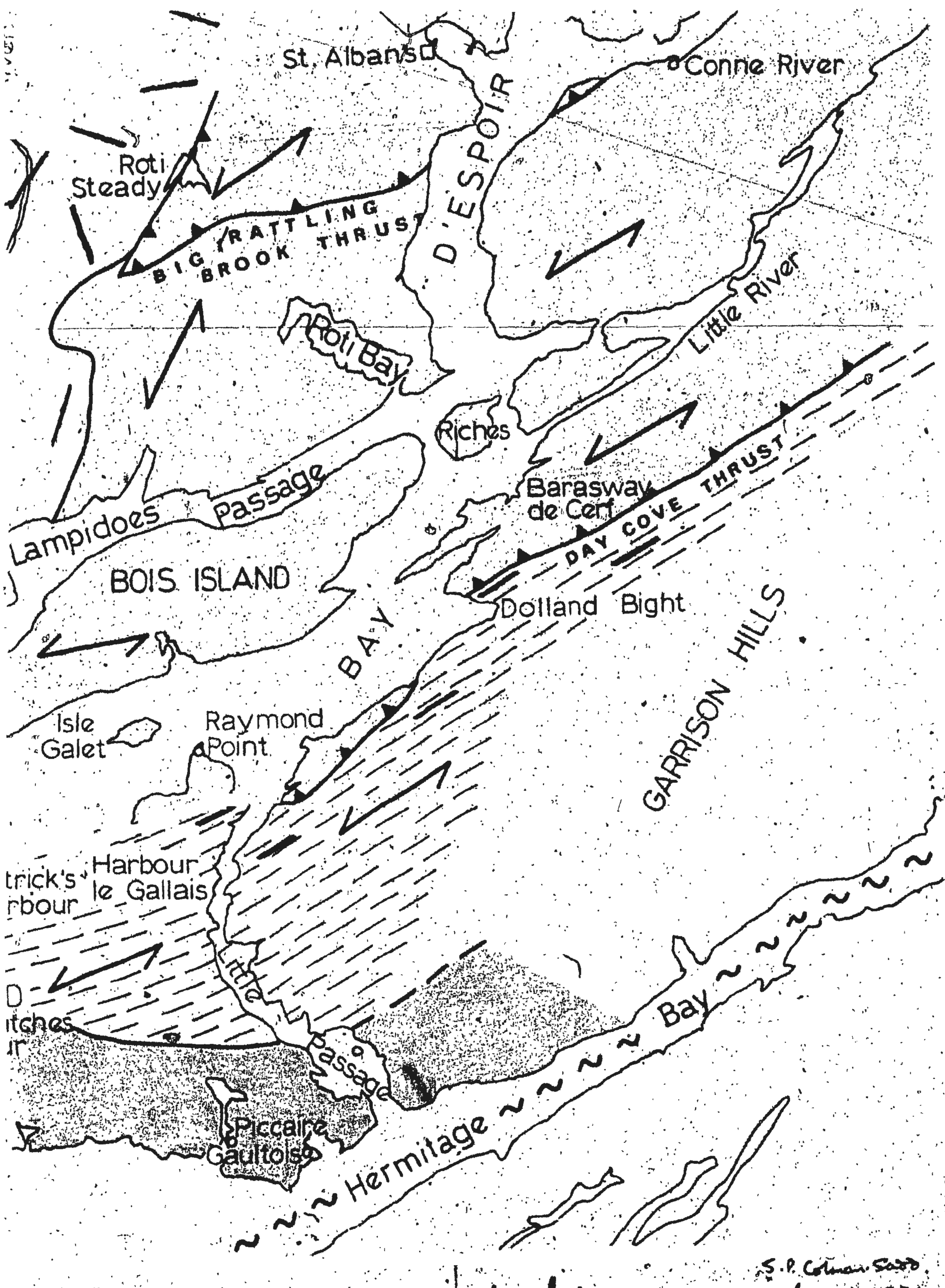
References in text
St. Veronica's
St. Joseph's Cove
Swanger Cove
Rocky Hill
St. Alban's
Roti Steady
BIG RATTLING BROOK THRUST
D'ESPOIR
Salmon River
North Bay
East Bay
Roti Bay
Riches
Lampidoes Passage
BOIS ISLAND
Baraswa de Cerf
Dolland B
BAY
Northern Arm
Isle Galet
Raymond Point
D'ESPOIR


.Y D'ESPOIR AREA
N
ntact
of Unknown Nature
t Fault
ontact, Nature or
certain
end
Northwest
Brook
St. Veronica's
Head Bay
D'Espoir
St. Joseph's
Cove
Milltown
Conne River
Rocky
Hill
Swanger
Cove
Morrisville
St. Alban's
Conne River
River
Roti
Steady
BIG RATTLING BROOK THRUST
D'ESPOIR
Roti Bay
Little River
Riches
Baraswa
de Cerf
DAY COVE THRUST
Lampidoes Passage
BOIS ISLAND
Dolland Bight
BAY
GARRISON HILLS
Isle
Galet
Raymond
Point


North Bay
Facheux Bay
Northern Arm
BAY
Great Jervi Harbour
Pushthrough
McCallum
Richard's Harbour
Muddy Hole
4 of


River
St. Alban's
Salmon
North
Bay
Roti
Steady
BIG RATTLING
BROOK THRUST
D'ESPOIR
Roti Bay
East Bay
Riches
Lampidoes Passage
Barasw
de Cerf
DAY
BOIS ISLAND
Dolland
BAY
Northern
Arm
Isle
Galet
Raymond
Point
BAY D'ESPOIR
Patrick's
Harbour
Harbour
le Gallais
Great Jervis
Harbour
LONG ISLAND
Sam Hitches
Harbour
Little
Passage
Pushthrough
Stone Valley
Piccaire
Gaultois
Hermitage

5 of


St. Albans
Conne River
Roti
Steady
BIG RATTLING BROOK THRUST
D'ESPOIR
Little River
Roti Bay
Riches
Lampidoes Passage
Barasway de Cerf
DAY COVE THRUST
BOIS ISLAND
Dolland Bight
BAY
GARRISON HILLS
Isle Galet
Raymond Point
Harbour le Gallais
trick's rbour
Little Passage
Piccaire
Gaultois
Hermitage Bay
S.P. Colman-Sadd
August 1974

6 of 6

GEOLOGICAL MAP OF EASTERN

SUPERFICIAL DEPOSITS OMITTED

EARLY PALAEOZOIC OR LATE PRECAMBRIAN

POST BAIE D'ESPOIR GROUP INTRUSIONS

NORTH BAY GRANITE AND ASSOCIATED INTRUSIONS (including sheets of metasediment)
- Foliated
- Massive

BAIE D'ESPOIR GROUP

ISLE GALET FORMATION
- acid igneous rocks
- basic igneous rocks
- graphitic schist
- metagraywacke
- semipelitic chlorite schist

1 of

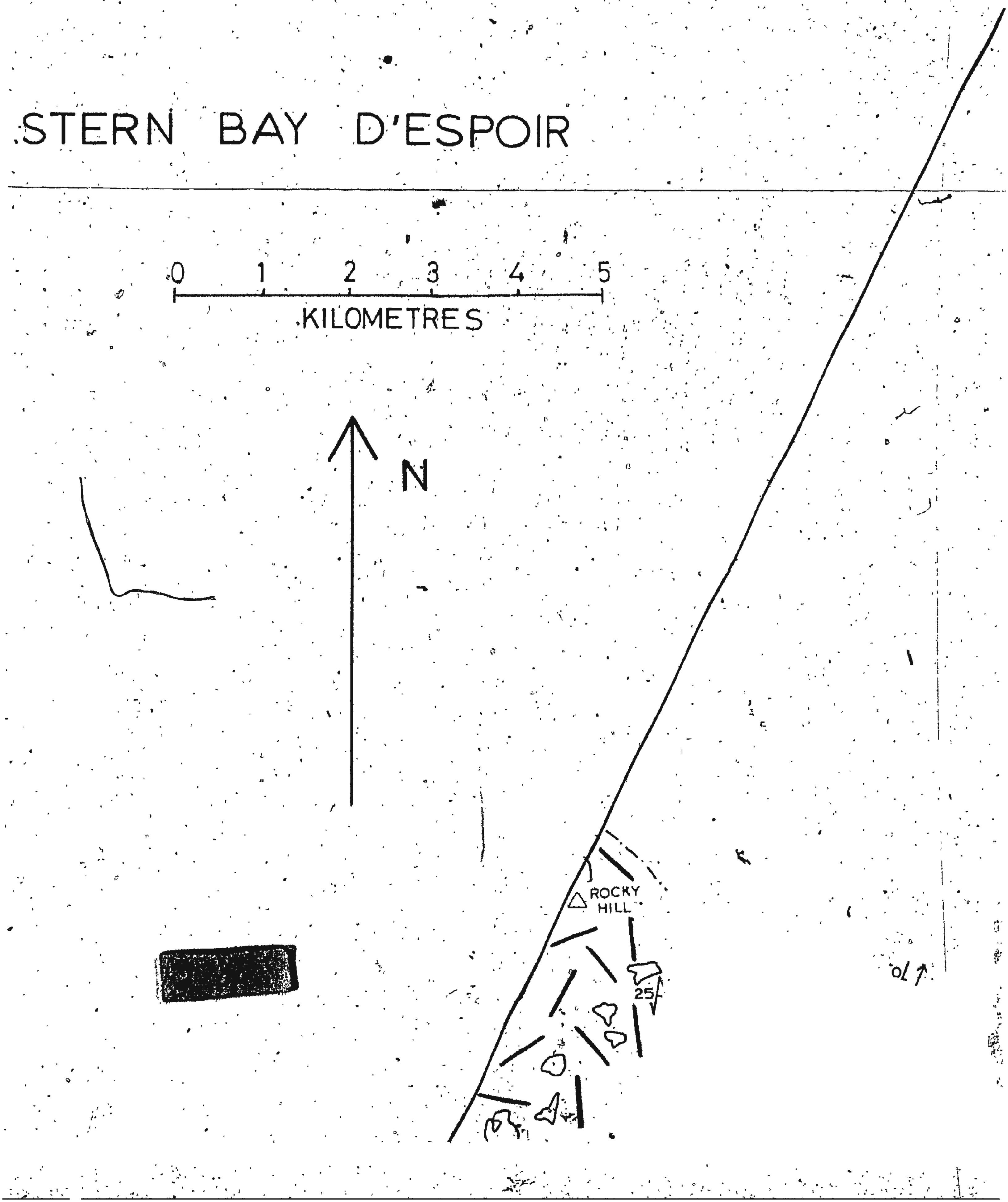
RICHES ISLAND FORMATION
- semipelitic chlorite schist
- psammite

ST. ALBAN'S FORMATION pelite and siltstone

ROTI STEADY FORMATION biotite and graphitic schist

PRE OR SYN. BAIE D'ESPOIR GROUP INTRUSIONS

GAULTOIS GRANITE


STERN BAY D'ESPOIR
0 1 2 3 4 5
KILOMETRES
N
ROCKY HILL
25
70
[redacted]

NA 2

3 of
ST VERONICA'S
HEAD
OF BAY
D'ESP
ST JOSEPHS
SWANGER
COVE
70
85
57
79
16
60

ST. ALBAN'S FORMATION pelite and siltstone

ROTI STEADY FORMATION biotite and graphitic schist

PRE OR SYN BAIE D'ESPOIR GROUP INTRUSIONS

GAULTOIS GRANITE

SEAL NEST COVE TONALITE

PRECAMBRIAN

LITTLE PASSAGE GNEISSES

MASSIVE TONALITE

TONALITIC GNEISS

PSAMMITIC GNEISS

AMPHIBOLITIC GNEISS

D_1 REWORKING

D_2 REWORKING

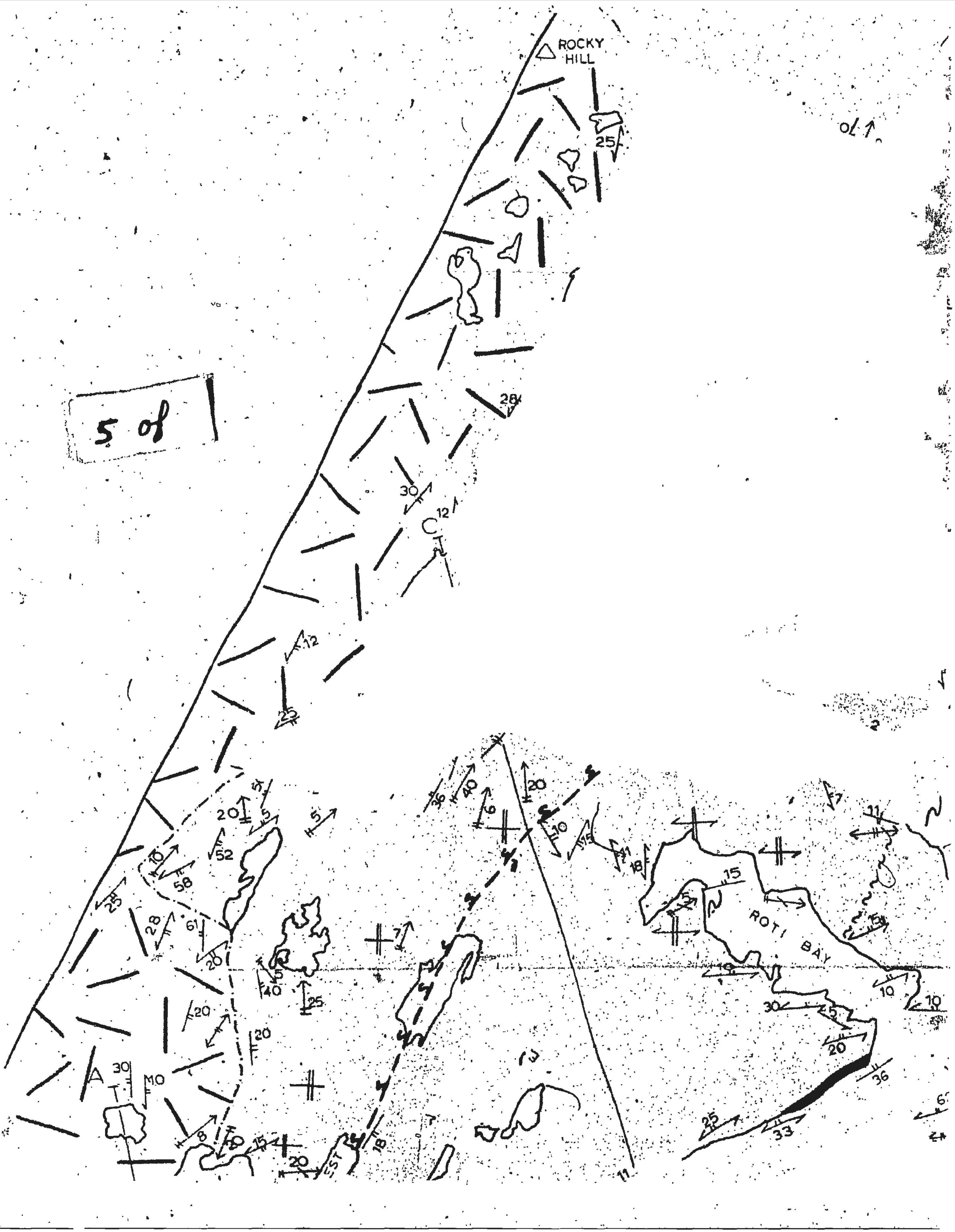
inclined	vertical	horizontal	overturned		
30			43	tops known	Bedding
28				tops unknown	Bedding
31				S_2	Schistosity
13				S_1	Schistosity
82				pre Baie d'Espoir Gp.	Schistosity

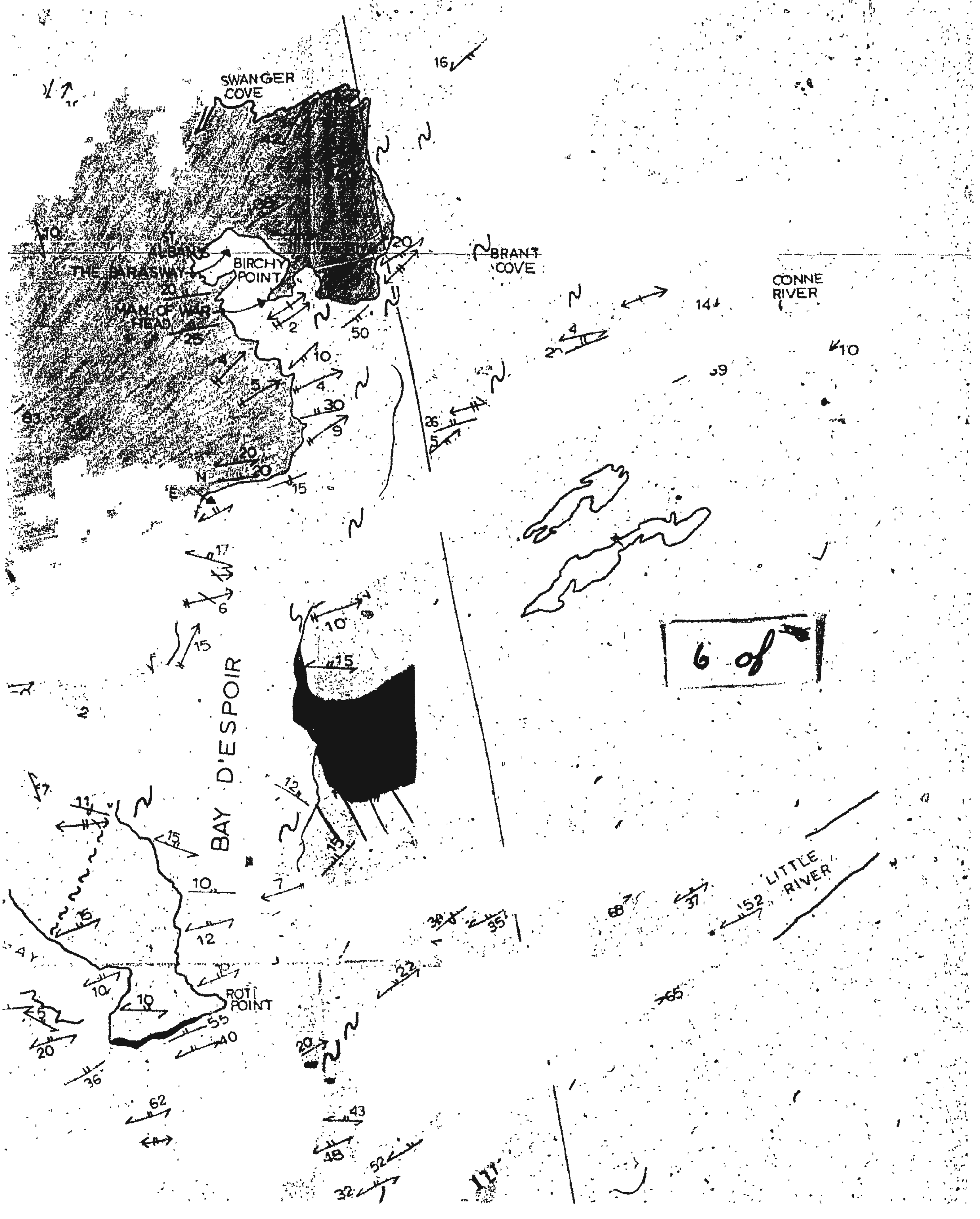
plunging	horizontal		
12		F_2	Fold axes
28		F_1	Fold axes
19		pre Baie d'Espoir Gp	Fold axes
16		L_2	Mineral lineation
33		L_1	Mineral lineation
10		Intersection of S_2 and pre S_2 surface	

D_2 vergence (to be viewed from east)

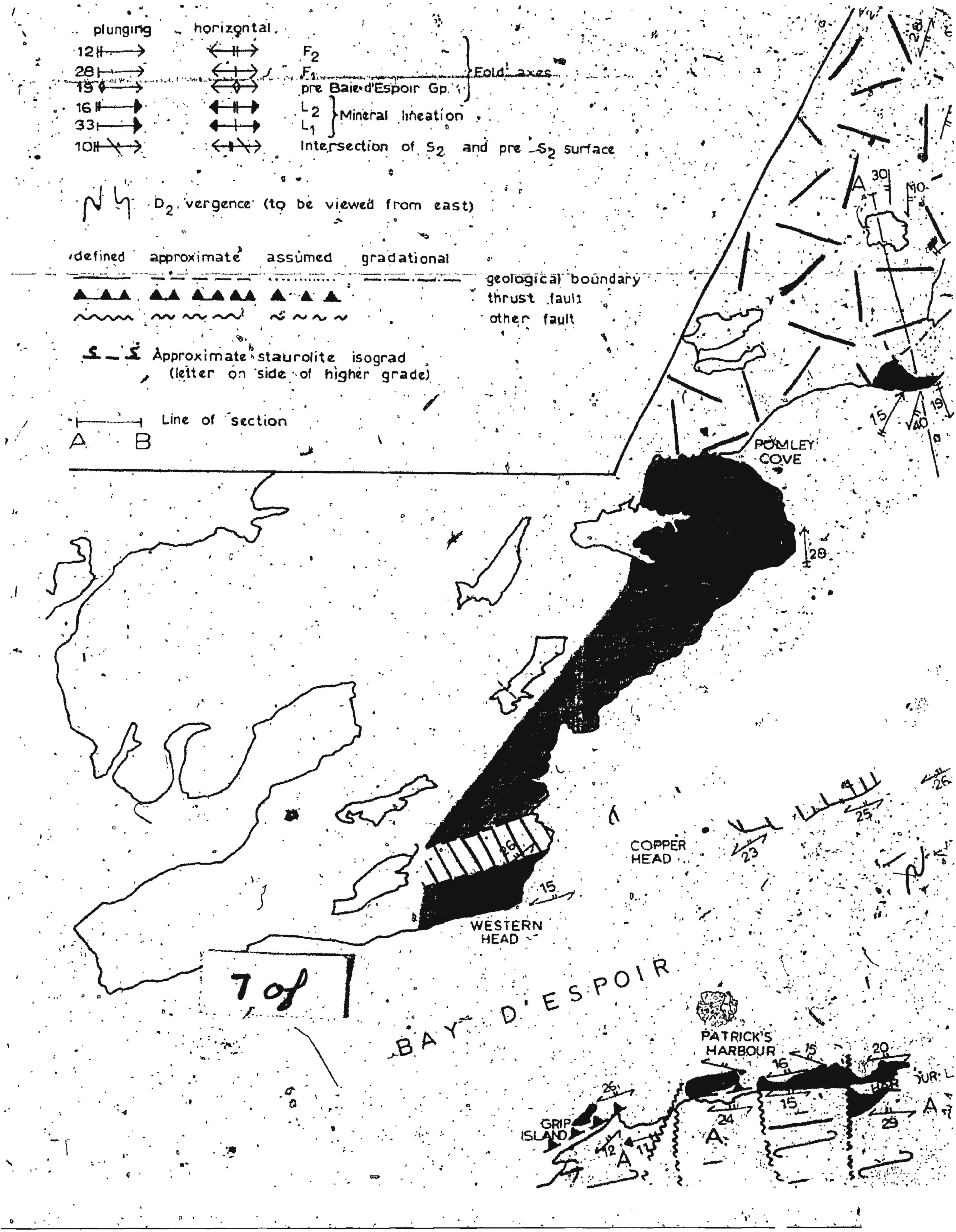
4 of

...dational

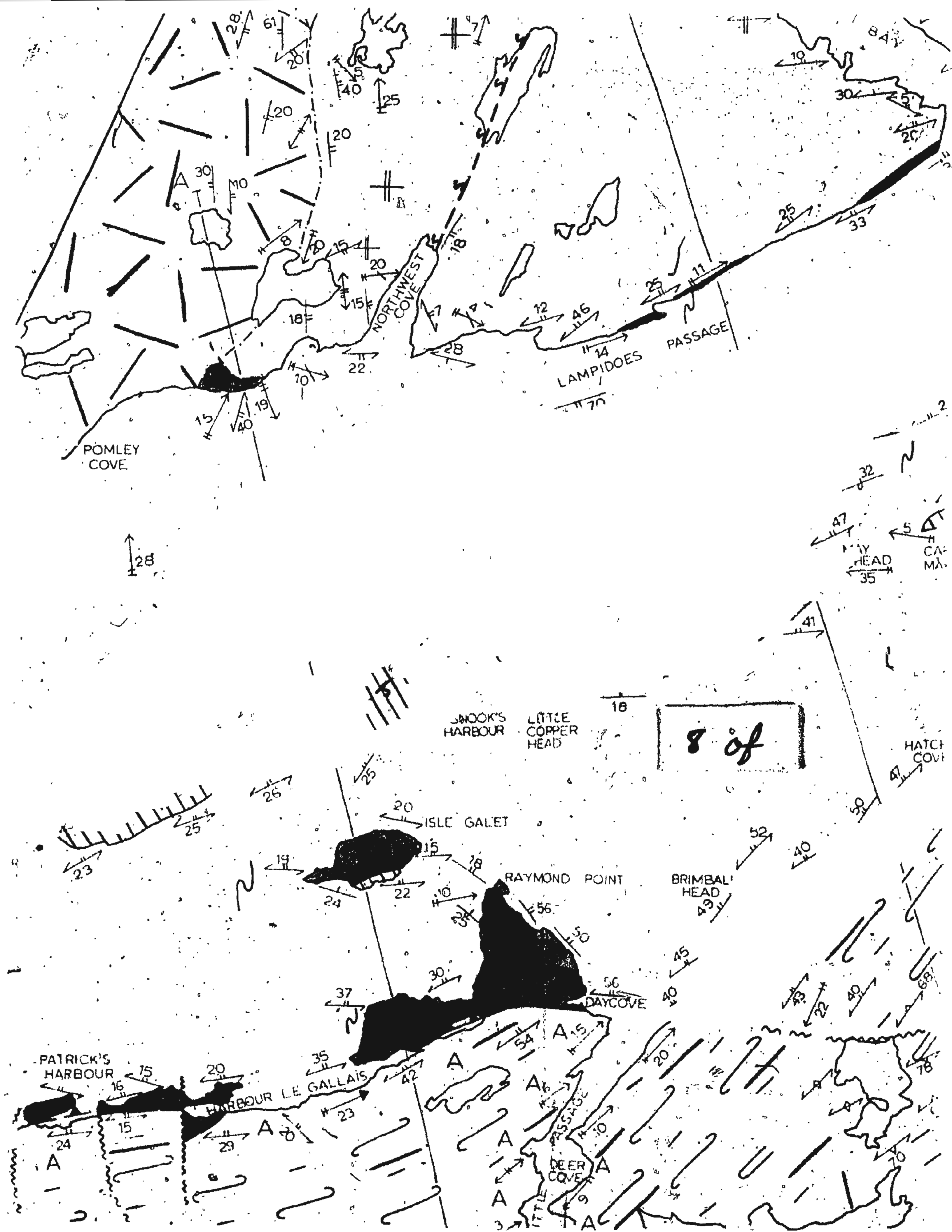

ROCKY HILL
ROTI BAY

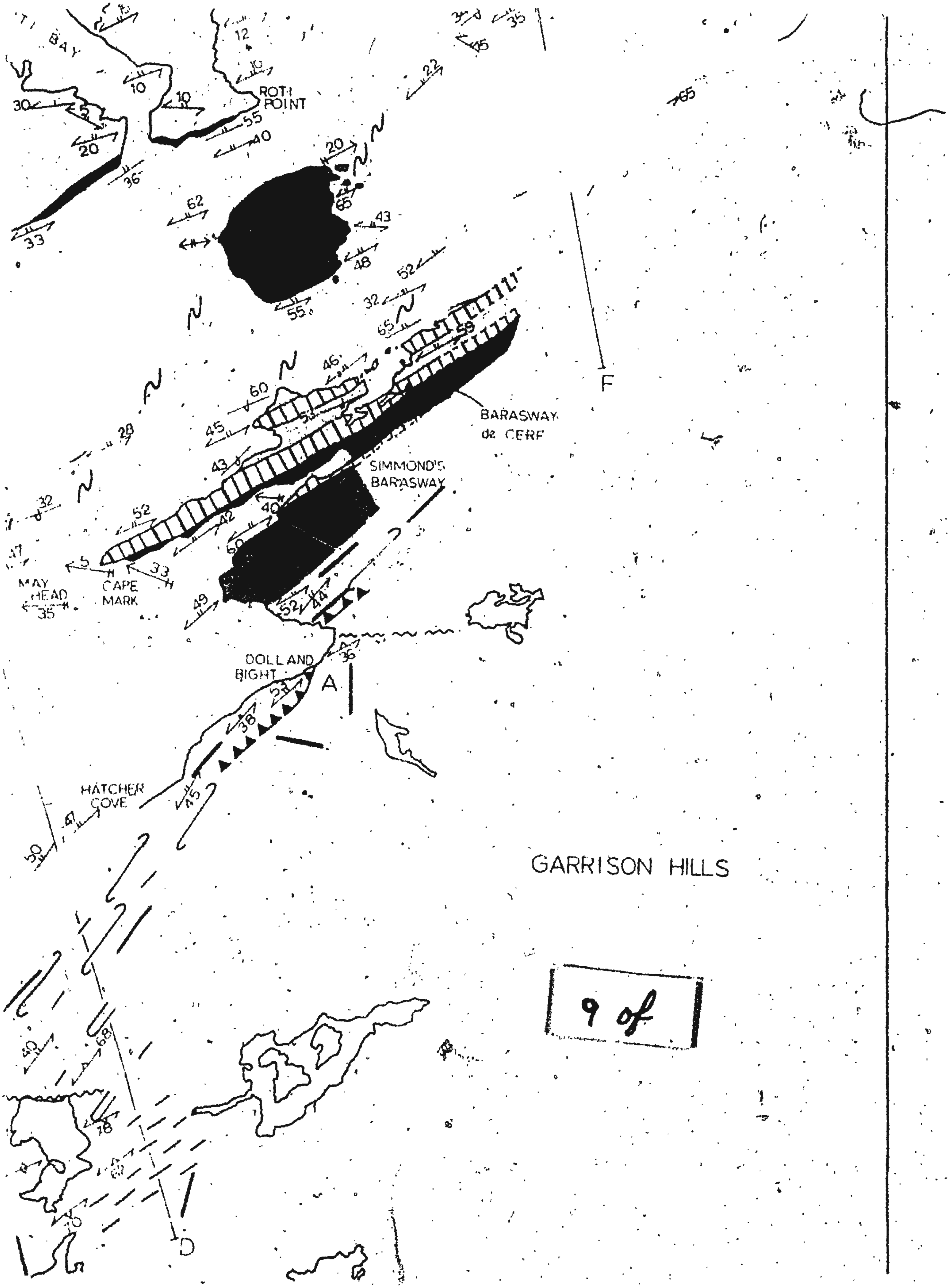

SWANGER COVE
ST. ALBANS
THE BARASWAY
BIRCHY POINT
MAN OF WAR HEAD
BRANT COVE
CONNE RIVER
BAY D'ESPOIR
LITTLE RIVER
ROTI POINT

6 of

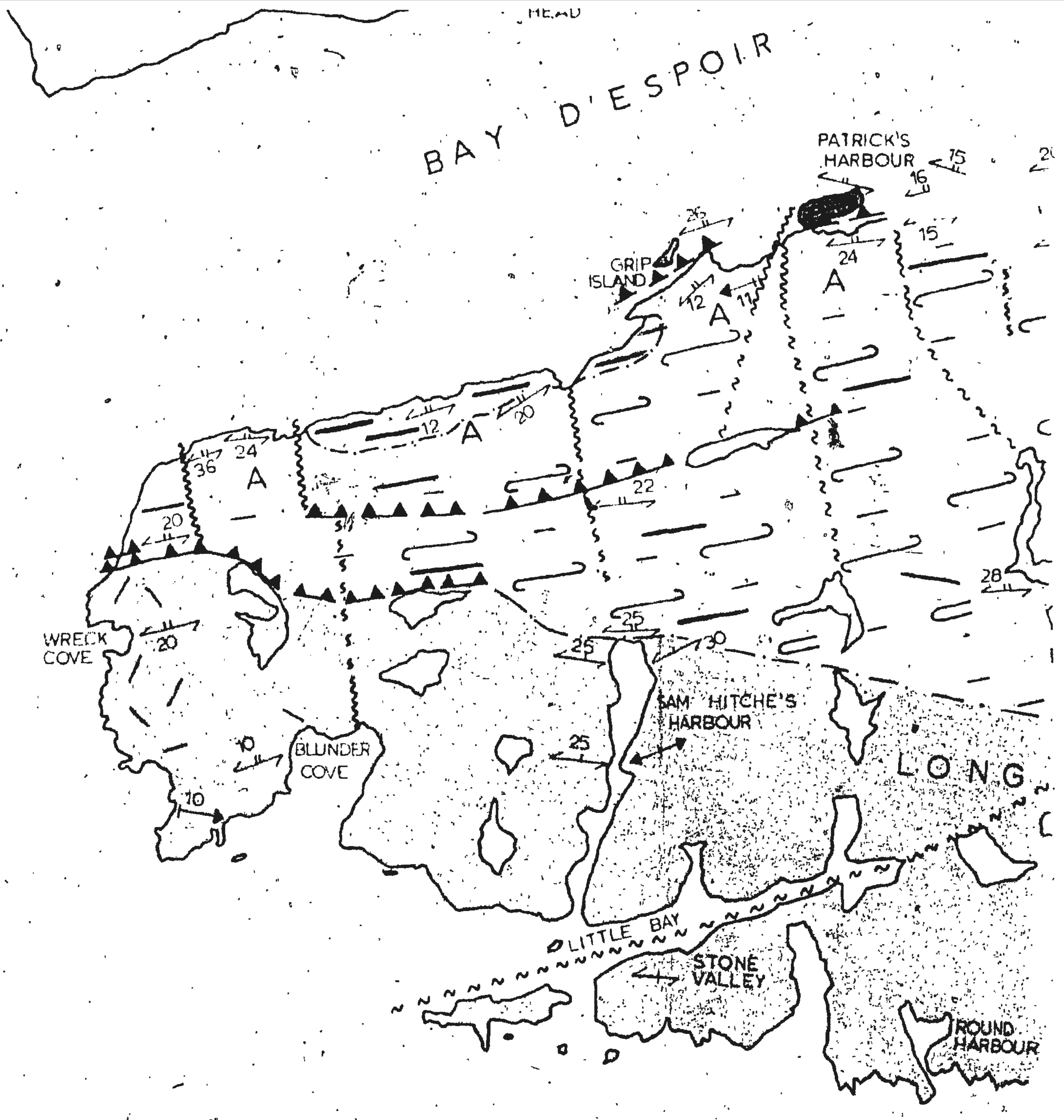


plunging
horizontal
F2
F1
pre Baie d'Espoir Gp.
Fold axes
L2
L1
Mineral lineation
Intersection of S2 and pre S2 surface
D2 vergence (to be viewed from east)
defined
approximate
assumed
gradational
geological boundary
thrust fault
other fault
Approximate staurolite isograd
(letter on side of higher grade)
Line of section
A
B
POMLEY COVE
COPPER HEAD
WESTERN HEAD
BAY D'ESPOIR
7 of
PATRICK'S HARBOUR
GRIP ISLAND


POMLEY COVE
NORTHWEST COVE
LAMPIDOES PASSAGE
SNOOK'S HARBOUR
LITTLE COPPER HEAD
8 of
ISLE GALET
RAYMOND POINT
BRIMBAL HEAD
DAYCOVE
PATRICK'S HARBOUR
HARBOUR LE GALLAIS
DEER COVE

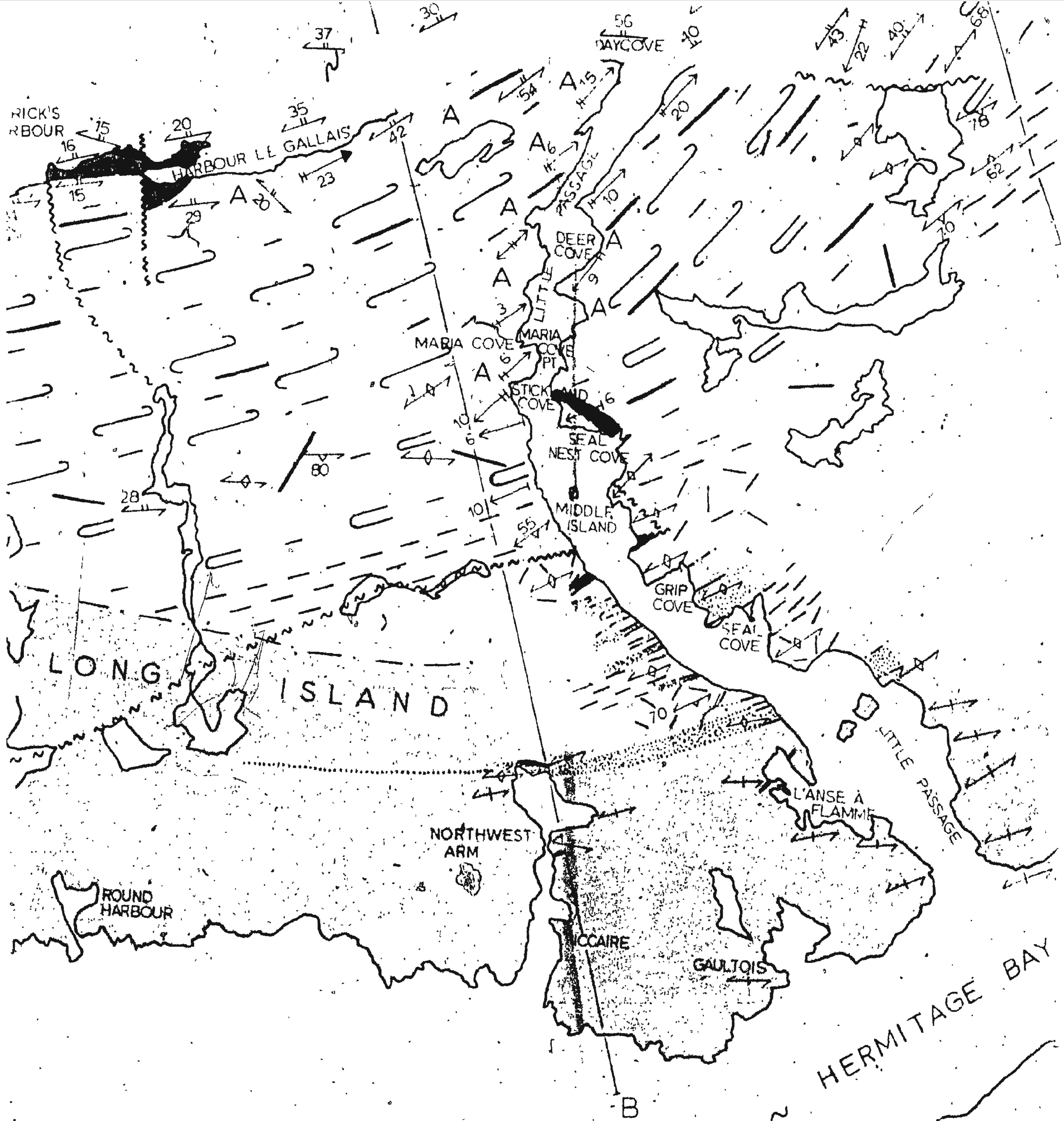

BAY
ROTH POINT
BARASWAY de CERF
SIMMOND'S BARASWAY
CAPE MARK
MAY HEAD
DOLL AND BIGHT
HATCHER COVE
GARRISON HILLS
F
A
D

9 of



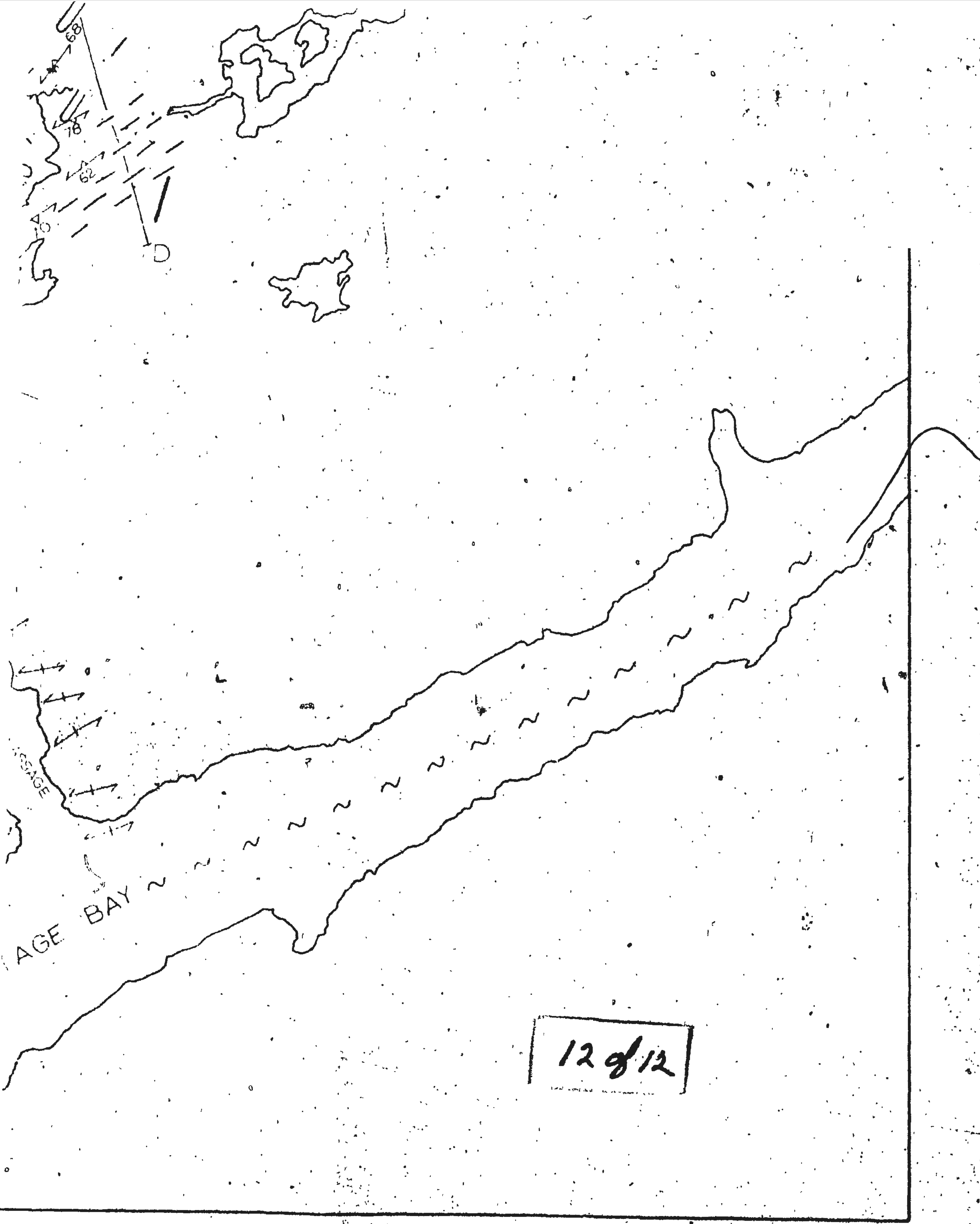
HEAD
BAY D'ESPOIR
PATRICK'S HARBOUR
GRIP ISLAND
A
WRECK COVE
BLUNDER COVE
SAM HITCHE'S HARBOUR
LONG
LITTLE BAY
STONE VALLEY
ROUND HARBOUR

10 of



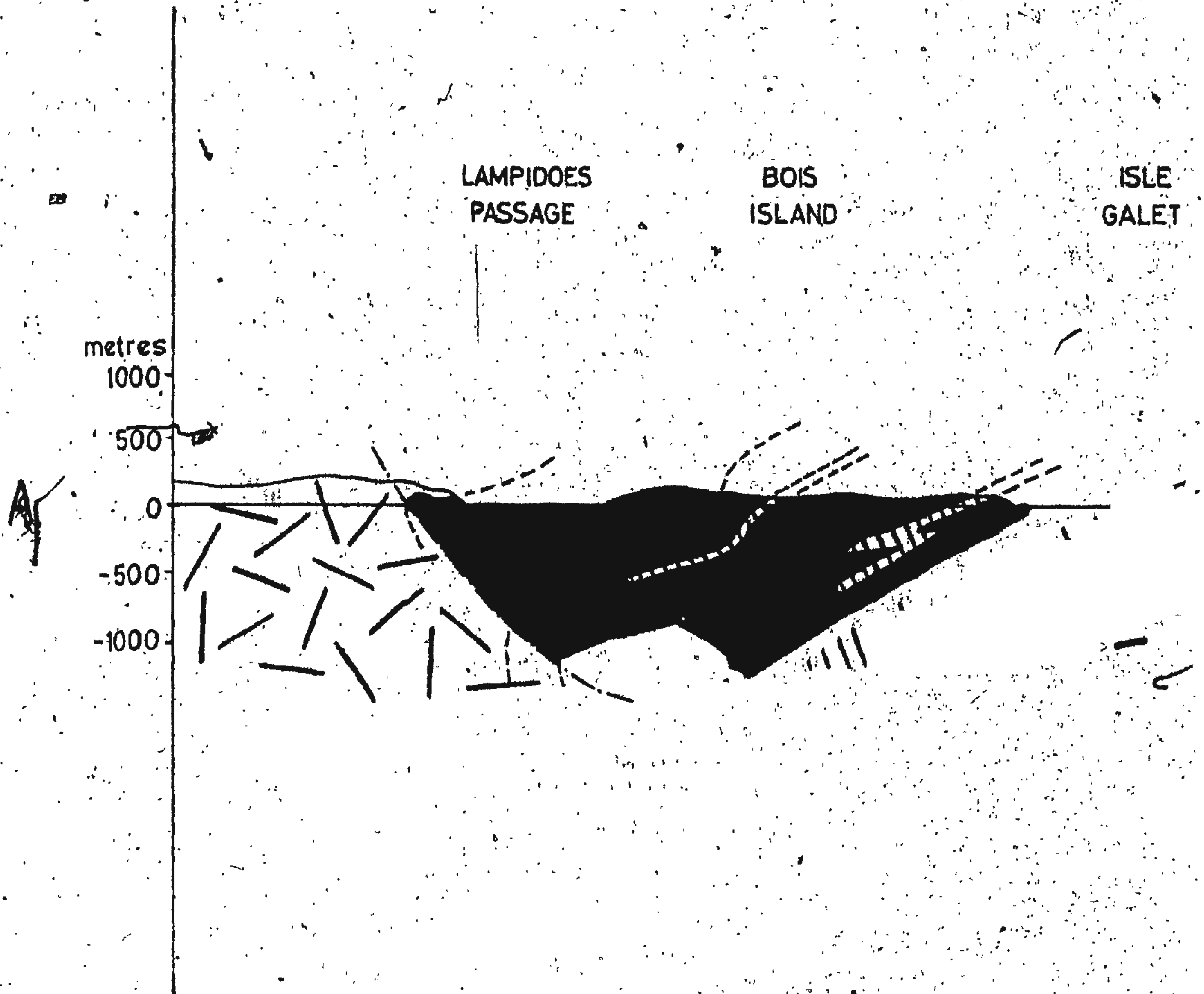
RICK'S
RBOUR
HARBOUR LE GALLAIS
DAYCOVE
LITTLE PASSAGE
DEER COVE
MARIA COVE
MARIA COVE PT
STICKLAND COVE
SEAL NEST COVE
MIDDLE ISLAND
GRIP COVE
SEAL COVE
LONG ISLAND
L'ANSE A FLAMME
NORTHWEST ARM
ROUND HARBOUR
GAULTOIS
HERMITAGE BAY
B

11 of



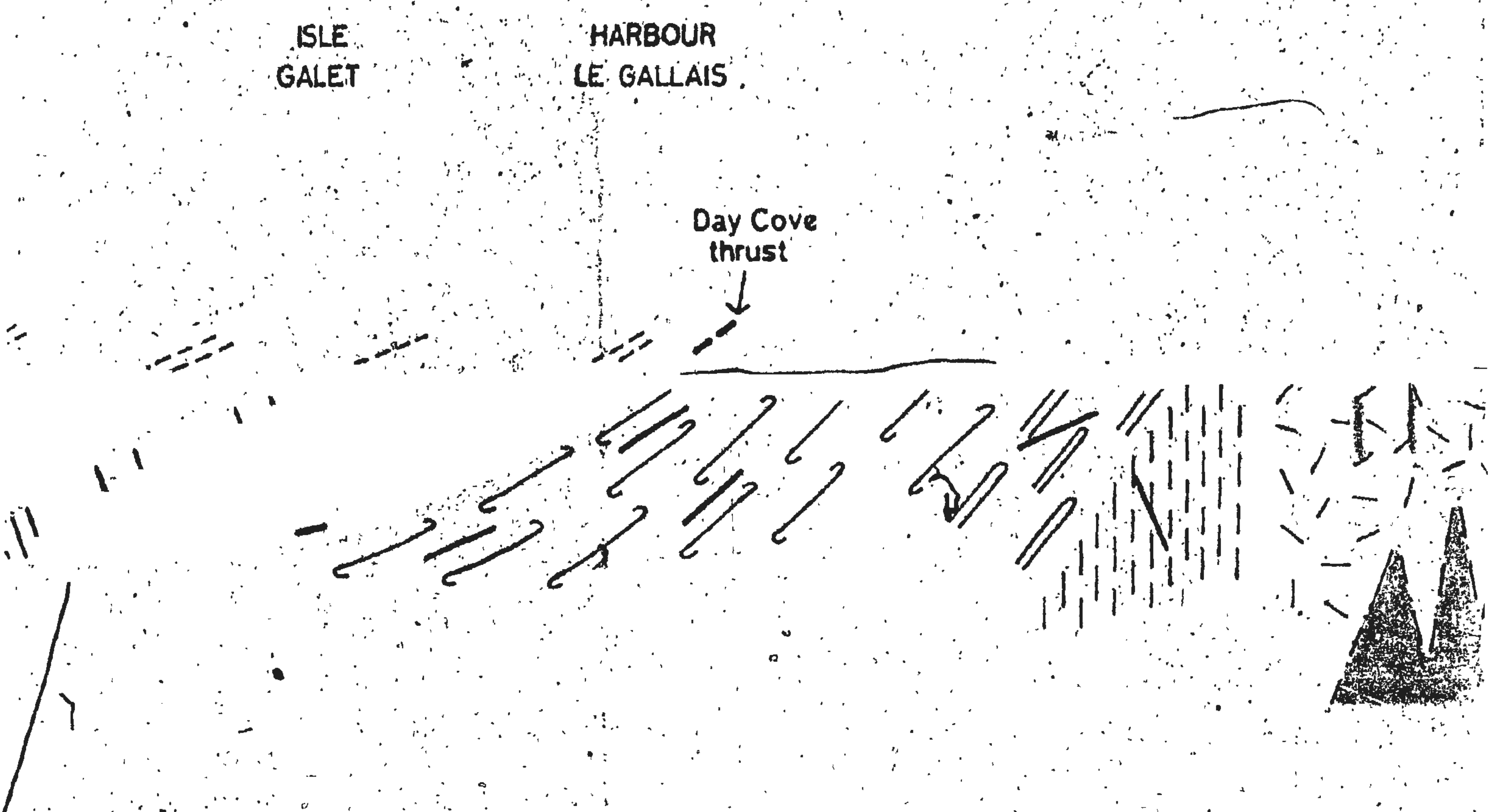
S.O. Colman-Sadd
August 1974.

SECT

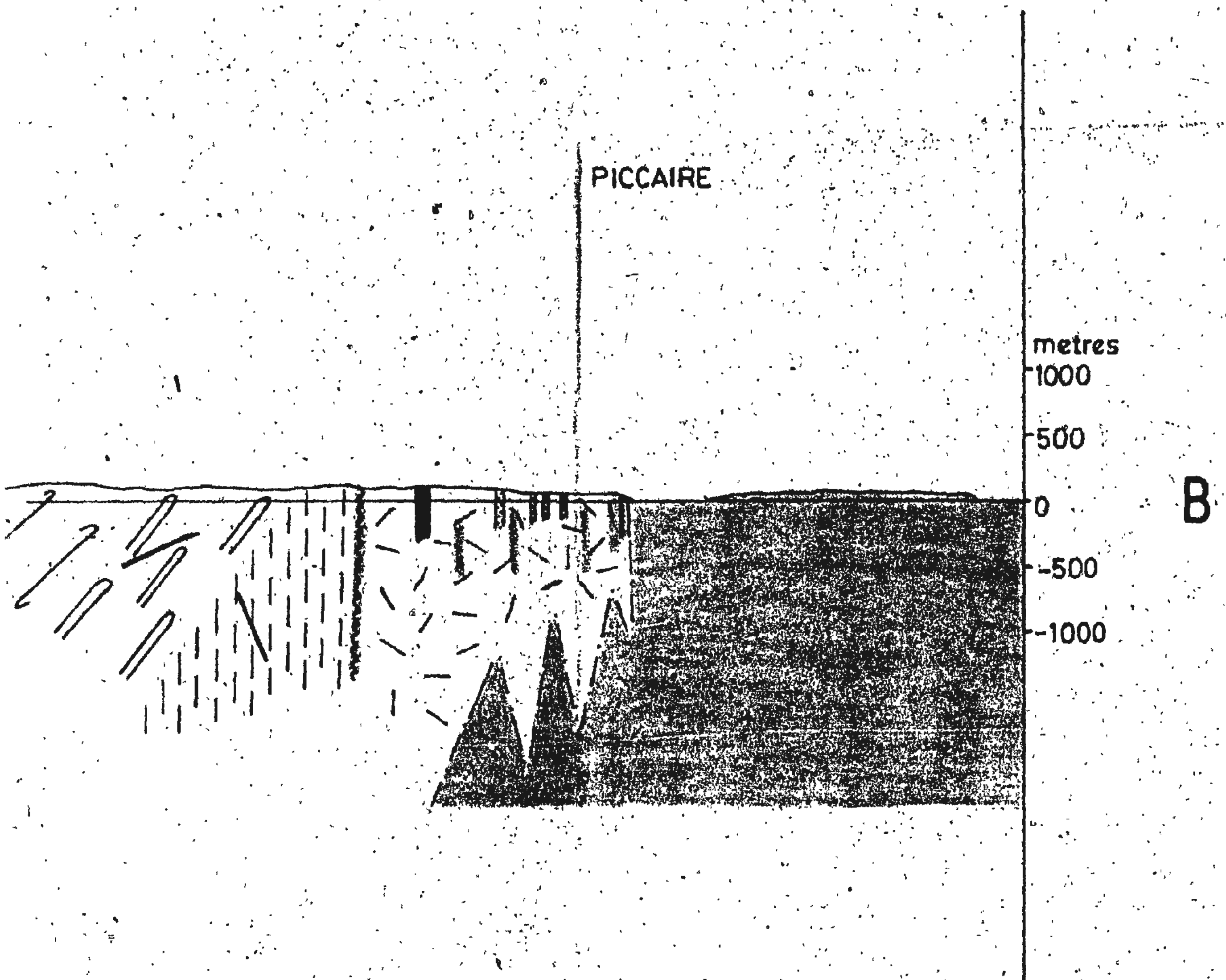

A
metres
1000
500
0
-500
-1000
LAMPIDOES
PASSAGE
BOIS
ISLAND
ISLE
GALET

1 of

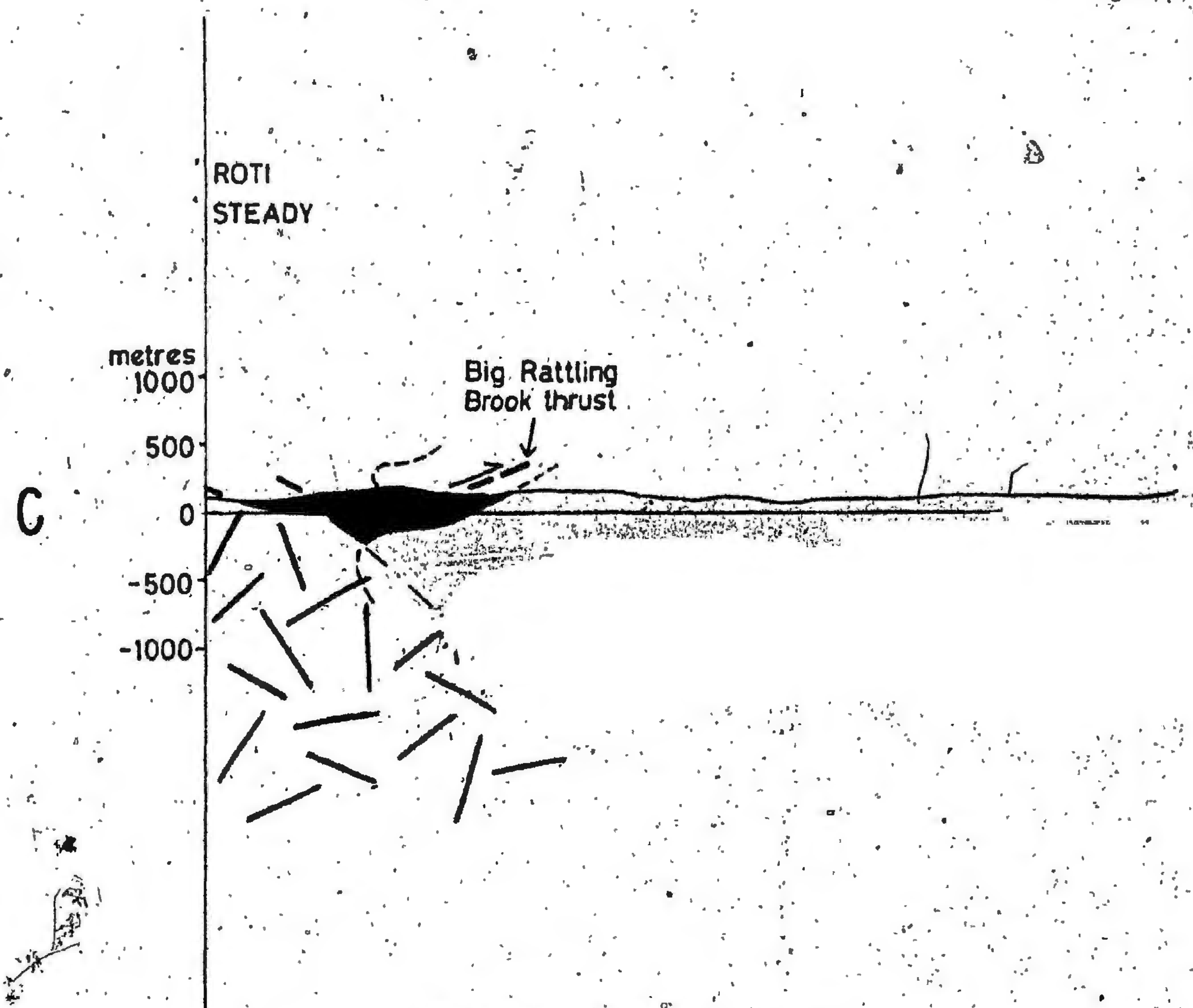
SECTIONS DRAWN FROM MAP 2



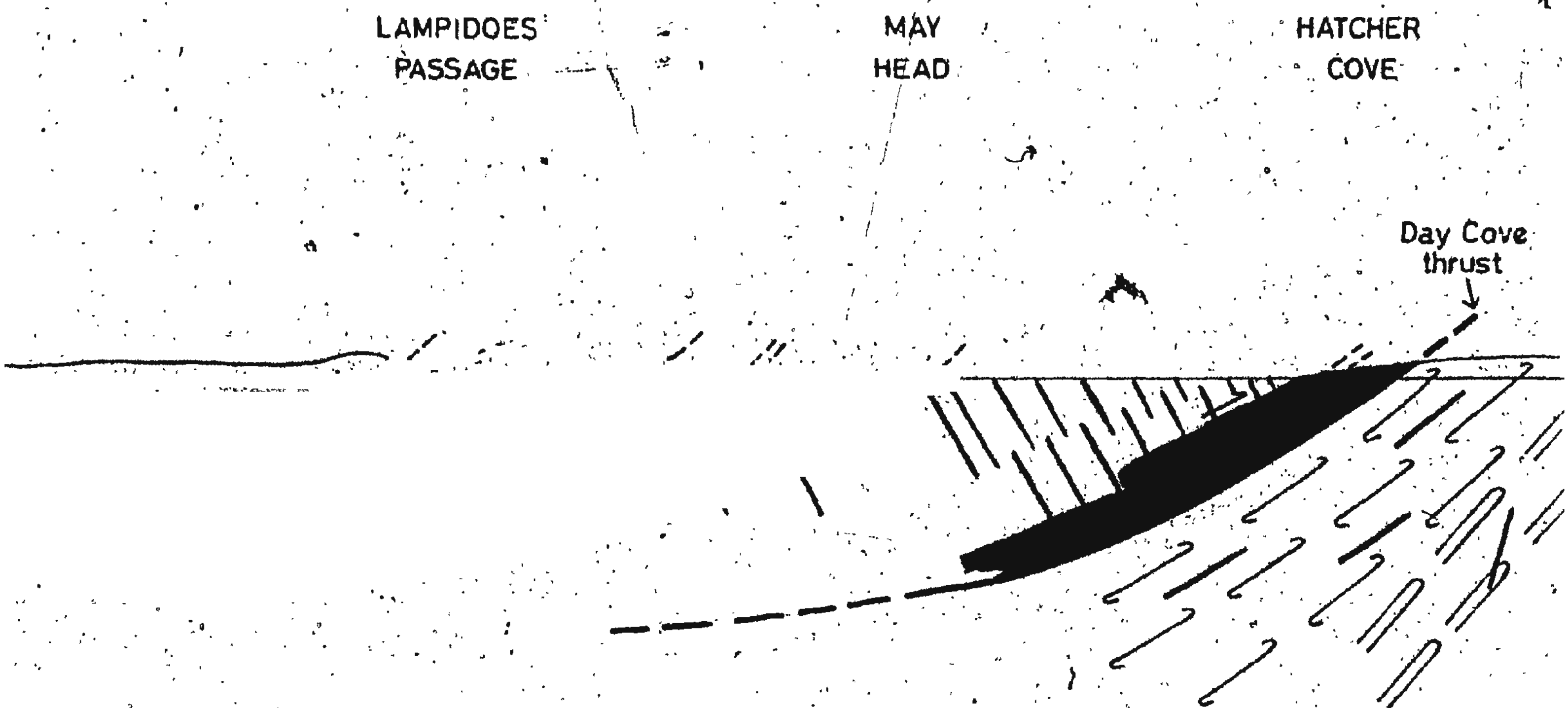
AP 2



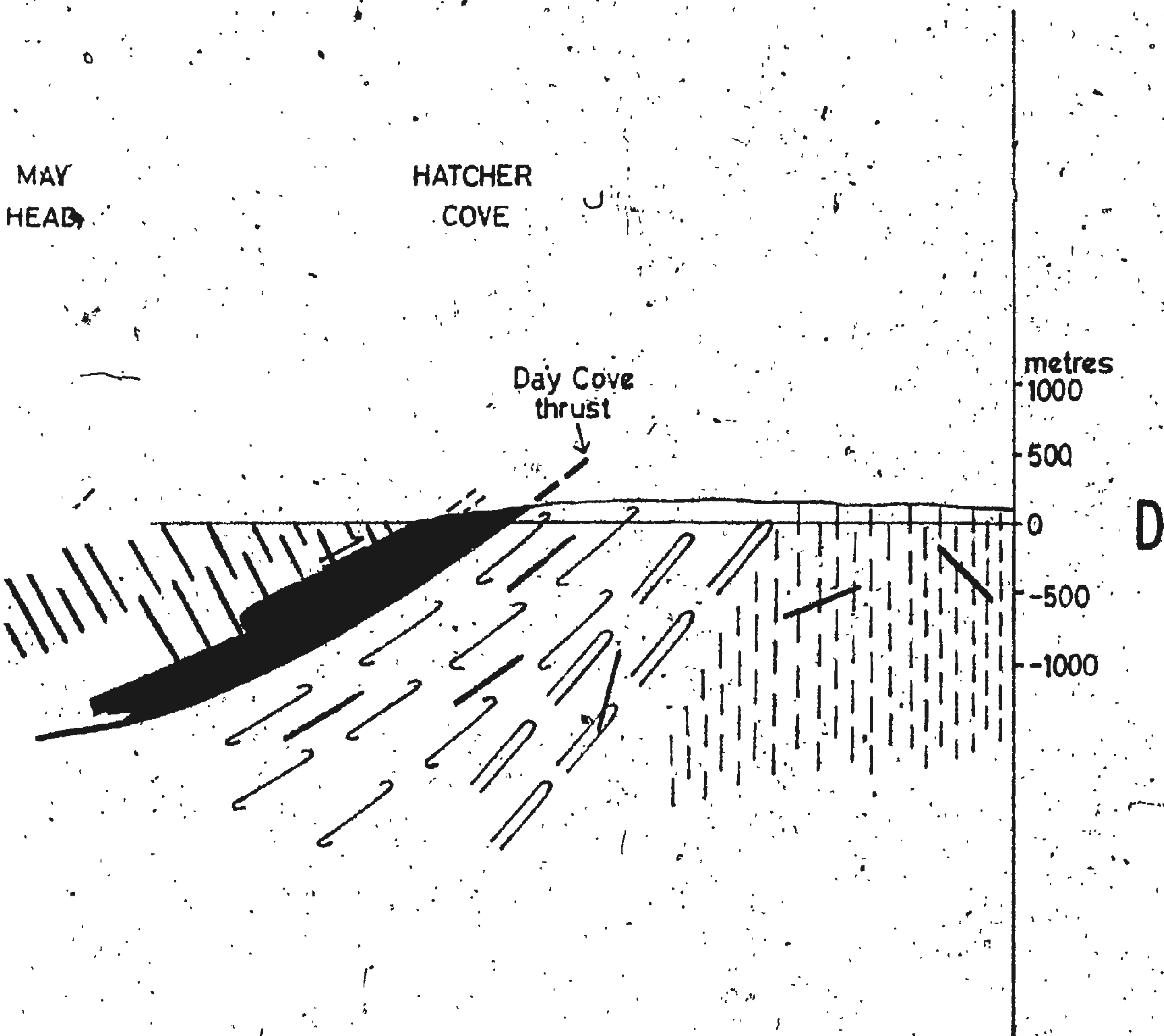
3 of


ROTI
STEADY
metres
1000
500
0
-500
-1000
C
Big Rattling
Brook thrust

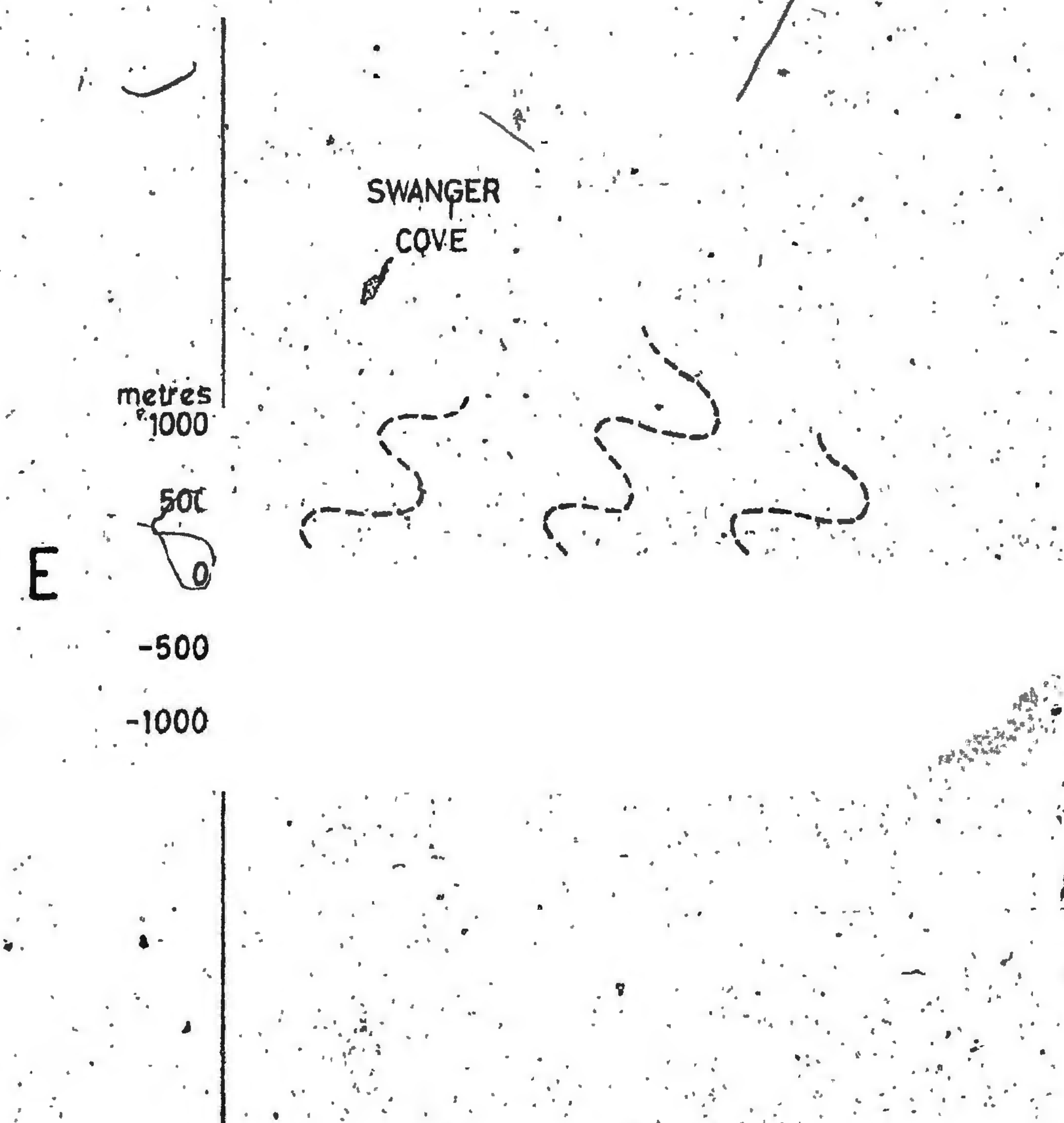
4 of



5 of.


MAY
HEAD
HATCHER
COVE
Day Cove
thrust
metres
1000
500
0
-500
-1000
D

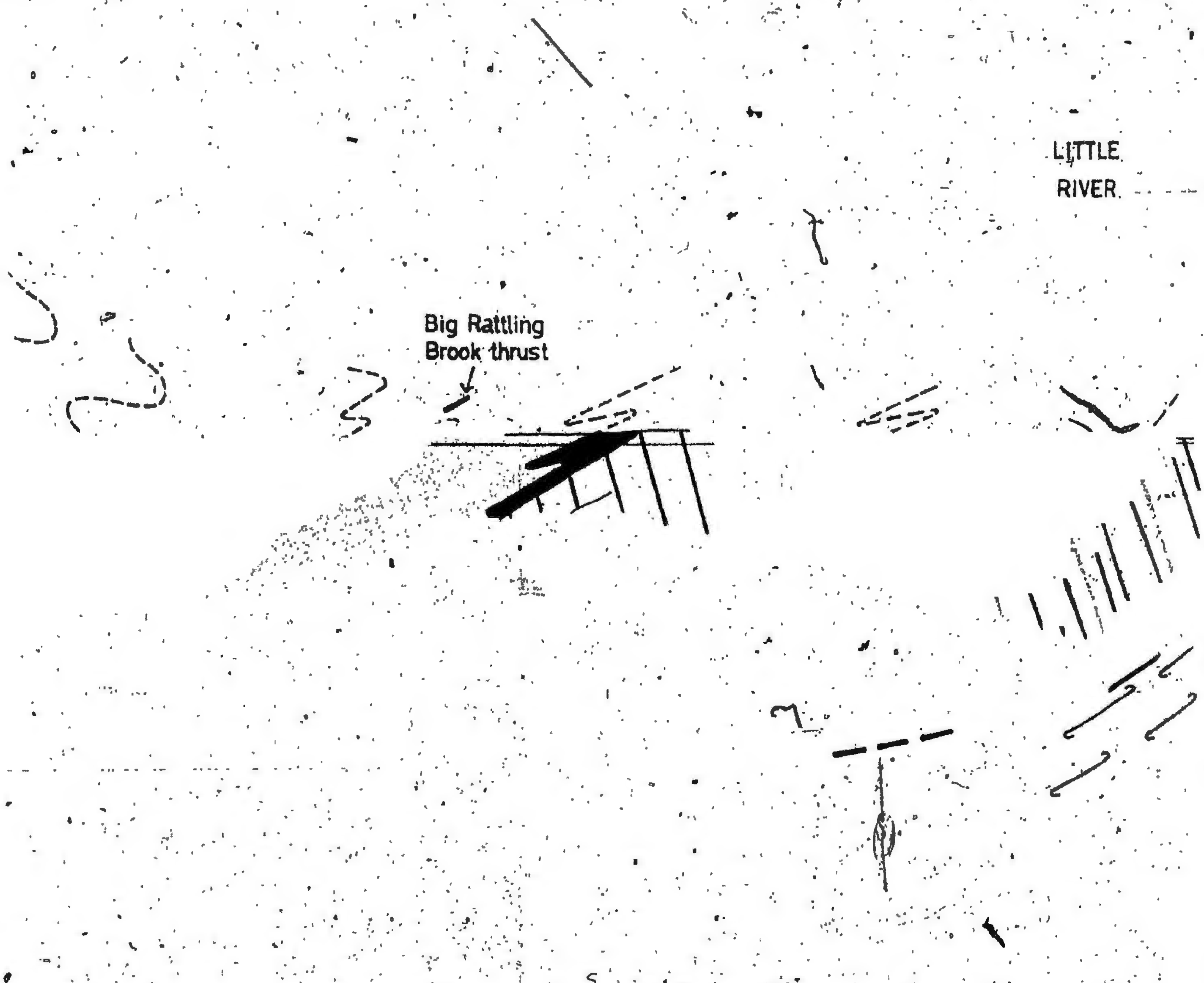
6 of



Legend as on Map 2 except that thrust

7 of

vertical a

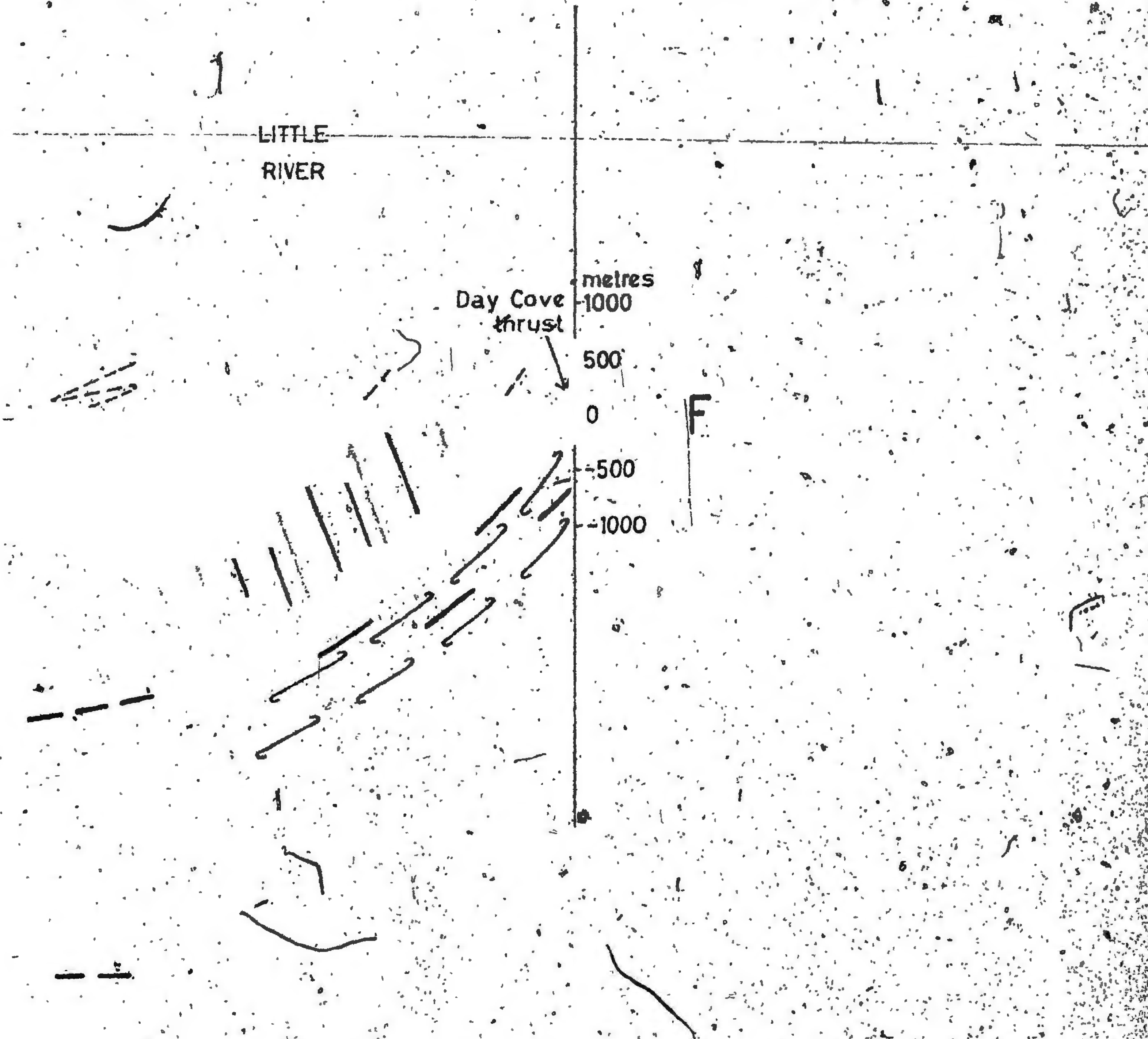


as on Map 2 except that thrust faults are indicated thus:

vertical and horizontal scale; no vertical exaggeration

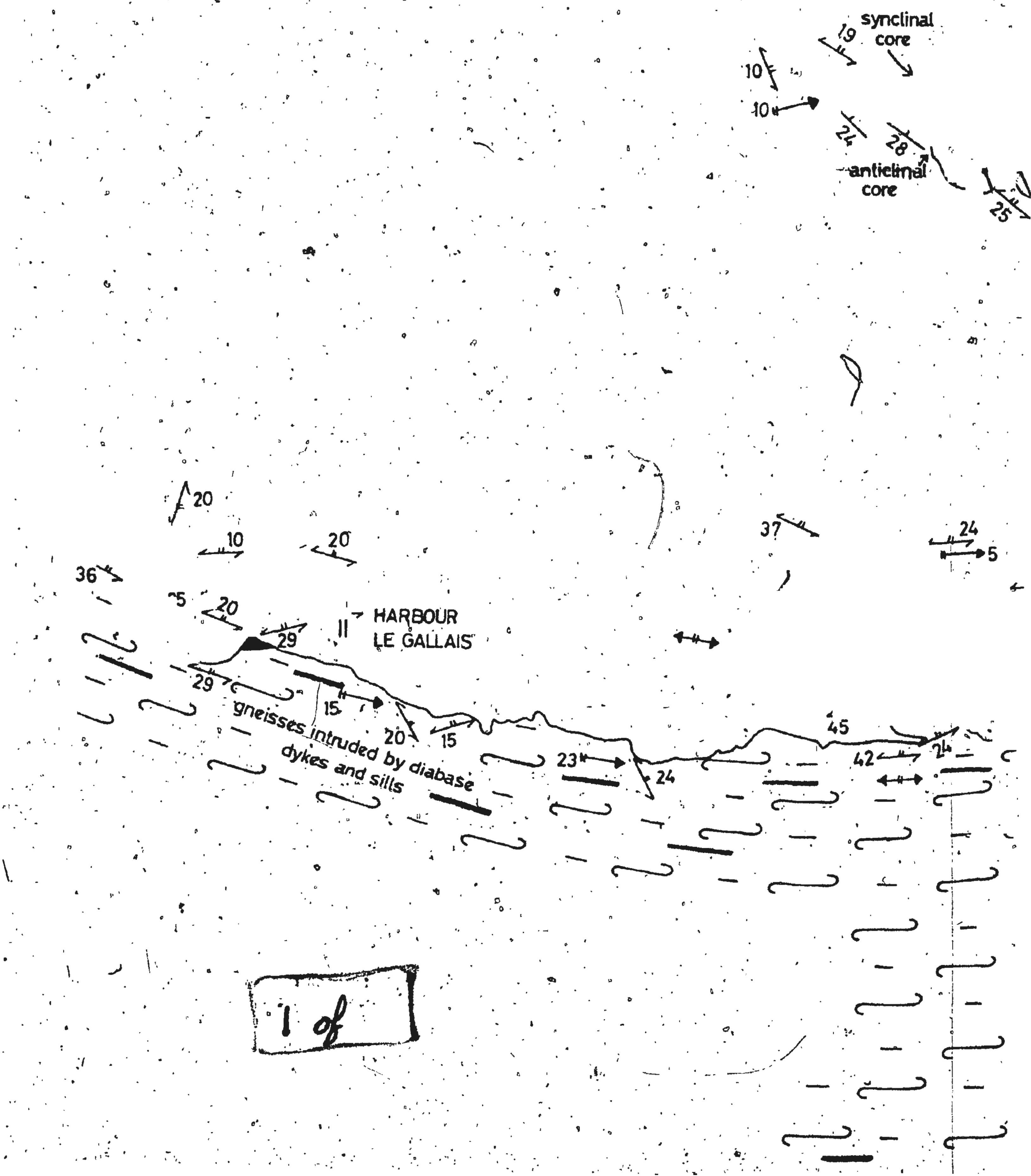
0 1 2 3 4 5

kilometres

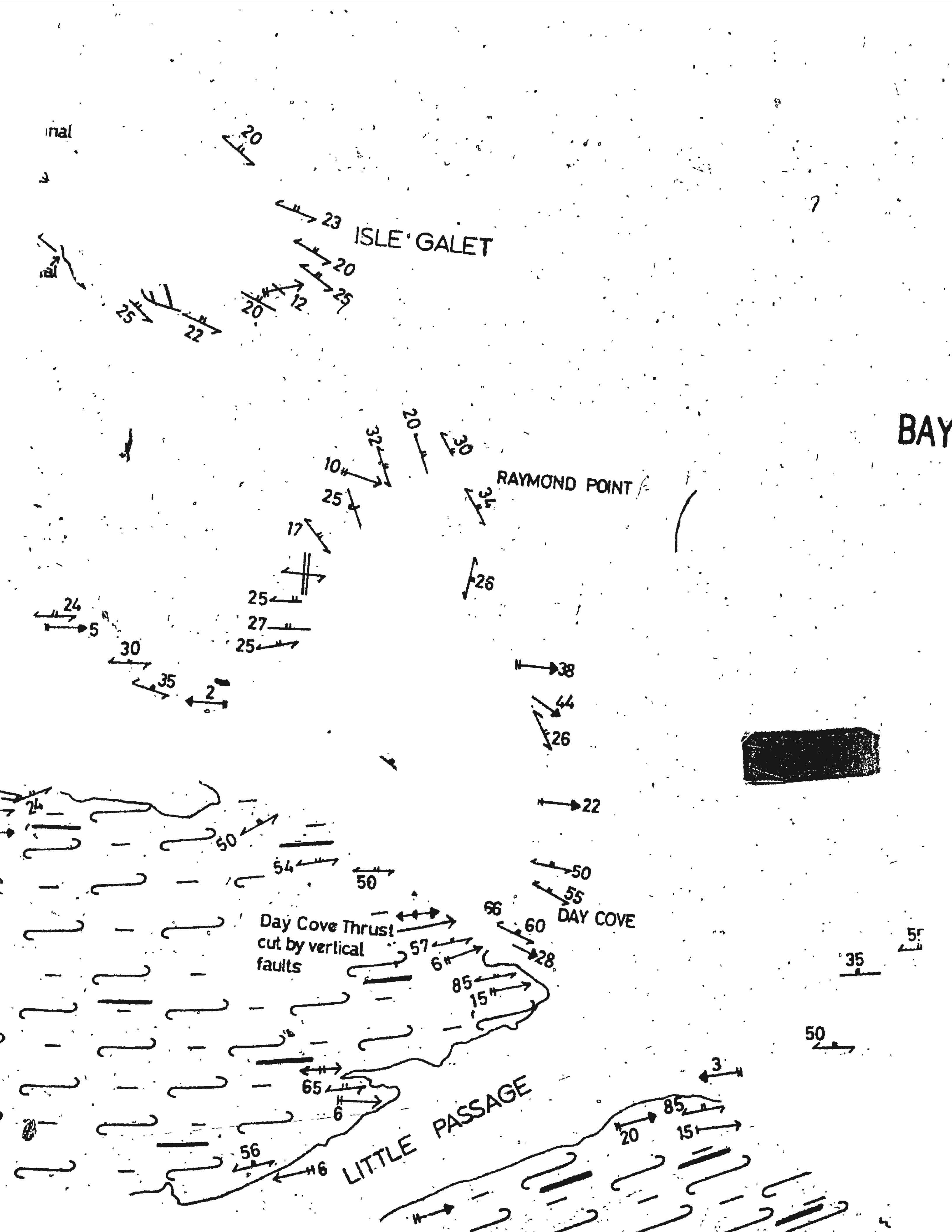


9 of 9

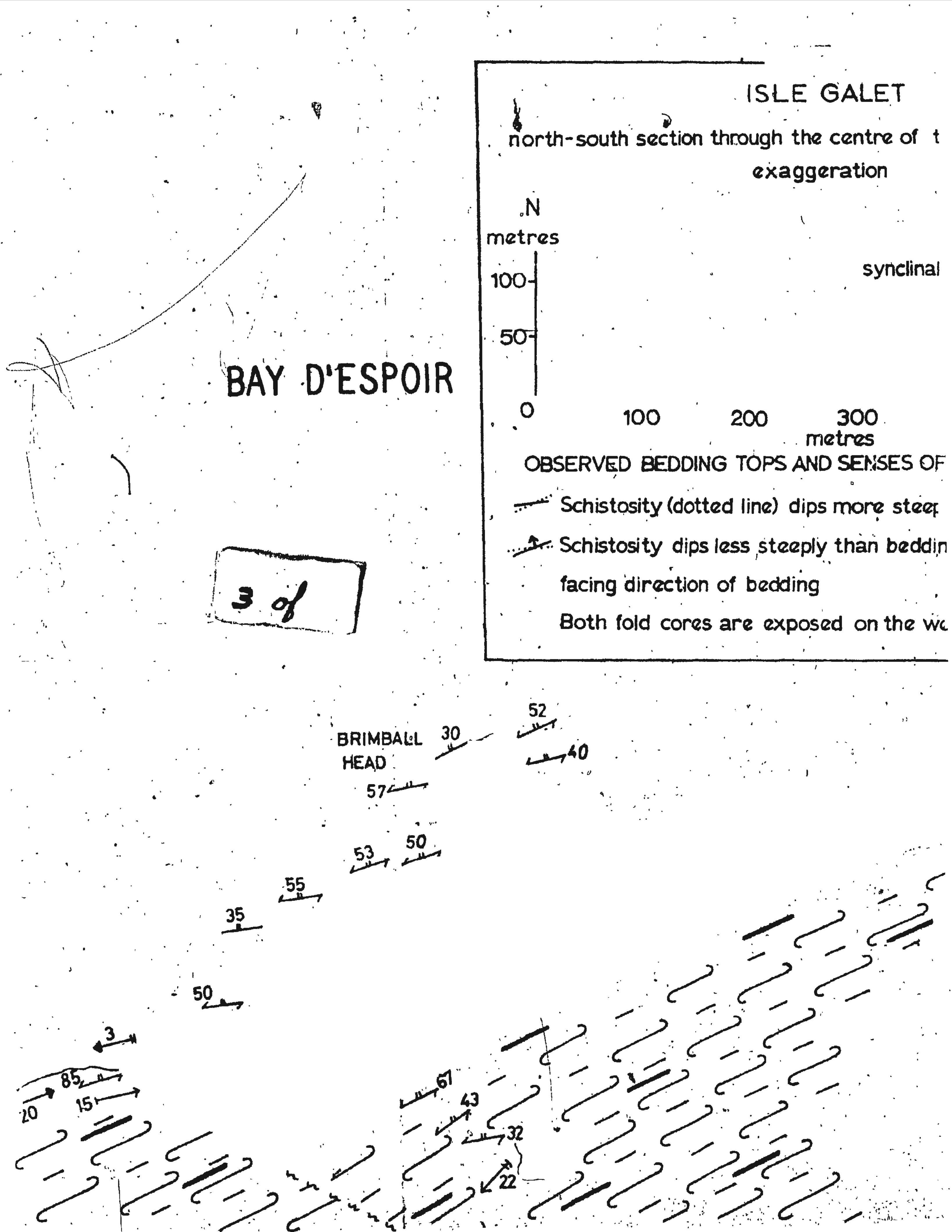
on


synclinal core
anticlinal core
HARBOUR LE GALLAIS
gneisses intruded by diabase dykes and sills

1 of



nal
ial
ISLE GALET
BAY
RAYMOND POINT
DAY COVE
Day Cove Thrust
cut by vertical
faults
LITTLE PASSAGE

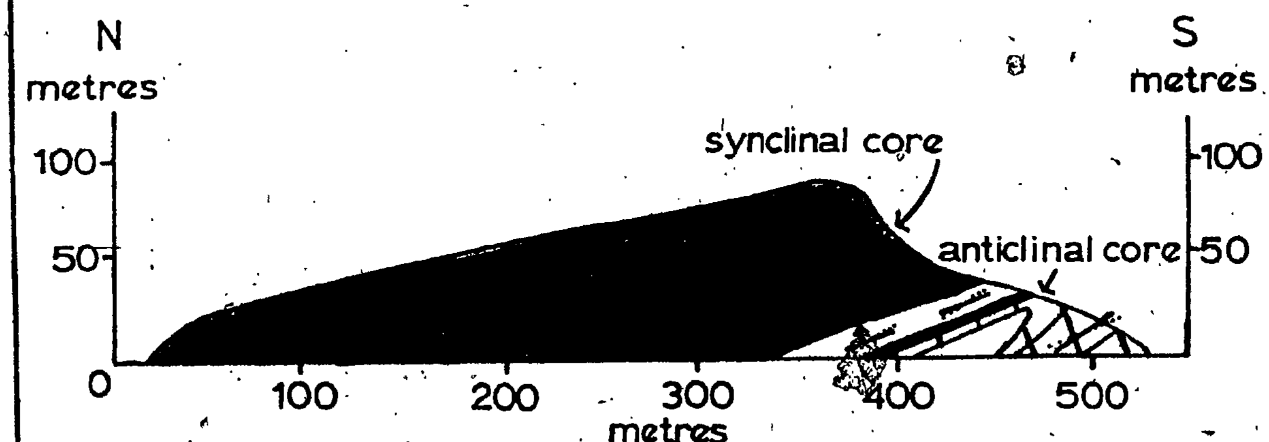

ISLE GALET
north-south section through the centre of t
exaggeration
N
metres
100
50
0
synclinal
100
200
300
metres
OBSERVED BEDDING TOPS AND SENSES OF
Schistosity (dotted line) dips more steep
Schistosity dips less steeply than beddin
facing direction of bedding
Both fold cores are exposed on the wc
BAY D'ESPOIR
3 of
BRIMBALL HEAD
30
52
40
57
53
50
55
35
50
3
85
20
15
67
43
32
22

MAP 3

01R

ISLE GALET

north-south section through the centre of the island; no vertical exaggeration

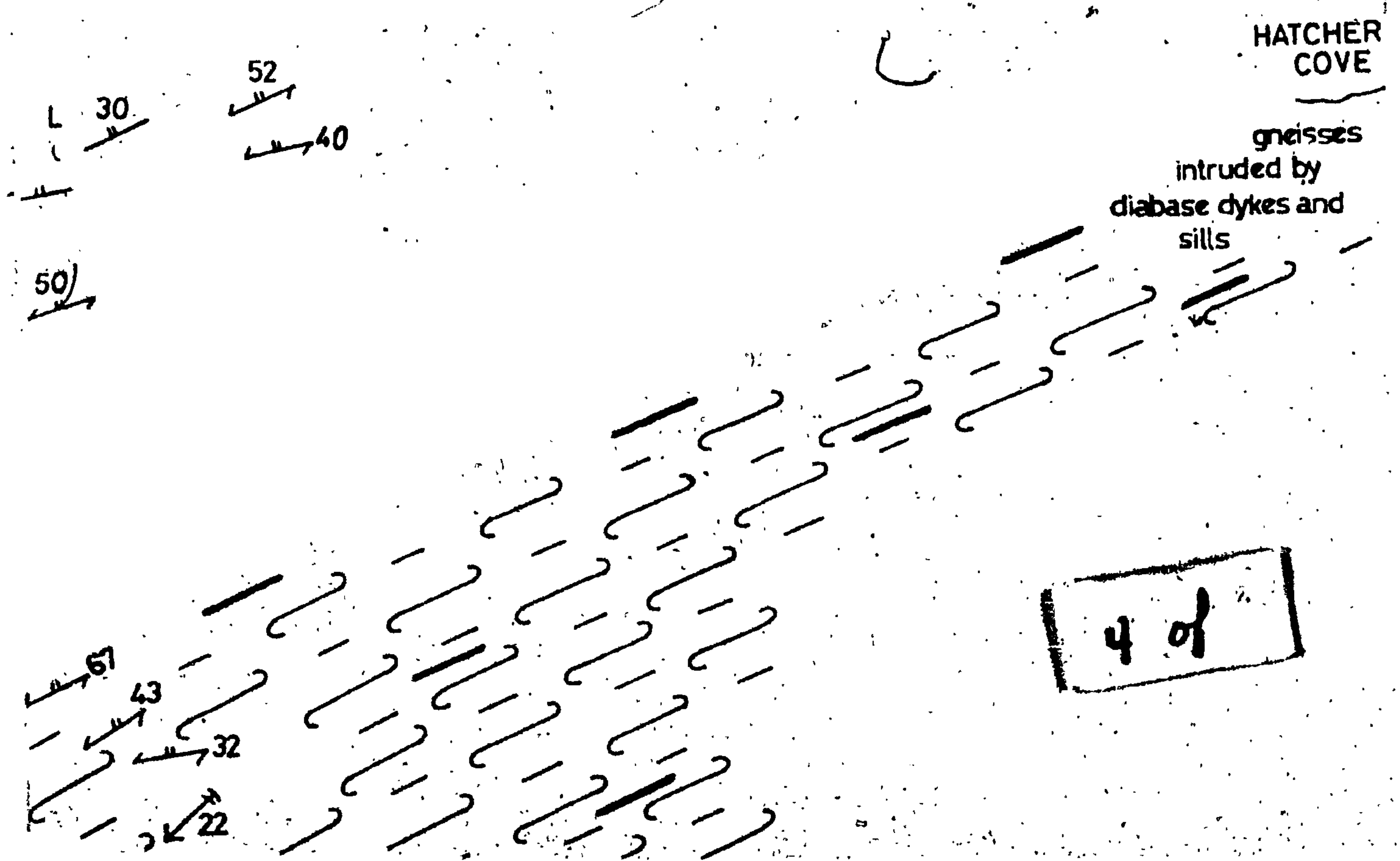


OBSERVED BEDDING TOPS AND SENSES OF VERGENCE

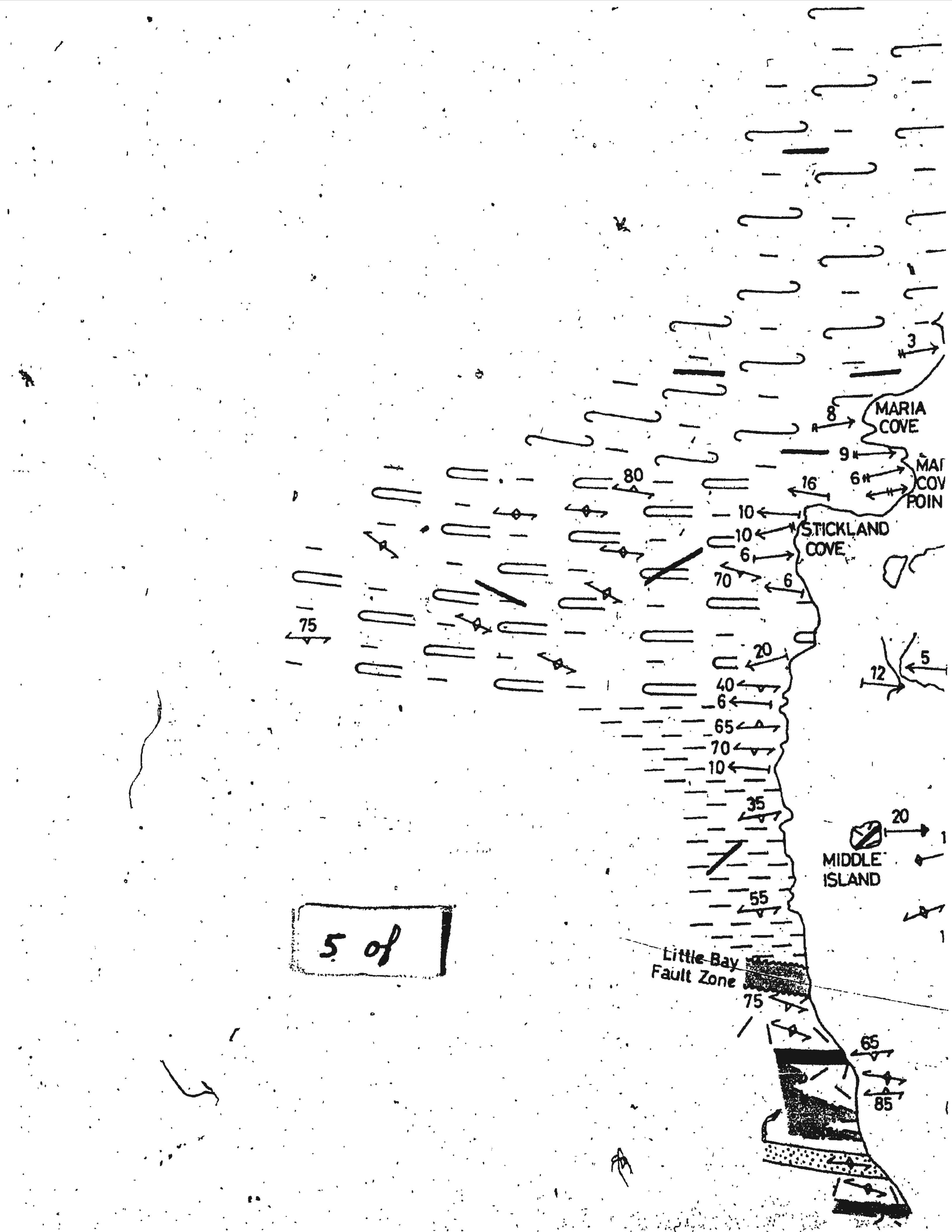
Schistosity (dotted line) dips more steeply than bedding

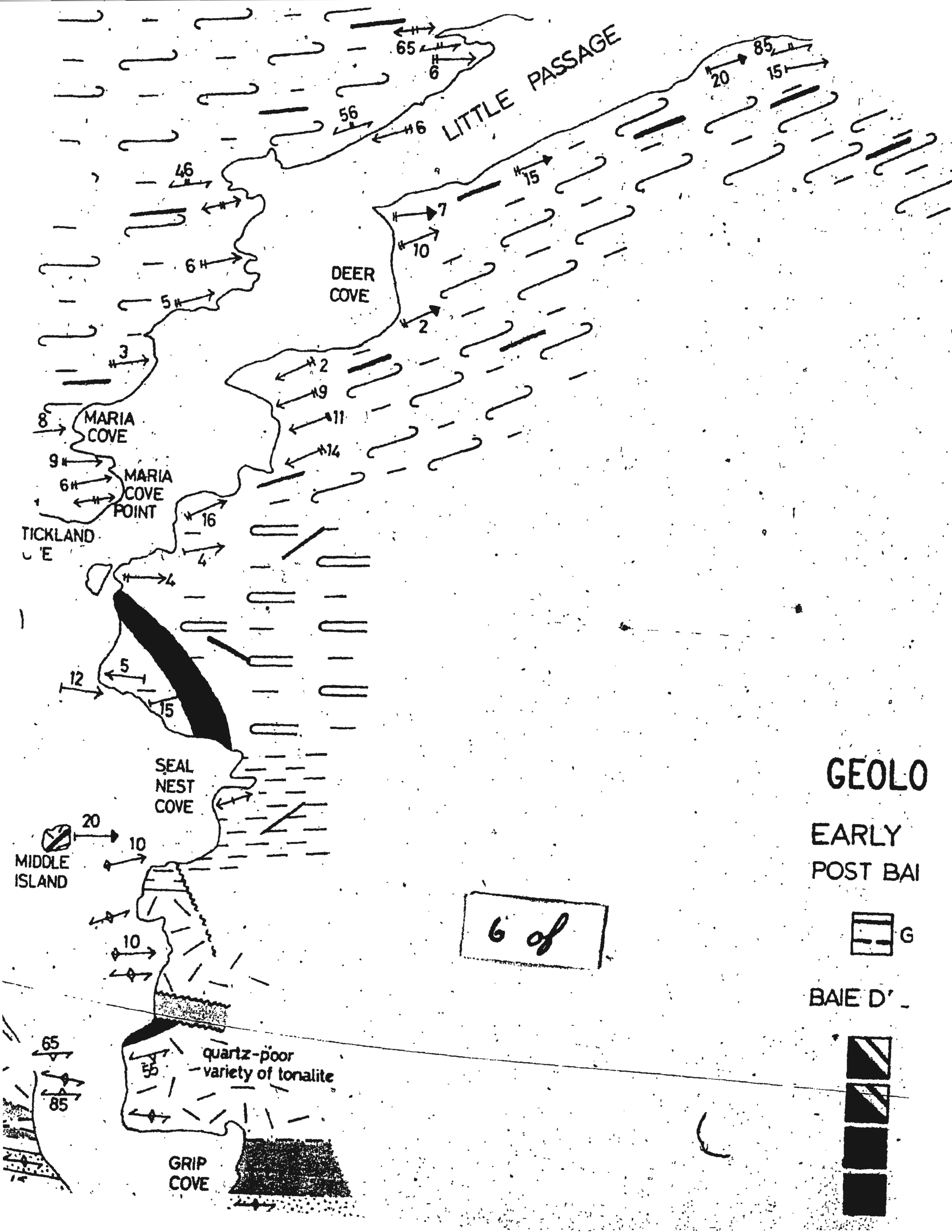
Schistosity dips less steeply than bedding; arrow indicates facing direction of bedding

Both fold cores are exposed on the west end of the island

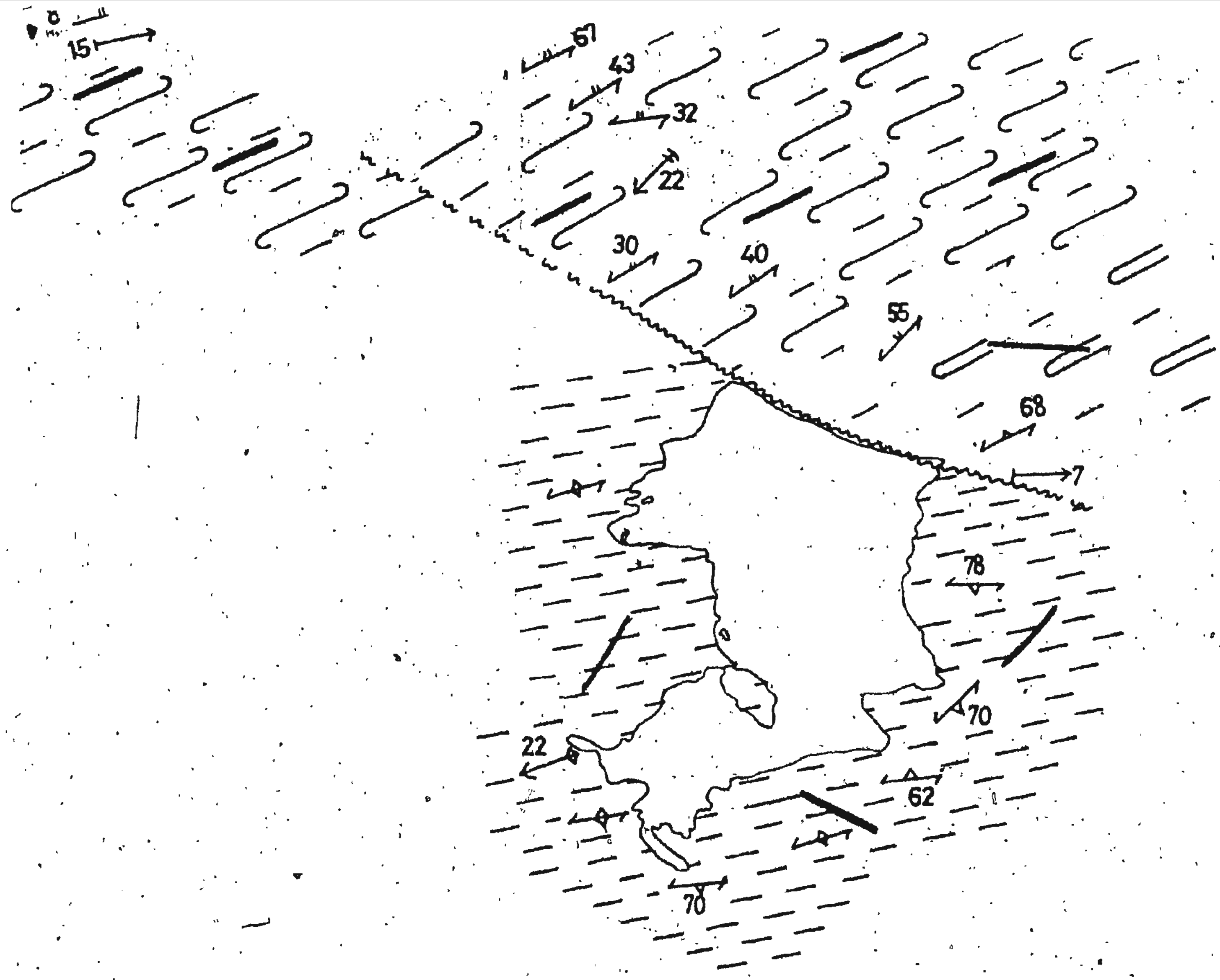


4 of


MARIA COVE
STICKLAND COVE
MIDDLE ISLAND
Little Bay Fault Zone
5 of



LITTLE PASSAGE
DEER COVE
MARIA COVE
MARIA COVE POINT
TICKLAND
SEAL NEST COVE
MIDDLE ISLAND
quartz-poor variety of tonalite
GRIP COVE
6 of
GEOLO
EARLY
POST BAI
G
BAIE D'



GEOLOGICAL MAP OF LITTLE PASSAGE

EARLY PALAEOZOIC OR LATE PRECAMBRIAN

POST BAIE D'ESPOIR GROUP INTRUSIONS

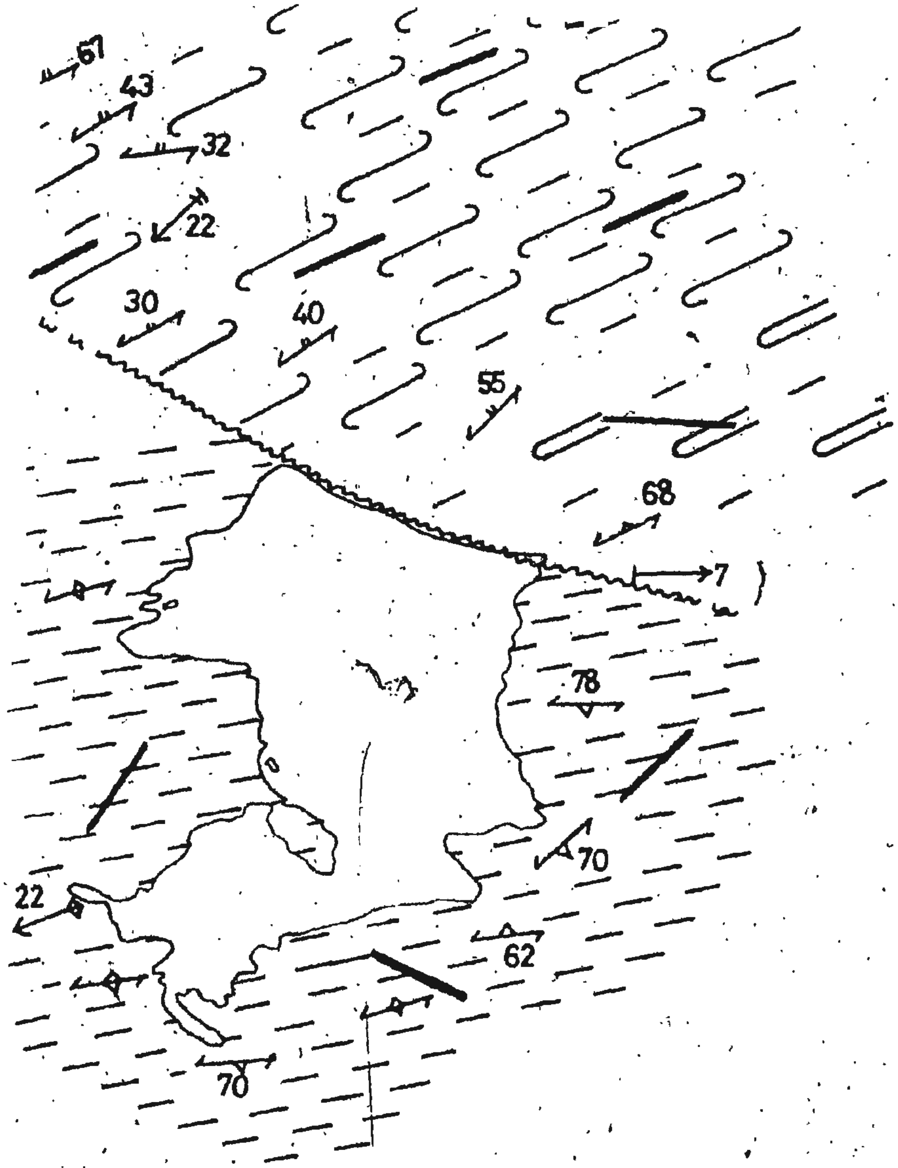
GARNETIFEROUS LEUCOCRATIC GRANITE VEINS

BAIE D'ESPOIR GROUP

7 of

ISLE GALET FORMATION
- acid igneos rocks
- basic igneous rocks
- graphitic schist
- semipelitic chlorite schist

ONS



AP OF LITTLE PASSAGE

ЭIC OR LATE PRECAMBRIAN

·GROUP INTRUSIONS

8 of

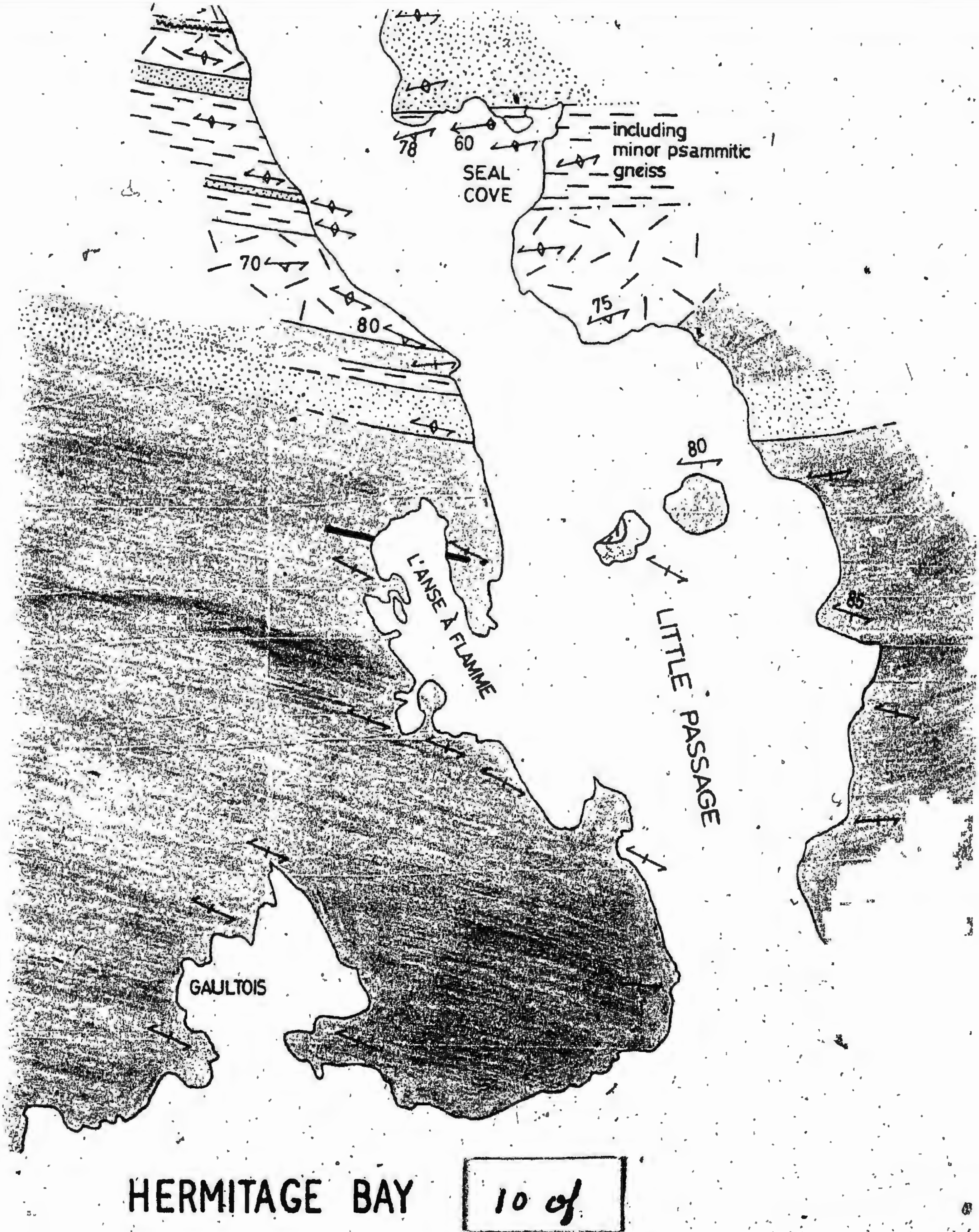
N

'S LEUCOCRATIC GRANITE VEINS

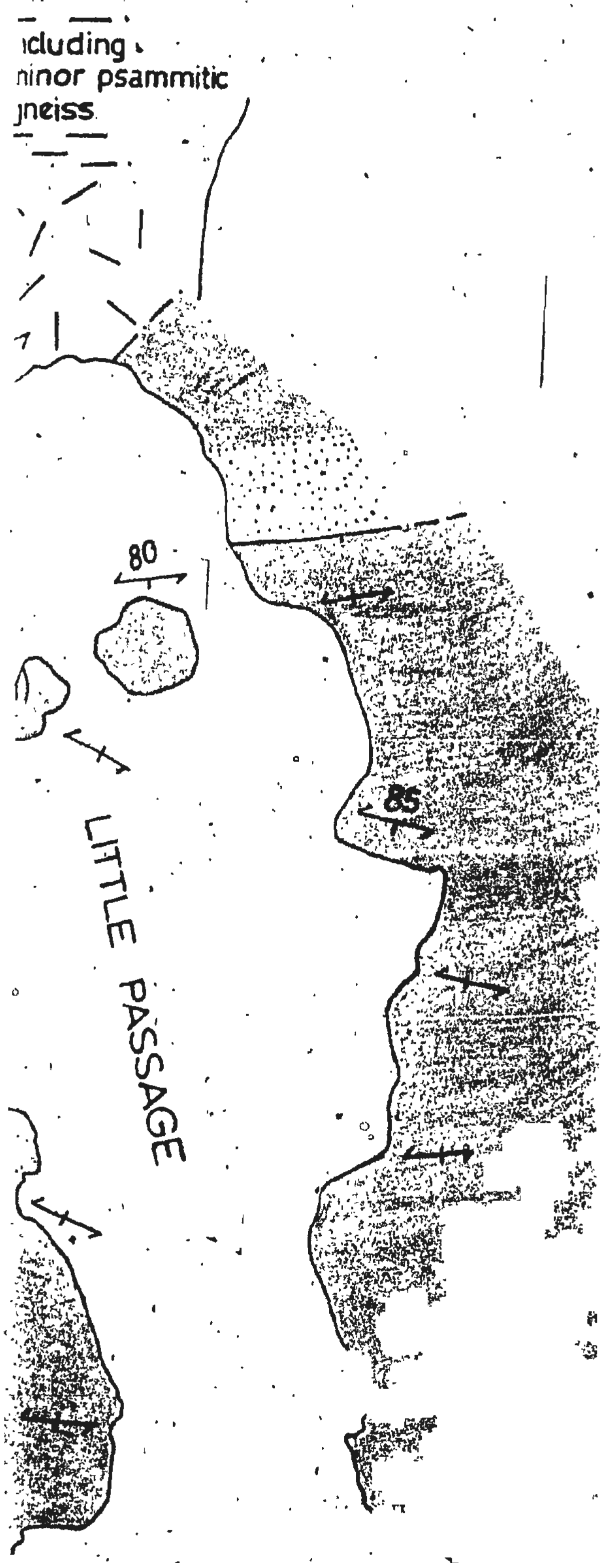
IP

·RMATION
- acid igneos rocks
- basic igneous rocks
- graphitic schist
- semipelitic chlorite schist

70
7
NORTH
WEST
ARM
equigranular
granite
PICCAIRE
equigranular
granite
GAULT
HERMI
9 of


including
minor psammitic
gneiss
SEAL
COVE
78
60
70
80
75
80
85
L'ANSE À FLAMME
LITTLE PASSAGE
GAULTOIS
HERMITAGE BAY

10 of



PRE OR SYN BAIE D'ESPOIR GROUP INTRUSIONS

GAULTOIS GRANITE

SEAL NEST COVE TONALITE

PRECAMBRIAN

LITTLE PASSAGE GNEISSES

MASSIVE TONALITE

TONALITIC GNEISS

PSAMMITIC GNEISS

AMPHIBOLITIC GNEISS

D1 REWORKED GNEISS

D2 REWORKED GNEISS

defined app

inclined	vertical	horizontal	overturned	
36			23	tops known
22				tops unknown
35				S2
46				S1
21				pre Baie d'Espoir

plunging	horizontal	
		F2
		F1
		pre Baie d'Espoir Group
		L2
		L1
		intersection of S2 and pre S2 surfac

11 of

J'ESPOIR GROUP INTRUSIONS

ANITE

OVE TONALITE

NEISSES

IALITE

GNEISS

GNEISS

C GNEISS

D. GNEISS

ED GNEISS

0 1 2

kilometres

defined	approximate	assumed	gradational	
				geologic contact
				thrust fault
				other fault

zontal overturned 23

tops known
tops unknown
Bedding

S2
S1
pre Baie d'Espoir Group
Schistosity

2
1
pre Baie d'Espoir Group
L2
L1
intersection of S2 and pre S2 surface

S. J. Colman
August 1974