THE GEOLOGY AND STRUCTURE OF THE HARE BAY, ALLOCHTHON AT QUIRPON ISLAND, NORTHERN NEWFOUNDLAND

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THE GEOLOGY AND STRUCTURE OF THE HARE BAY ALLOCHTHON AT QUIRPON ISLAND, NORTHERN NEWFOUNDLAND.

by

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ABSTRACT

The rocks on Quirpon Island represent a well exposed cross section through the lower transported slices of the Hare Bay Allochthon and the uppermost parts of the autochthon. This thesis examines in detail the structural geometry of a part of the Hare Bay Allochthon. Its purpose is to analyze in detail the deformational and metamorphic histories of the individual thrust slices and of the uppermost autochthon in order to correlate these hisories as far as possible. Detalied field work reveals a reversed metamorphic gradient. Also, structural complexity and the numbers of generations of structures increases in higher slices. The highest slice at Quirpon, the retrogressed, mylonitic, actinolite greenschists of the Goose Cove Schist, rests above the sedimentary and volcanic rocks of the Maiden Point Formation to which heat was transferred from the cooling greenschists causing pervasive lower greenschist facies metamorphism. Much of the underlying middle Ordovician Goose Tickle Formation flysch, previously believed to be entirely autochthonous throughout the Hare Bay area, occurs as discrete, detached slivers within the Maiden Point Formation. Large scale, isoclinal, pre-cleavage folds have been identified in both of these formations and are syn-emplacement in age. A well defined magnetic anomaly immediately east of Quirpon Island may

indicate the presence of an outlier of ophiolite of the White Hills Peridotite, the highest structural slice in the Hare Bay Allochthon.

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INTRODUCTION

Location and Access

The coastal island of Quirpon is situated 6km east of L'Anse au Meadows, an authenticated Norse settlement, on the Great Northern peninsula of Newfoundland. The island is 6.5km long and at its widest point is 3km across. The north end of the island terminates at Cape Bauld which protrudes into the Strait of Belle Isle slightly further than Cape Norman, the northernmost tip of the island of Newfoundland. The south end of the island juts into and shelters Quirpon harbour from the northeasterly Atlantic fetch (Fig. 1, located in back pocket). It was here, at 'Karpont', that the Jacques Cartier expedition sought shelter from the crushing ice pack in the spring of 1534 before continuing on the historic voyage of discovery up the St. Lawrence River. Quirpon is presently served by a 20km long dirt road that joins the magnificent, newly-paved Northern Peninsula Highway about 12km northwest of St. Anthony.

Geological Setting

Quirpon Island is part of the Hare Bay Allochthon, a complex and extensively outcropping association of allochthonous sedimentary, volcanic, intrusive and metamorphic rocks. The allochthon is exposed for 80km in a belt about 15km wide, from Cape Bauld, on Quirpon Island in the north to Sugarloaf Cove, south of Canada Bay (Fig. 2, located in back pocket).

The allochthon is located at the northernmost limit of exposure of the Appalachian orogen. In recent studies, there is consensus of opinion that the orogen can be interpreted in terms of plate tectonic models (e.g. Church and Stevens, 1971; Dewey and Bird, 1971, and Williams, 1976), from the birth and evolution of the Iapetus Ocean in the late Precambrian to its eventual destruction in middle Ordovician times. Williams (1976) has divided the Newfoundland Appalachians into four tectonic lithofacies zones which are, from east to west, the Avalon, Gander, Dunnage and Humber Zones.

The Hare Bay Allochthon is situated in the Humber Zone which, in this model, represents the stable northeastern Atlantic-type ancient continental margin of the North American craton. The Dunnage Zone represents the vestiges of the Iapetus Ocean that were not completely destroyed during collision of the North American craton against the eastern margin of Iapetus and the platform of the Avalon "microcontinent", which fall respectively into the Gander and Avalon Zones.

Regional geological history

Tectonic elements of the Humber Zone are:

(1) a pre-existing Precambrian crystalline basement of Grenvillian age (The Long Range Complex).

(2) unconformable deposits of lower Cambrian coarse clastic sediments (e.g. Bateau, Bradore and Forteau Formations) and coeval basalt flows and dykes (Lighthouse Cove Formation) (Williams and Stevens, 1969), related to rifting of the craton and birth of Iapetus, and the subsequent development of a thick continental rise prism of Precambrian to Cambrian clastic rocks with associated volcanism (Maiden Point Formation), derived from the North American craton to the west.

(3) development of a Cambro-Ordovician shallow shelf carbonate sequence (St. George and Table Head Formations, and coeval slope facies carbonate slump deposits of the Cow Head Formation) reaching its maximum development in Tremadoc/Arenig times (Tuke, 1968).

(4) blanketing of the carbonate bank by a Llanvirn-age, easterly-derived flysch (Goose Tickle Formation) (Tuke, 1968).

(5) emplacement of the Hare Bay allochthon which, includes an ophiolite with its dynamothermal aureole (St. Anthony Complex) over autochthonous terrain of the northeastern margin of North America.

Purpose and scope of study

The present study was carried out for the following reasons; (1) to examine in detail the structural geometry of the lower part of the Hare Bay Allochthon, covering internal geometry of the units and their contact relationships.

(2) to analyze in detail the deformational and metamorphic histories of the different thrust sheets in the allochthon and of the autochthonous rocks, and to compare and correlate these histories as far as possible in order to develop a regional deformation scheme.

(3) to clarify and understand the deformation processes (kinematics and deformation mechanisms) involved in the formation and emplacement of the allochthon, with special reference to plate tectonic models.

CHAPTER 1

PREVIOUS WORK AND THE DEVELOPMENT OF IDEAS

Daly (1903) examined some of the Maiden Point pillow lavas of Quirpon Island and Jacques Cartier Island. He described in detail the variolitic structures and petrography concluding that the basalts were "greatly altered variolitic spilites."

Cooper (1937) made the first detailed description of the Hare Bay area, noting a lower limestone unit overlain by the Goose Tickle Slate. He suggested that the thickness of the Goose Tickle (600-1700m) was largely due to repetition by isoclinal folds and imbricate faults, and further recognised intense "plastic flowage" deformation that disrupted and often obliterated bedding. He recognised that the Hare Bay thrust fault had transported the White Hills Peridotite and the underlying aureole rocks as a large "decke" or sheet for a minimum horizontal distance of 18km. He also noted the St. Anthony (thrust) Fault which separates the Goose Cove Schist from the underlying Maiden Point Formation south of St. Anthony. He recognised the regional northeast-southwest structural trend, and noted the absence of large scale structures in the Goose Cove Schist, and that the structures in the overlying peridotite pre-date the regional structure.

Rodgers and Neale (1963) recognized the significance of older rocks above younger ones. They suggested that the Bay of Islands and Hare Bay Allochthons were large westward-transported klippen with a source region east of White Bay.

Stevens (1967) believed that the White Hills Peridotite was a transported pluton capped by a roof pendant (the Cape Onion Formation). This theory was later modified by Williams (1975) who mapped the Cape Onion Formation as a separate slice and suggested it may once have been the top of an ophiolite.

Tuke (1968) recognised that the Goose Tickle Formation rested disconformably on the Table Head Formation, and modified Stevens' (1967) date of final allochthon emplacement from Caradocian to Llanvirnian. He demonstrated the tectonic contact of the "Eastern Sequence" (including the Northwest Arm, Maiden Point and Cape Onion Formations, and the St. Anthony Complex) above the "Western Sequence" (including the White Islands Formation, St. George Group, Table Head and Goose Tickle Formations).

Tuke (1968) postulated a northwesterly sense of allochthon movement based on slickensiding and southeast-dipping fold axial surfaces. He further correlated the Maiden Point Formation with the Fleur de Lys Supergroup and suggested that it formed the roof of the peridotite. Williams (1975) also equated the Maiden Point sandstones with the Fleur de Lys clastics of the Grey Islands in northern White Bay (Kennedy _et al._, 1973), and further correlated the Maiden Point Formation with the Summerside Formation of the Humber Arm Supergroup. Stevens (1970) correlated the Maiden Point and Northwest Arm Formations with the lower flysch unit and middle carbonate unit respsectively, of the Curling Group (Bay of Islands) and noted the absence of the upper flysch unit at Hare Bay (the easterly-derived Blow-Me-Down Brook Formation of the Bay of Islands Allochthon).

Jamieson (1979) noted that the Maiden Point gabbros are sill-like in form near the top of the Maiden Point slice on the north shore of Hare Bay and at St. Anthony, Cape Onion and Quirpon. She noted that the gabbros are locally deformed along faults and in small shear zones, and that cleavage in the sandstones often does not pass into the intrusions. These observations led her to agree with Cooper's (1937) interpretation that deformation of the Maiden Point Formation had already begun when the gabbros were intruded. Jamieson (1977) demonstrated a petrographical and geochemical link between the Maiden Point gabbros at Partridge Point, the Cape Onion Volcanics and the Ireland Point Volcanics, a suite of undeformed calc-alkaline basaltic pillow lavas and pyroclastic rocks. She interpreted these, together with the Maiden Point gabbros at Quirpon, as forming an originally comagmatic igneous suite prior to emplacement.

Stevens (1970) suggested a late Arenig age for the first movements of the ophiolite and concurred with Rodgers and Neale's (1963) hypothesis of final emplacement of the allochthon by gravity sliding. He maintained that the ophiolite controlled emplacement by successive peeling of underlying slices from their substrate. He further suggested that the ophiolite was partially exposed during final emplacement since it provided material to the easterly-derived flysch of the Goose Tickle Formation.

Dewey and Bird (1971) noted the similarity between the garnet amphibolites beneath the ophiolite of the Humber Arm and Hare Bay allochthons and interpreted these rocks as transported Fleur de Lys Supergroup equivalents. This correlation was also described by Smyth (1971) who referred to similar lithology and structure in the Eastern Sequence of the Fleur de Lys Supergroup. Church and Stevens (1971) postulated, that if contact aureoles imply high-temperature emplacement then they could have been emplaced in one of two ways: either directly onto continental margin deposits of the Fleur de Lys Supergroup immediately following inception of an accreting ridge or during ocean closing while the ridge was positioned close to the continental margin.

Smyth (1971; 1973) and Williams and Smyth (1973) detailed the structure of the Hare Bay allochthon. They reasoned that the aureole was formed at an early stage because foliated aureole blocks are found in melange zones. Williams and Smyth (1973) suggested that the aureole/ultramafic contact was the level of earliest detachment. They further suggested that the aureole protoliths probably consisted of tuffs, agglomerates, pillow lavas, minor black pelites, thin recrystallized limestones and local psammites. Smyth (1973) noted that in the basal part of the Goose Cove Schist, exposed on Fishot Island, deformation has not obliterated the protolith which consists of graded greywackes. Metamorphosed interbedded agglomerate, tuff and porphyritic pillow lavas are also recognizable here. In the Goose Cove area, with decreasing distance from the overlying peridotite, the intensity of deformation and grade of metamorphism increase obliterating original lithologies within the Goose Cove Schist (Smyth, 1973, and Jamieson, 1979) which passes structurally upwards into the Green Ridge Amphibolite. The amphibolite lies structurally below the White Hills Peridotite west of Goose Cove which forms the highest structural slice in the Hare Bay Allochthon.

Smyth (1973), Williams & Smyth (1973) and Malpas et al., (1973) noted the inverted metamorphic sequences at Hare Bay and suggested that the genesis of garnet amphibolite during obduction could be considered alternative to the production of blueschists along a Benioff zone. More recently the dating of hornblendes from the aureole rocks led Dallmeyer (1977) to suggest that obduction began some 20 m.y. earlier at Hare Bay (480± m.y.) than at the Bay of Islands (460±5 m.y.). He postulated that this diachronism was perhaps due to the ophiolite being closer to the continental margin in the Hare Bay area.

Detailed work in the last decade has been carried out by several workers. Smyth (1973) and Williams and Smyth (1974) described the different tectonic slices that comprise the allochthon and their structural stacking order, in an area south of Hare Bay, while Williams *et al.* (1973) reported on the area north of Hare Bay. Williams and Smyth (in press) mapped the entire allochthon and adjacent autochthonous rocks. DeLong (1976) mapped the Cape Onion Formation and analyzed the geochemistry of the pillow basalts and gabbros. Jamieson (1979) analysed the dynamothermal aureole beneath the White Hills Peridotite north of Hare Bay around Goose Cove in order to interpret the protolithic material of the aureole rocks based on detailed geochemistry. She analyzed the metamorphic petrogenesis and the pressure/temperature gradients of these rocks with a view to modelling the metamorphic conditions during emplacement of the peridotite. Talkington (1981) has worked extensively on the White Hills Peridotite in an attempt to understand the petrogenesis and the pressure/temperature conditions pertaining to the evolution of this deep-seated mantle tectonite. Talkington & Jamieson (1979) based on their own work and others, have produced a short synthesis on the geology of the St. Anthony Complex.

Structure of the Hare Bay Allochthon

The Hare Bay Allochthon consists of six major thrust slices as defined by Smyth (1973). These slices may or may not all be present in any one section through the allochthon, but the stacking order of slices is never varied (Williams et al., 1973).

On Quirpon Island the lowest unit in the Allochthon, the Northwest Arm Slice, is missing, and instead the second unit, the Maiden Point Slice, comprising the Maiden Point Formation, rests directly on autochthonous rocks of the Goose Tickle Formation of Llanvirn age. This defines a lower age limit for emplacement of the allochthon. The White Islands Formation forms the lowest and chronologically oldest autochthonous unit 4km east of Quirpon Island. It is of possible Early Cambrian or Late Precambrian age (Williams and Stevens, 1969) and rests stratigraphically below the Goose Tickle Formation.

Three structural units found above the Maiden Point Slice south of Hare Bay and at Cape Onion are missing in the Quirpon section. These are the Croque Head, St. Julien Island and Cape Onion Slices (Smyth 1973) (Fig. 2, located in back pocket). Instead, the Maiden Point Slice on Quirpon Island is juxtaposed with the Goose Cove Schist which forms the highest structural slice in this section of the Allochthon. Northwest of Goose Cove (in structurally ascending order) the Goose Cove Schist, Green Ridge

Amphibolite and Long Ridge Metagabbro lie structurally below the White Hills Peridotite (Jamieson, 1979) (Fig. 2), which together form the White Hills Slice. West of Goose Cove the Goose Cove Schist is in gradational structural and metamorphic contact with the structurally lower Ireland Point Volcanics (Cooper, 1937; Jamieson, 1977; 1979; Talkington & Jamieson, 1979). The Goose Cove Schist is interpreted as having formed from the deformation and metamorphism of the Ireland Point Volcanics and the Maiden Point Formation (Williams & Smyth, 1973; Talkington & Jamieson, 1979).

The Maiden Point Formation is separated from the underlying Goose Tickle Formation by a shaley melange zone containing sloughed off and sheared blocks of both formations. The Goose Cove Schist is separated from the Maiden Point Formation by a well defined ductile shear zone that appears to be developed mainly in mylonitized sandstones of the Maiden Point Formation.

Analysis of the rocks on Quirpon Island is necessary because there is no recent work which deals with the detailed structural geometry of the lower part of the Hare Bay Allochthon. Relationships between deformation and metamorphism (an important aspect of the orogenic evolution of the terrain) have also been largely ignored. Further, inconsistencies exist in available literature, e.g. between Church and Stevens (1971) and Williams (1975) interpretation of the top of the ophiolite, and between

Tuke's (1968) and Williams and Stevens' (1969) and Williams and Smyth's (in press) interpretation of the White Islands Formation. Also many workers have ignored the available geophysical evidence as a tool for interpreting subsurface geology and for delineating the seaward extension of the Allochthon. This thesis provides the first detailed geological map and structural description and interpretation of Quirpon Island.

CHAPTER 2

THE AUTOCHTHON

Introduction

The autochthonous rocks in the area of study consist of two sedimentary units. These are the coarse sandstones of the White Islands Formation of possible Early Cambrian age (Tuke, 1968), and the calcareous flysch of the overlying Goose Tickle Formation of Llanvirn age (Tuke, 1968; Stevens, 1970; Smyth, 1973). Throughout this thesis the reader is advised to refer to Figure 1 (located in back pocket) which indicates the position of all places and localities referred to in the text.

The White Islands are a group of three small islands, the largest of which is 1km long, situated 4km east of Quirpon Island (Figs. 1 & 2, located in back pocket). Tuke (1968) noted the occurrence of about 700m of white sandstones on these islands and correlated them with other occurrences in Labrador and Canada Bay that belong to the Bradore Formation. Outside the study area the sandstones are exposed along the southern Labrador coast around Bradore Bay where they rest unconformably on Precambrian basement of Grenvillian age (Smit, 1971). Betz (1939) and Smyth (1973) also noted an unconformity between the Bradore Formation and the underlying rocks of the Long Range

Complex south of Hare Bay. Williams and Stevens (1969), however, correlate the sandstones with the Bateau Formation of Belle Isle, and Stevens (pers. comm., 1980) believes that they may belong to the Hawkes Bay Formation. Since, at present, there is insufficient evidence to place these rocks in one of these three formations with any certainty, it is suggested that the sandstones be termed the White Islands Formation, although the base and the top of the formation are not seen. This name will be used in discussions throughout the present work.

The Goose Tickle Formation, a northeasterly-derived calcareous flysch (Tuke, 1968; Stevens, 1970; Smyth, 1973), is exposed extensively on the mainland around Quirpon harbour and occurs as inliers on Quirpon Island. It is seen lying disconformably above the carbonates of the Table Head Formation at Schooner Head (Tuke, 1968) and southwest of Raleigh (this author). The top of the Goose Tickle Formation is marked by a tectonic contact with the overlying allochthonous Maiden Point Slice. The contact zone consists of several metres of highly sheared, rubbly, cleaved shale.

Several major units are missing between the White Islands Formation and the Goose Tickle Formation on Quirpon. These include, from oldest to youngest, the Forteau, Hawke Bay, March Point, Petit Jardin, St. George and Table Head Formations, some of which are seen in more complete sections south of Hare Bay (Smyth, 1973).

White Islands Formation

The rocks of this unit consist of medium-grained (1-5mm diameter), clean-washed, white quartzites with pink feldspar forming up to 30% of the total grain content. The beds vary from about 0.5m to 1m in thickness and are all massive with sedimentary layering picked out by small variations in grain size and feldspar content. Sedimentary structures such as cross-bedding and grading are absent in outcrop, however micro-cross bedding, defined by black laminae, is seen in fallen blocks. The quartzite exposed on White Rocks, some small supratidal cliffs 1.5 km west of the White Islands, contains thin magnetite-rich lenses (H. Williams, pers. comm.).

Shale

A single shale band approximately 10m thick, occurs in the sandstones on the east coast of the main island. The shale is dark grey, mica-rich and finely cleaved, making it very friable. H. Williams (pers. comm.) found the eastern edge of the shale to be rich in talc. It contains numerous rodded and flattened pods of quartz and wherever the shale is silty it contains boudinaged veins of quartz and brown-coloured calcite. These boudins are often severely disrupted and broken into gravelly, sub-angular pieces, giving a spotted appearance to the shale. Possible shale rip-up clasts are found east of the shale in the adjacent sandstone which suggest that the sandstone youngs eastwards. Beds dip moderately to steeply eastwards between 45° and 60° and are cut by a single, strongly developed fracture cleavage which dips more steeply eastwards at about 80°.

Petrography

Strained quartz, fresh K-feldspar (largely microcline with lesser microperthite), minor amounts of plagioclase (An34) and rare, small particles of opaques form the constituent grains of the quartzite. Quartz occurs either as single, strained grains or, rarely, as polycrystalline aggregates of strained grains with embayed and scalloped grain boundaries.

Grains are mostly sub-rounded to well-rounded, the larger grains being best rounded and occasionally showing fairly pronounced sphericity. Smaller grains are sub-rounded to sub-angular. There is a considerable range in grain size (1-5mm) which masks a poorly developed bimodality. The texture is subwacke, grains being both matrix and grain supported. The matrix, which may form over 50% of the total rock, consists of sericite and lesser amounts of recrystallized microcrystalline aggregates of quartz and feldspar, with minor fine-grained interstitial subhedral grains of carbonate indicative of some minor late stage replacement.

The sericite matrix forms a strong foliation wrapping around the constituent grains. Recrystallized quartz forms fine-grained blebs in the pressure shadows of some detrital quartz grains; where these blebs are still in optical contact with the old grains they form digitate-like structures in the pressure shadows. Where grains touch, the grain boundaries are commonly embayed indicating that pressure solution has operated. The contacts are now sites for recrystallized grain material or sericite.

Goose Tickle Formation

Cooper (1937) described a thick unit of slates and calcareous shales at Goose Tickle at the head of Hare Bay which he named the Goose Tickle Slate. Betz (1939) named the same unit the Englee Formation at Canada Bay. The name Goose Tickle Formation was proposed by Tuke (1968). At the type section about 300m of strata are exposed (Stevens, 1970) and about 500m in Pistolet Bay (Tuke, 1968). The Goose Tickle Formation is exposed on Quirpon Island in a major antiformal inlier approximately 2km long in Grandmother's Cove, and is surrounded by the Maiden Point Formation. There are also small inliers at Lighthouse Cove, The Whale, and south of Whale Point. Small outcrops are found in Quirpon harbour, on Vincent Island, Jacques Cartier Island and on three of The Islets. Extensive outcrop occurs along the harbour shore from at least south of Jacques Cartier Island in the west to Cobbler Island in the east.

The Goose Tickle Formation lies in structural contact below the Maiden Point Formation. The contact is a major structural discontinuity which is defined by a shale-rich melange zone several metres wide that contains tectonically rafted clasts of both Goose Tickle and Maiden Point Formation lithologies. The melange formed at the same time as large scale pre-cleavage isoclinal folds in both the Goose Tickle and Maiden Point Formations and is related to juxtaposition of the two units during emplacement. The bottom of the Goose Tickle Formation is not seen in the Quirpon area.

The lithology consists of alternating buff-weathering, grey/green, fine- to medium-grained calcareous sandstones and siltstones with finely cleaved black shale, usually with either sandstones or shales predominating. Both shales and sandstones are cut by a steep east-dipping cleavage that is axial planar to tight to isoclinal folds which also affect the Goose Tickle Formation/Maiden Point Formation contact. This deformation overprints folds of an earlier generation which affect certain parts of the Goose Tickle Formation (see Chapter 6) and which are not associated with an axial plane foliation. The whole formation has suffered considerable internal disruption of lithologies during emplacement of the overriding thrust slices (c.f. Cooper, 1937). Tectonism has caused boudinage of sandstones in areas where less competent shales dominate. A consistent stratigraphy of the formation could not be determined because of the effects of deformation.

Sandstones

The sandstones are fine- to medium-grained and occur in beds up to 0.75m. thick, and may be massive or show sedimentary structures characteristic of Bouma cycles. The beds have massive, graded bases with occasional scour-and-fill features and sharp contacts against underlying shale or silt, passing up into a plane bed stage and occasionally into climbing ripples (Plates 1&2). Beds with rippled tops commonly show convolute laminations. These features are best developed on rock D. of The Islets where at least eight Bouma cycles can be observed (Plate 2a). Minor small scale slump folds were also observed in one or two localities. The siltstones most commonly show millimetre laminations with no detectable grading, and may show micro-ripples, micro-climbing ripples, micro-loading and convolute laminae.

Plate 1a

Graded bedding and ripple-laminated tops in sandstone beds, Goose Tickle Fm.

Plate 1b

Bouma cycle, coarse, graded base, massive undifferentiated centre and climbing ripples at top. Note loading from base of rippled top, some loads have become detached and rest in the massive centre portion of the bed, Goose Tickle Fm.


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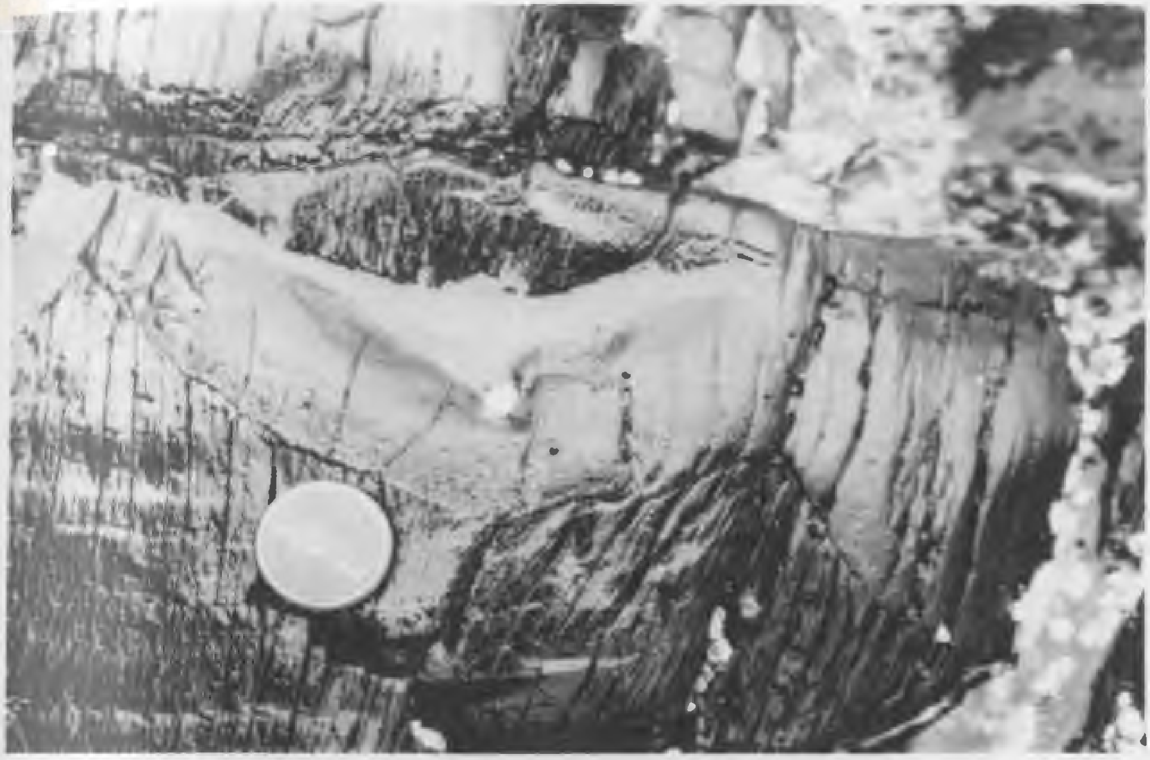
Plate 2a

Scour and fill troughs with coarse, graded sandstone. Note slaty cleavage in shale and coarse fracture cleavage in sandstone, Goose Tickle Fm., rock D. of the Islets

Plate 2b

Small scale laminated soft sediment folds, Goose Tickle Fm., Quirpon harbour



Shales

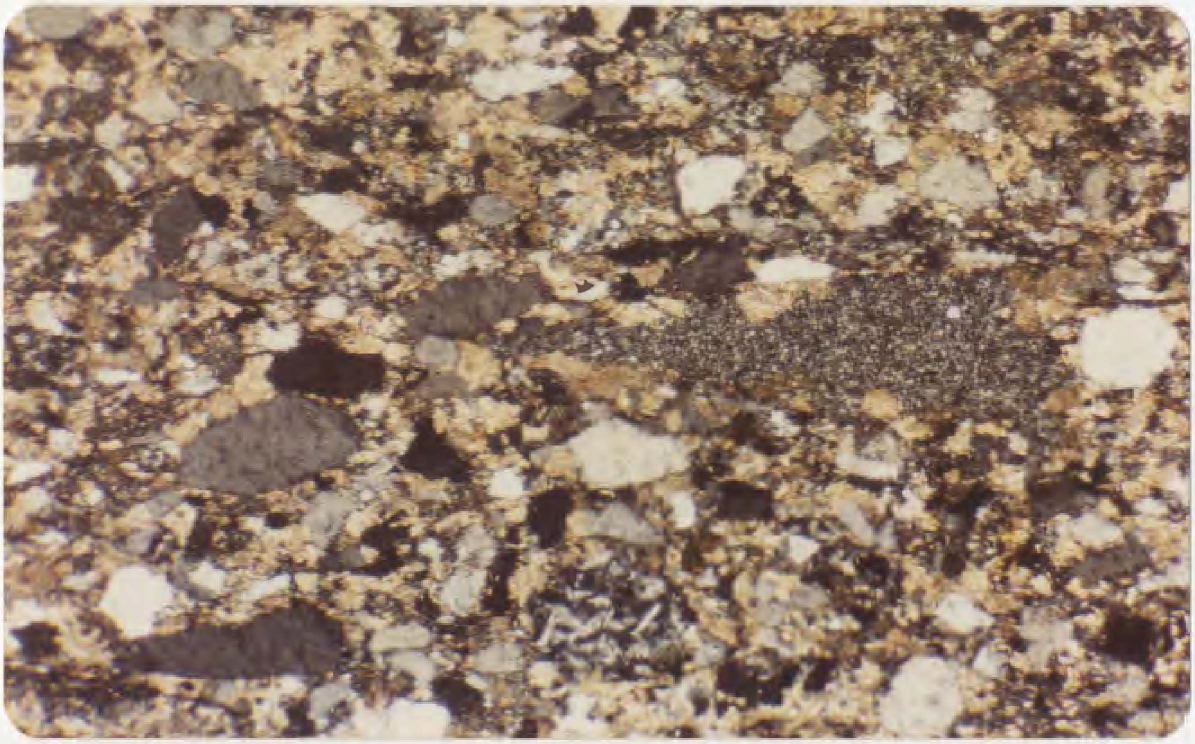
The shales are commonly grey or black pyritiferous and finely cleaved showing few or no sedimentary structures. Small scale bedding laminations are occasionally seen in the field but are mostly obliterated by the development of an intense cleavage and the effects of late stage brittle movement along cleavage planes.

Petrography

Up to 90% of the constituent grains in the sandstones consist of quartz, mostly of single strained grains. Numerous altered volcanic fragments occur preserving randomly oriented fine laths of plagioclase as well as several grains of fresh to partially sericitized plagioclase (An33). Grains of K-feldspar (microcline and microperthite), small opaque shale clasts, small laths of muscovite commonly bent around larger grains, and rare grains of fine-grained chlorite are also found (Plate 3). Accessory minerals occur also, such as zircon, (rare, very fine, rounded grains), rare grains of partially chloritized (penninite) chromite and very rare unaltered tourmaline. The sandstones are fine- to medium-grained (up to 2mm diameter), subangular to subrounded with either poorly developed bimodality or gradations in grain size. Grains are generally poorly rounded and rarely approach any degree

Plate 3

Photomicrograph of Goose Tickle sandstone. Constituent grains are strained quartz (up to 90%), K-feldspar (dark grey), altered volcanic fragment containing laths of partially sericitized plagioclase (lower centre) and elongate grain of microcrystalline chert (centre right). Specimen #6-9-10)



of sphericity. The texture is subwacke since grains are mostly matrix-supported. However, where some grains touch, pressure solution features have developed.

Matrix

Between 25-50% of the total rock is matrix material, consisting of colourless microcrystalline chlorite, and fine- to medium-grained subhedral carbonate in varying proportions; the carbonate always replaces the chlorite. There is widespread minor alteration of chlorite and of some plagioclase grains to stilpnomelane.

CHAPTER 3

THE ALLOCHTHON

Maiden Point Formation

Cooper (1937) used the name Maiden Point Sandstone to designate a 2200m thick sequence of clastic sediments along the south shore of Hare Bay. Tuke (1968) renamed the unit Maiden Point Formation because he observed that sandstones comprised only 50% of the unit. He described a type section 200m thick in the Hare Bay area of which the lower 150m consisted of lavas, agglomerates, tuffs and minor ultrabasic intrusions. Betz (1939) proposed the name Canada Head Formation for similar rocks in the Canada Bay area which Williams and Smyth (in press) correlated with the Maiden Point Formation. Cooper (1937) noted that lava and tuff were interbedded with the sediments, and dioritic and gabbroic sills and plugs have also been noted in association and included as part of the Maiden Point Formation by Williams and Smyth (in press). Gabbro intrusions are common within the Maiden Point Formation on Quirpon Island and, because they are restricted to the unit are included in it.

The Maiden Point Formation is exposed on Quirpon Island and Jacques Cartier Island and is aerially the most extensive formation. It consists of steeply eastward-dipping psammites, semi-pelites and minor shales associated with several bodies of variolitic pillow lavas and massive diorites of basaltic composition. The basalt outcrops are lensoid in form, the two largest extending from west of Pigeon Cove to Dumenil Point and from Pigeon Cove to east of Merchant Island, respectively. Both of these units are 3km long and vary in thickness from about 10m to over 30m. The sandstones host several small bodies of gabbro which vary in form from lensoid, subconcordant, sill-like bodies, to more strongly discordant small intrusions. Contact relations are not consistent, showing in places the development of narrow thermal contact aureoles, tectonised margins or both (Plate 4a). The sandstones are cut by several small (few cm) to large scale (tens of metres) intraformational shear zones containing rubbly shale, which, at Degrat Harbour, Sheep Island and Degrat Island cause considerable complex disruption and mixing of lithologies.

Psammites and semi-pelites

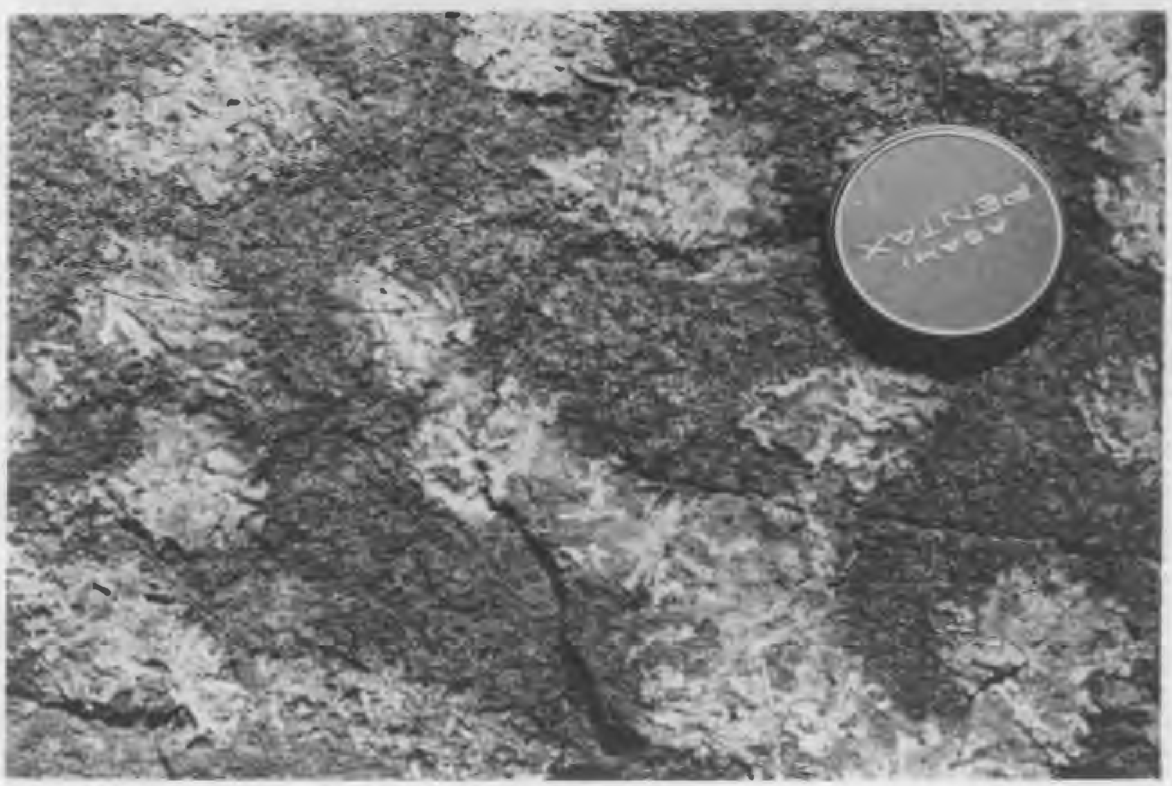
The sandstones are mostly buff-weathered, massive to crudely layered and medium- to very coarse-grained, in beds 0.5 to 1.0m thick. They commonly contain small black shale rip-up clasts. The sand grains are mostly of quartz, characteristically of smoky or blue varieties, seen very

Plate 4a

Gabbro (left)/sandstone (right) contact in the Maiden Point Fm. Contact parallel to strike of beds. Sandstone contact aureole contains metamorphic stilpnomelane and is slightly deformed

Plate 4b

Pegmatitic pockets of coarsely crystalline plagioclase in finely crystalline gabbro body, Maiden Point Fm., Pigeon Point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distinctly in the coarser beds. Blue quartz is commonly associated with deformed quartzites in medium grade metamorphic terrains and is a typical feature of the Fleur de Lys Supergroup (T.J. Calon, pers. comm.). Minor amounts of feldspar show as white grains.

Sedimentary structures are mostly obliterated in places where bedding and cleavage are parallel, but are often preserved where a moderate angle is developed between bedding and cleavage. This condition occurs in the northeastern part of the island between Pigeon Cove and Lighthouse Cove. Here grading is apparent in some upright beds together with loading, scour and fill structures and occasional ripple cross-bedded tops (Plates 5,6 & 7a). One bed in Colombier Cove contains large (0.5m) laminated sandstone rolled rip-up clasts indicative of soft sediment reworking (Plate 7b).

Small sand volcanoes 5-10cm across were occasionally seen on upper bedding surfaces north of Pigeon Cove (Plate 8a). In places these are associated with numerous white burrow-like structures developed normal to bedding. These features are commonly seen in massive beds throughout the sandstones and are thought to be dewatering structures which closely resemble the type D or stress pillars described by Lowe (1975), (Plate 8b). He suggested that these structures may represent flow paths of partial or complete fluidization in a sediment undergoing hydroplastic shear. In the Maiden Point Formation sandstones they are

Plate 5a

Graded sandstone bed showing parallel laminations and load structure at base, Maiden Point Fm.

Plate 5b

Cross-bedded and loaded siltstone (pale band) overlain by massive coarse grained graded sandstone bed, Maiden Point Fm.

Plate 6a

Basal view of load structures developed by coarse sandstone in black shale, Maiden Point Fm., Colombier Cove

Plate 6b

Basal view of combined loading and flute structures (bottom right), Maiden Point Fm., Colombier Cove

Plate 7a

Cross-bedded white sandstone band in massive, unbedded dark sandstone bed, Maiden Point Fm., Dumenil Pt.

Plate 7b

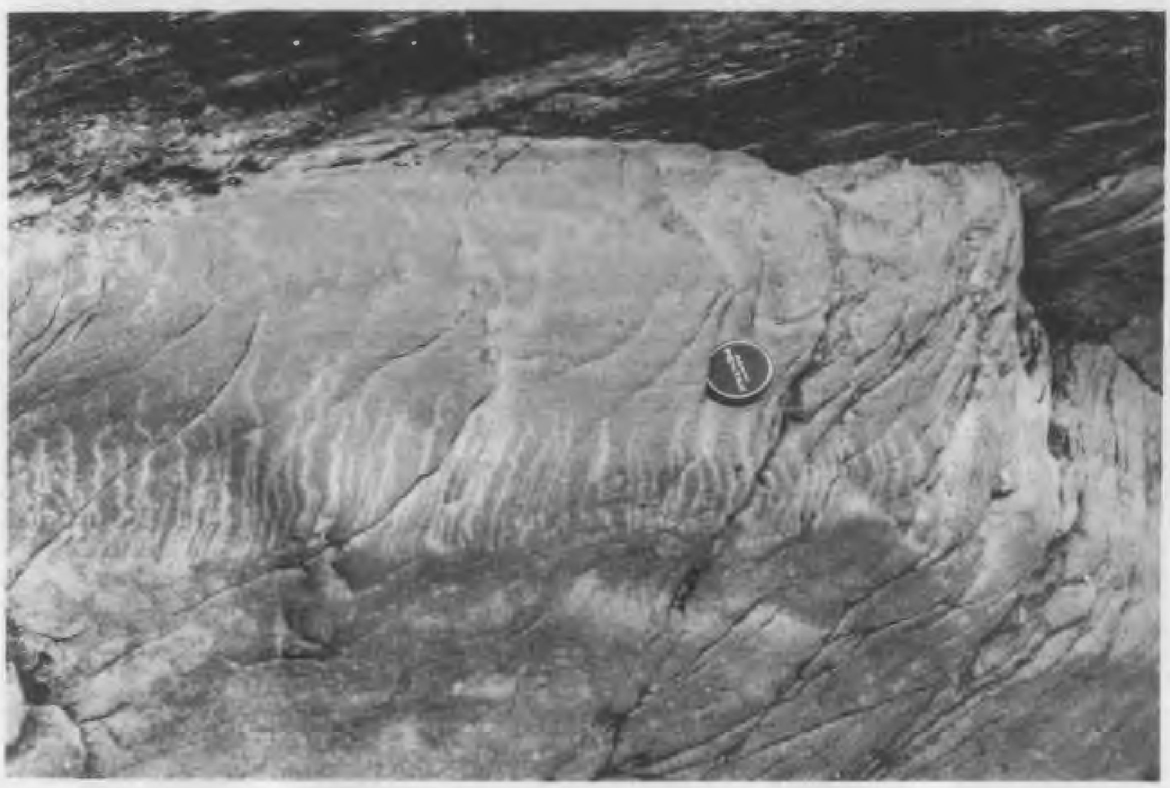
Fine laminated siltstone/sandstone rip-up clasts in a massive sandstone bed, Maiden Point Fm., Colombier Cove

Plate 8a

Sand volcanoes (approx. 5-10 cm across) on upper bedding surface, Maiden Point Fm., north of Pigeon Cove

Plate 8b

Burrow-like dewatering pillars resembling type D or stress pillars (Lowe, 1975) which formed by hydroplastic shear during rapid deposition. Note that 1) the pillars are developed only in the centre portion of the bed, and 2) pillars are truncated at the bottom but have ragged upper surfaces. Crinkling of the pillars is related to horizontal movement of fluidized sediment, sediment compaction during consolidation and probably by later volume reduction associated with pressure solution type of deformation. Direction of younging not known. Maiden Point Fm., Pigeon Cove



developed only in the central portions of the beds and are never seen to extend either to the bases or the tops. They are commonly crinkled which may be due in part to the horizontal movement of the fluidized sediment (Lowe, 1975), sediment compaction, and probably by later volume reduction, (dilational strain) during deformation.

Sandstones occasionally grade into strongly cleaved shales which usually occur as thin beds and as ramifying intercalations in the sandstones and have accommodated much of the deformation. Domains rich in shale have commonly developed into significant intraformational rubbly shale shear zones, for example at Colombier Point and Degrat Harbour (Plate 9). The relative incompetency of the tectonized shales has resulted in severe disruption and, in some instances, boudinage and rotation of the sandstone beds into parallelism with the cleavage in the shear zones (Plate 10a). These zones may reflect original shale-rich boulder conglomerate horizons.

Petrography

Quartz grains form 90-95% of the sandstones and are associated with microcline, microperthite, plagioclase (An 31-35), microcrystalline chlorite, minor shale flakes, muscovite and opaques. Plagioclase occurs as smaller, more numerous grains but in terms of volume percentage is usually less common than K-feldspar. The sorting is

Plate 9a

Small scale intraformational melange zone developed in a shale band, containing angular pieces of sloughed off sandstone from adjacent beds. Note that cleavage (S2) and bedding are parallel, Maiden Point Fm., west coast of Quirpon Island

Plate 9b

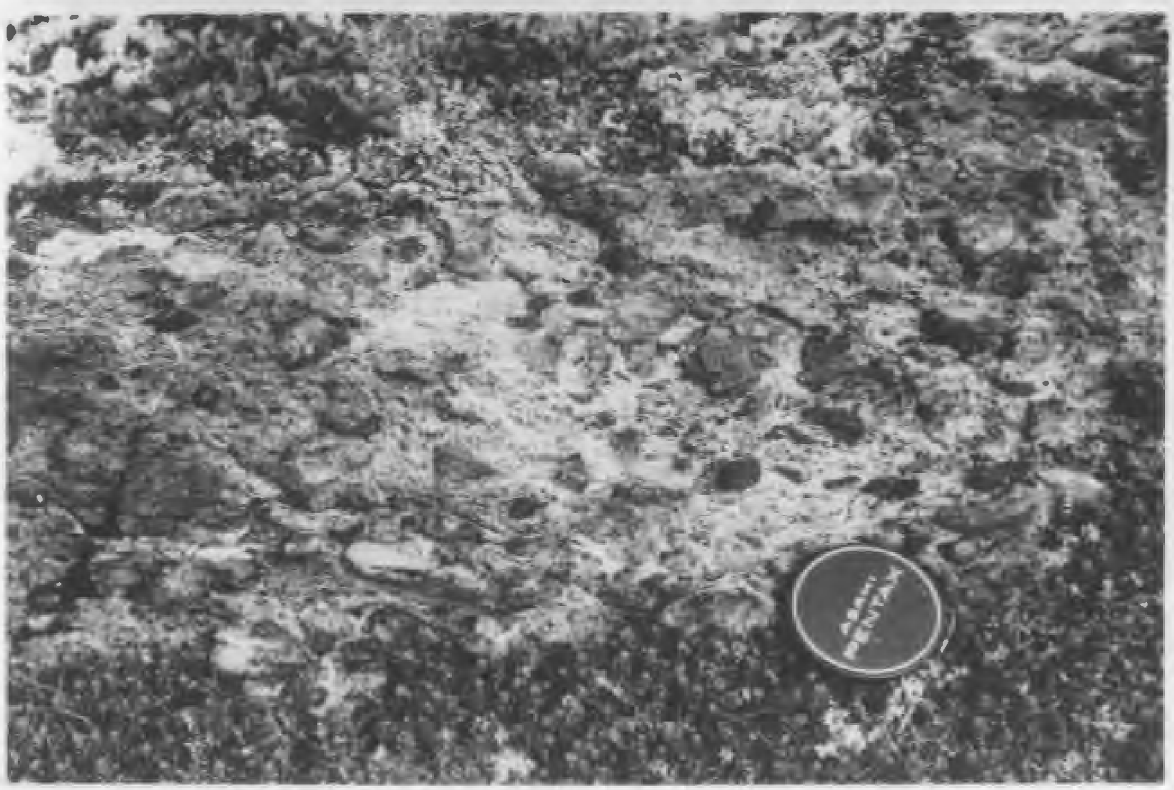
Large scale intraformational shaley melange zone containing large boudinaged blocks of sandstone sloughed off from adjacent sandstone units. Note that boudins and sharp edge of melange zone are parallel to the cleavage (S2), Maiden Point Fm., Colombier Point

Plate 10a

Small-scale shear zone. Interbanded shales and sandstones result in necking, boudinage and rotation of sandstone beds in the less competent shale. Note that the cleavage (S2) is parallel to the rotated bedding, Maiden Point Fm.

Plate 10b

Brecciated pillow lava at a sheared sandstone/pillow lava contact, Maiden Point Fm., west coast of Quirpon Island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moderate with grains in each studied specimen ranging from fine silt (<0.5mm) to fine gravel grade (2-4mm). Grains are subangular to subrounded, the larger grains being well rounded.

Quartz consists of both single and polycrystalline strained grains, the latter showing a range of microstructures from equilibrium foam textures to rare ribbon quartz. The dominant sedimentary texture is subwacke, the grains being largely matrix-supported. The matrix material, which may form up to 60% of the total rock, consists of colourless to pale green chlorite with lesser sericite which together form the penetrative foliation, S1. Partial sericitization of the feldspars is common, particularly in sandstones from the contact aureoles of the gabbros. Very late stage carbonate was observed in one specimen as fine anhedral crystals filling cracks in the grains.

Pillow Lavas

Pillow lavas occur as lensoid bodies within the sandstones, though Daly (1903) placed them stratigraphically above the Maiden Point sediments. They also occur as large blocks from a few metres to tens of metres across associated with intraformational shear zones on the southern part of Quirpon Island and at Degrat Harbour. Contacts with the sandstones are generally poorly exposed but appear in several places to be modified by differential movement between the two lithologies resulting in the formation of broken pillow lavas (Plate 10b, facing p.36).

The margins of the pillow lava bodies are generally deformed and carry a crude foliation, but the main parts of the large bodies generally contain pristine undeformed pillows. The two large bodies on Quirpon Island which extend from west of Pigeon Cove to Dumenil Point and from west Pigeon Cove to east of Merchant Island are probably volcanic flows in conformable succession with the sandstones. The smaller bodies may be aerially restricted minor flows that have been modified during deformation to form elongate lenses with deformed margins.

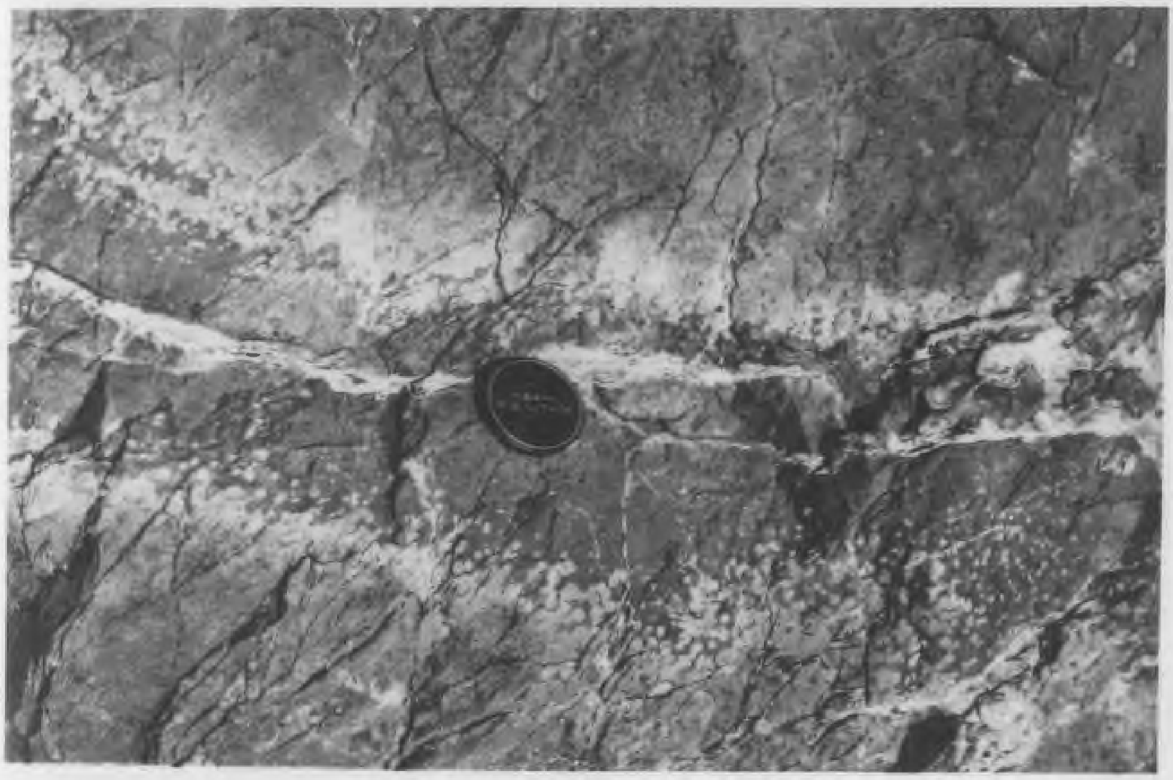
The pillow lavas are green to grey, weathering to a buff colour, and form very distinct, fresh-looking pillows which vary in shape and size from sub-spherical structures 0.25 to 0.5m in diameter (Plate 11a), to sausage-like lava tubes 3 to 5m long and up to 1.5m wide, as seen in north Degrat Harbour. One possible way-up structure was seen in the lavas at north Degrat Harbour where a "puncture-and-flow" structure was observed in a pillow bud suggesting that here at least the lavas are upright and young eastwards (Plate 11b). The pillow lavas are much affected by carbonate alteration, the pillow contacts being sites of veining and the pillows themselves often being net veined. One or two rare veins of rhodocrosite with calcite and

Plate 11a

Fresh-looking variolitic pillow lavas. Pillows range in shape and size from sub-spherical structures 0.25 to 0.5m wide to elongate lava tubes 3-5m long and up to 1.5m wide, Maiden Point Fm., north of Degrat Harbour

Plate 11b

Puncture-and-flow structure in a pillow frozen as a new pillow buds off (top centre), Maiden Point Fm., north of Degrat Harbour



chlorite were seen in the pillow lavas on Sheep Island. The pillow lavas on Degrat Island are characterized by being amygdaloidal and non-variolitic. They are also unique in being intruded by several narrow (0.5m wide) discontinuous dykes of diabase.

Varioles and rafted sediments

The pillow lavas are characterized by the development of grey/white sub-spherical varioles (the original variolitic material is now mostly altered to epidote) which range in diameter from 1 or 2 mm to 1 cm, very rarely reaching 2.5 cm. The varioles are usually smallest near the pillow margin, coarsening and coagulating towards the core which usually consists entirely of variolitic material (Plate 12). The pillows may or may not be vesiculated where varioles are absent. Minor amounts of black, calcareous laminated chert occur between some of the pillow lavas. These appear to have been disrupted and rafted during volcanic extrusion since they rest in undeformed pillow lithologies and bedding laminae are truncated against the pillows.

Pillow breccia

Minor lenses of pillow breccia occur in some of the flows. These consist of fragmented angular pebble- and

Plate 12

Detail of contact between two pillows to show calcite veining at contact and coagulation of sub-spherical varioles towards the pillow centres, Maiden Point Fm., north of Degrat Harbour

cobble-sized clasts of pillow lava in a finely comminuted calcareous matrix (Plate 13). The boundaries of these lenses with unbrecciated pillows are diffuse and gradational.

Massive basalts

Unpillowed massive basalt flows are associated with and usually situated on the eastern sides of the pillow lavas, for example on the east side of the large flow between Pigeon Cove and Merchant Island. These are green/grey weathering to a buff colour and are non-variolitic and non-vesiculated.

Tuff

A small diffusely-bounded body of medium to coarsely crystalline, heterogeneous calcareous light green tuff is exposed on the southeast tip of Quirpon Island. It contains pillow clasts near contacts with pillow lava and numerous rounded pebbles and cobbles of an autobrecciated nature. It also hosts a xenolith of recrystallized, folded and cleaved shale and laminated silt band about 0.5m wide. The tuff is cut by a northwest-southeast-trending diabase dyke.

Plate 13

Pillow autobreccia in a pillow lava flow. Note fragmented angular pebble- and cobble-sized pillow clasts resting in a finely comminuted calcareous-rich matrix, Maiden Point Fm., central Quirpon Island

Petrography

The pillow lavas have a completely devitrified and altered ground mass of fine-grained chlorite (largely penninite) felted and/or acicular actinolite, often associated with hornblende (with rare piemontite cores). The amphiboles are associated with fine-grained anhedral crystals of sphene, subhedral to anhedral clinozoisite, carbonate, and rare zoisite. In one section several comminuted pieces of shard material were seen. Abundant pseudomorphs probably after laths of plagioclase are common (Plate 14). The pseudomorphs are often partially replaced associated with acicular actinolite overgrowths and/or by chlorite and sericite with minor amounts of fine-grained anhedral green biotite.

Varioles and vesicles have indistinct sub-spherical outlines and have variable modal mineral compositions usually involving an association of microcrystalline quartz, chlorite, euhedral crystals of clinozoisite and anhedral carbonate. any one of which may be dominant (Plate 15). Varioles may contain randomly oriented "dusty" feathery microlites now pseudomorphed by fine grained sphene (Plate 16).

Specimens retrieved from the massive basalt flows do not have vesicles or varioles but have otherwise similar petrography to the pillow lavas, so a description will not be repeated here. However, it should be noted that the

Plate 14

Photomicrograph to show sericitized euhedral pseudomorph after plagioclase in porphyritic and vesiculated portion of Maiden Point pillow lava. Note circular sericite-filled vesicles. Matrix of unfoliated devitrified microlitic material (crossed polars). (Specimen #4-7-4)

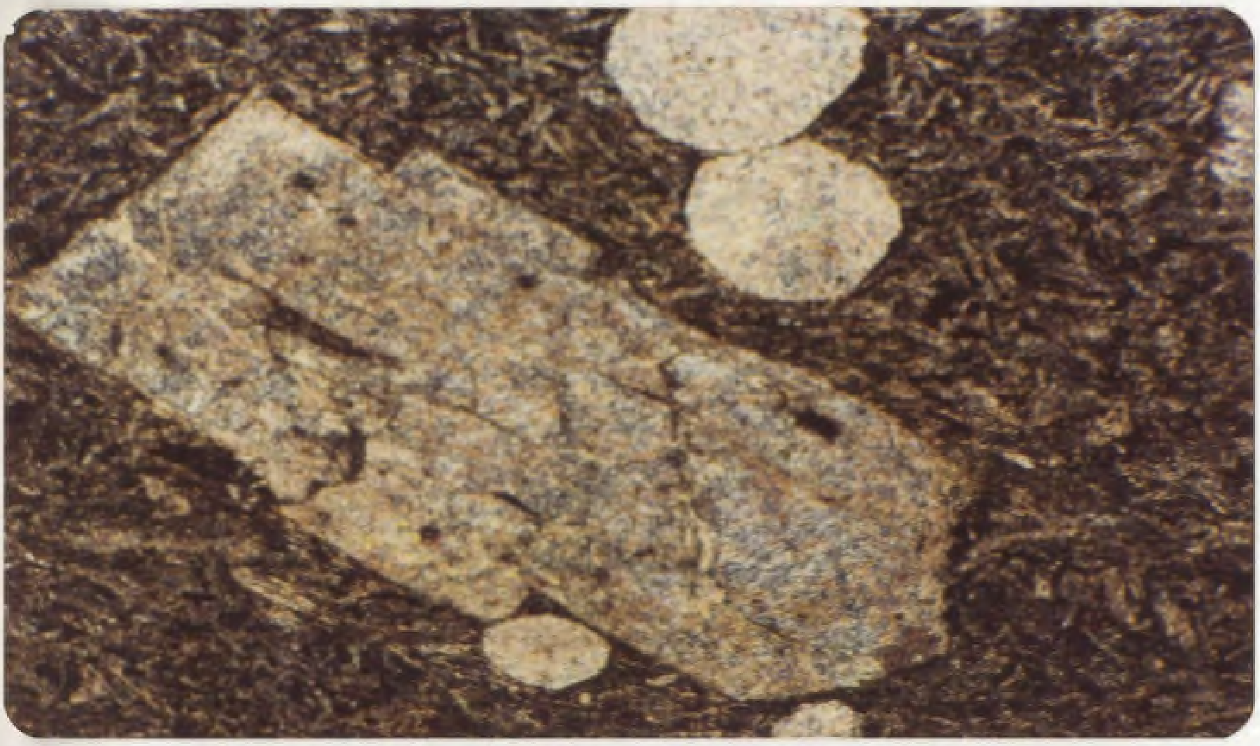
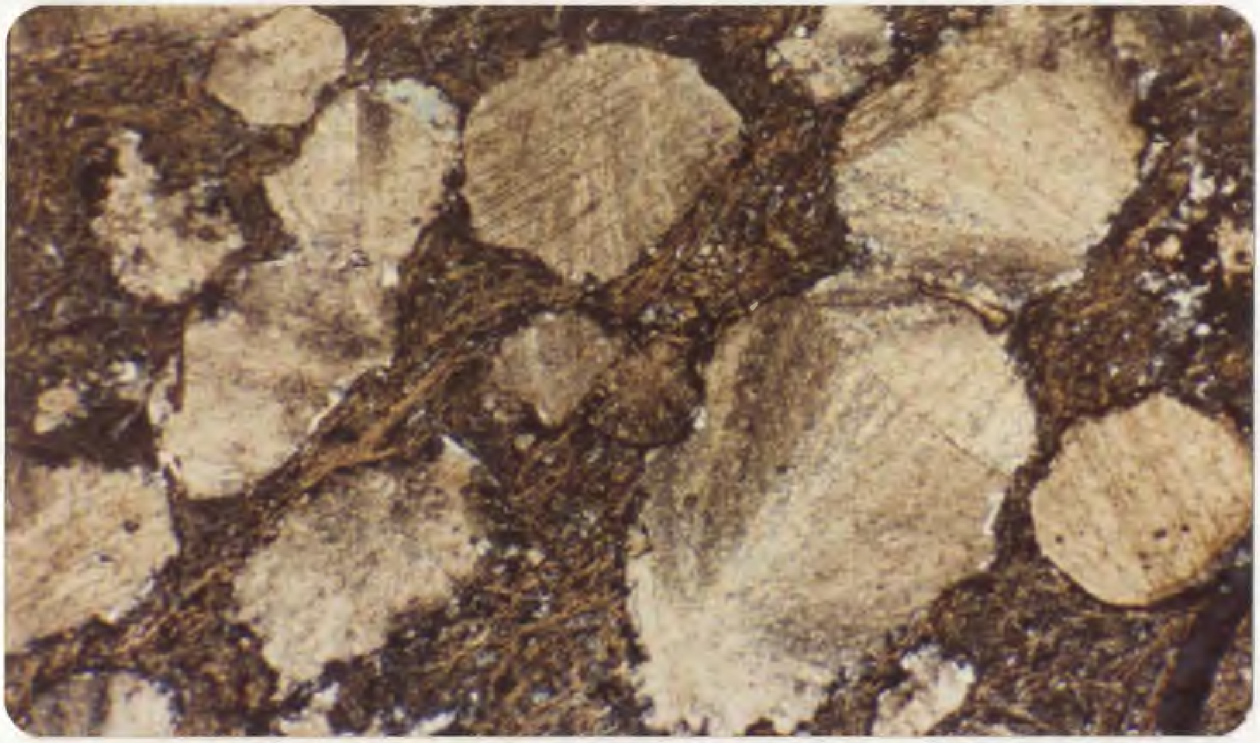


Plate 15a

Photomicrograph of vesiculated Maiden Point pillow lava. Vesicles filled with slightly strained calcite showing extensive deformation twinning. Matrix of unfoliated devitrified microlitic material (crossed polars). (Specimen #15-7-2)

Plate 15b

Photomicrograph of vesiculated Maiden Point pillow lava. Vesicles filled with anhedral calcite and laths of euhedral clinozoisite (pale blue). Matrix of unfoliated microlitic material (crossed polars). (Specimen #4-7-3)



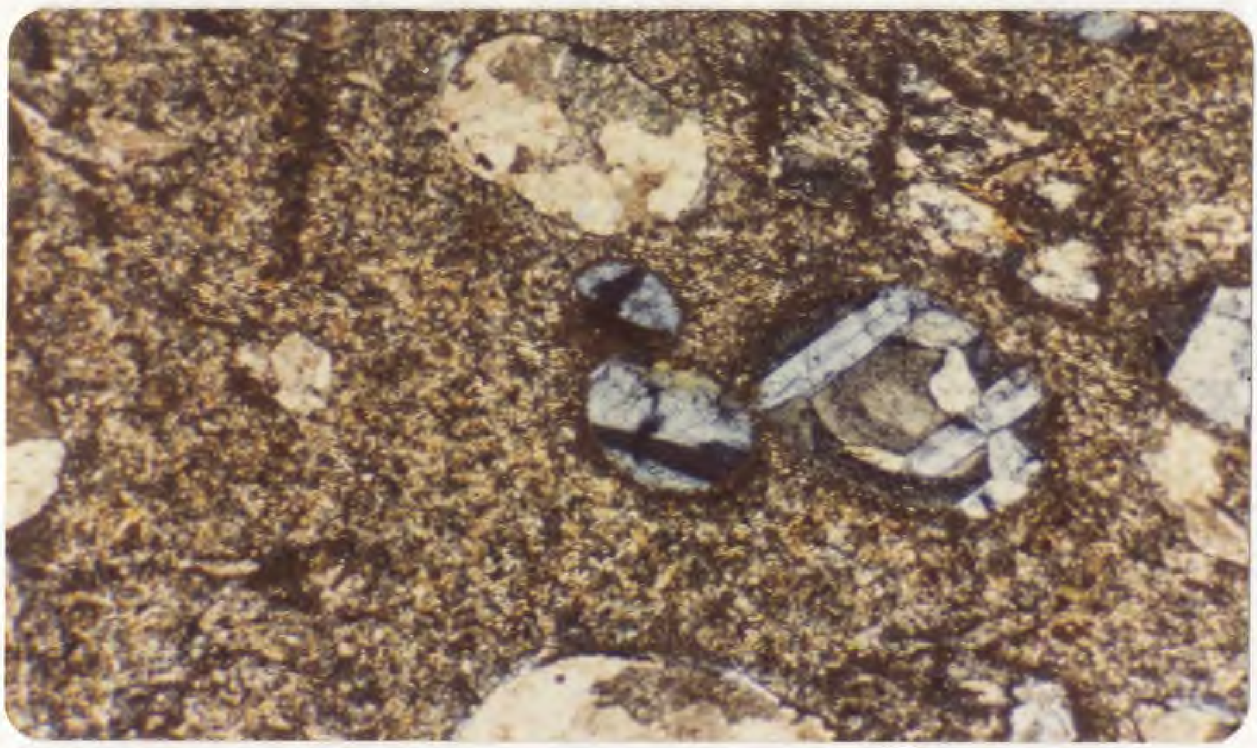
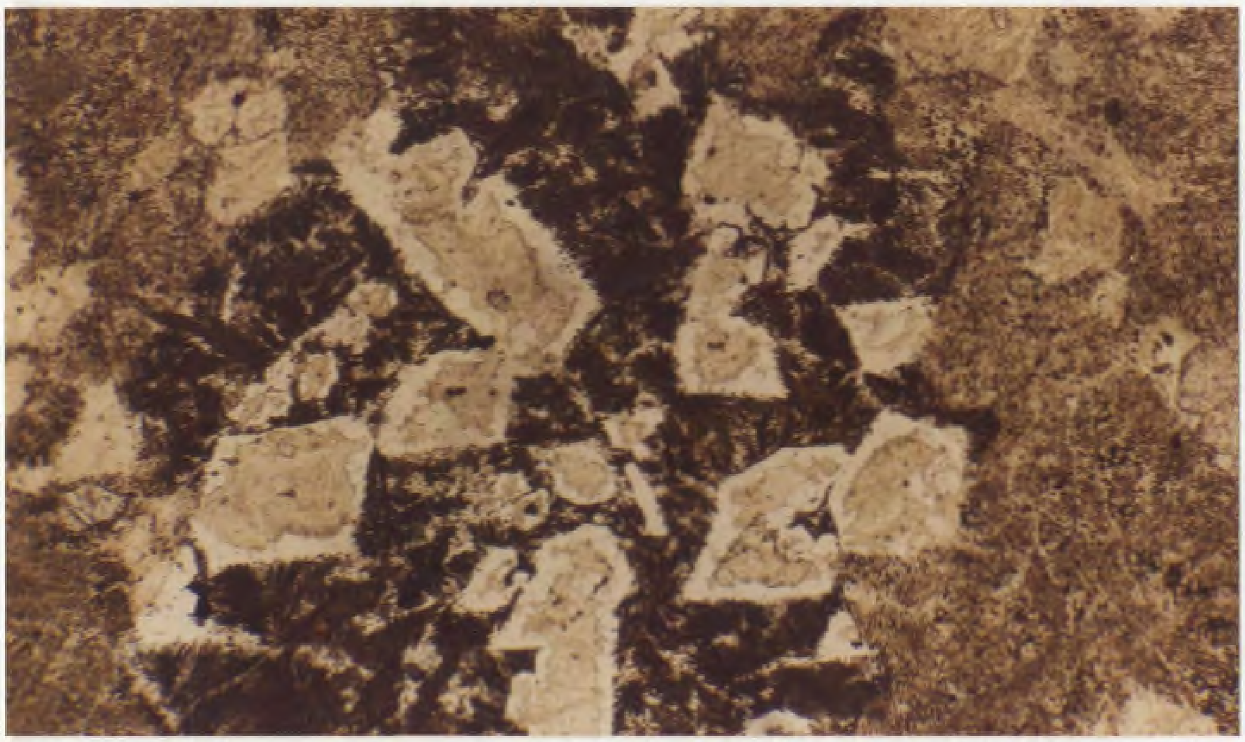


Plate 16

Photomicrograph of variolitic Maiden Point Fm. pillow lava. Variole (dark brown) contains randomly oriented "feathery" pseudomorphous sphene microlites. Euhedral pseudomorphs (after plagioclase?) filled with sericite/clinozoisite (clear)/chlorite (pale green) associations. (Specimen #6-9-3)



altered matrix is commonly host to numerous small phenocrysts of Ti-augite with inclusions of fresh sphene. The augite is altered to actinolite with chlorite along cracks and is rimmed by brown to green to colourless hornblende and actinolite associations (Plate 17).

Gabbros

Several small gabbro intrusions occur withmn the Maiden Point Formatmon sandstones, but in three places they are situated along the contacts between sandstones and pillow lavas. One body occurs in the contact zone between the Maiden Point Formation and the Goose Cove Schist. The gabbros are mostly sub-concordant sill-like lenses (c.f. Jamieson, 1979) but may show strongly discordant relationships (e.g. at Pigeon Point, and also at Cape Bauld). Gabbros may have well developed chilled margins and associated thin contact aureoles in the adjacent sandstones (e.g. North Pigeon Cove, see Chapter 7) (Plate 18). The sills commonly have strongly deformed margins, but otherwise do not carry an internal tectonic fabric (e.g. the sill at Grapnel Cove has a chilled margin and a corresponding narrow aureole which has been slightly deformed) (Plate 4a, facing p.28).

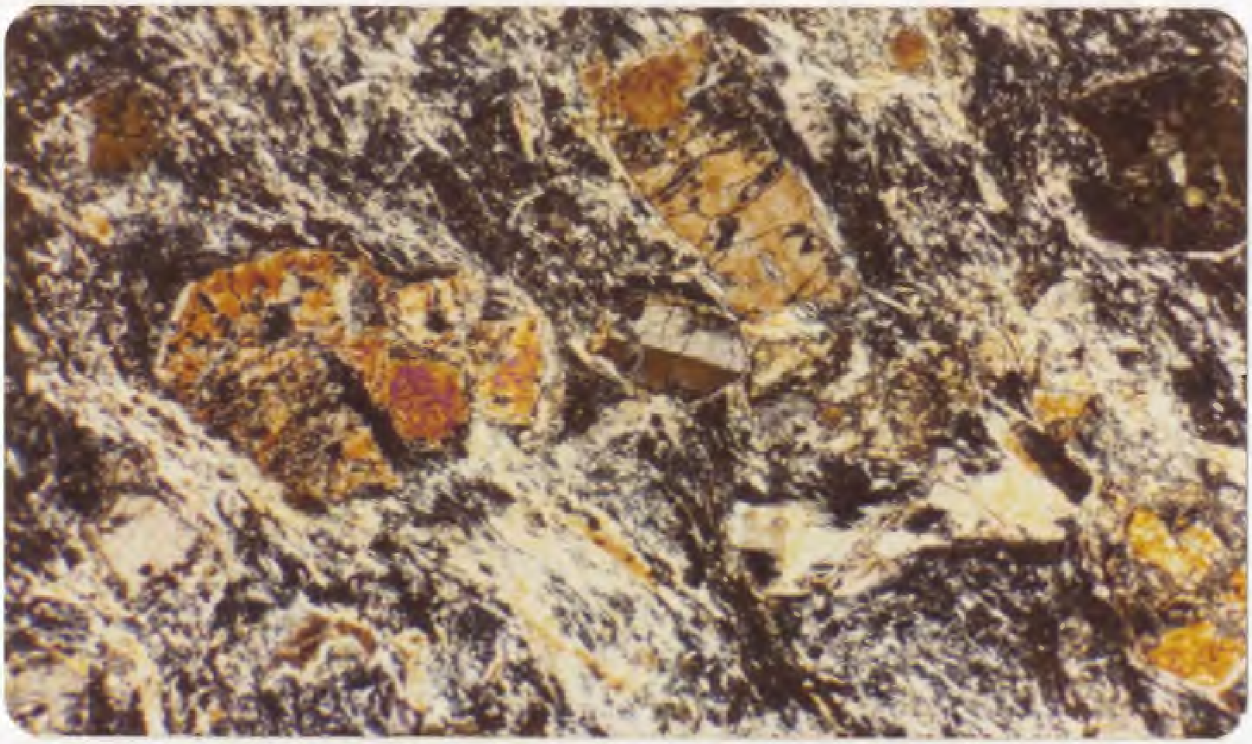
The gabbros are compositionally heterogeneous, even within single bodies, varying from coarse to fine-grained, isotropic, melanocratic hornblendites to feldspar-rich

Plate 17a

Photomicrograph of Maiden Point Fm. massive basalt. Ti-augite phenocrysts (grey and brown in prism section and yellow/orange in basal sections) fractured and partially altered to fibrous actinolite (pale yellow) resting in a crudely tectonically foliated devitrified chloritic matrix. (Specimen #6-9-4)

Plate 17b

Photomicrograph of Maiden Point Fm. massive basalt. "Hourglass" Ti-augite phenocrysts slightly altered to fibrous actinolite, resting in unfoliated devitrified chloritic matrix (Specimen #24-7-1)



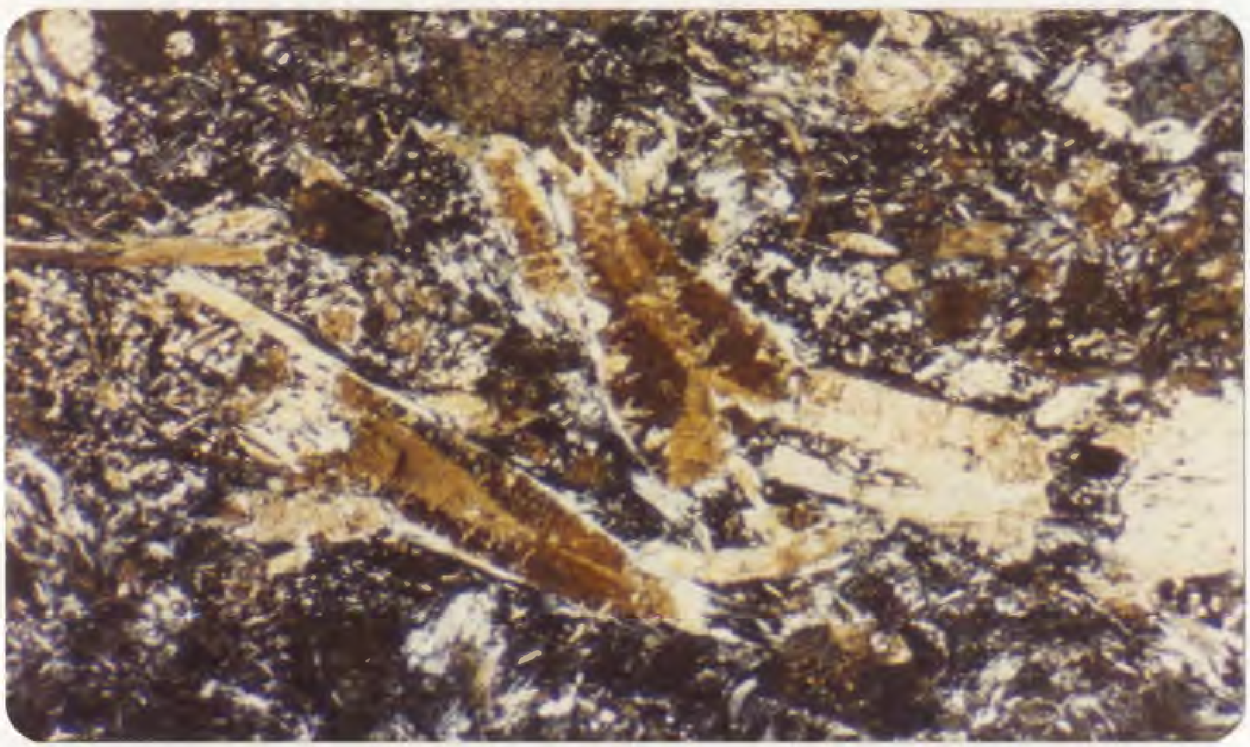
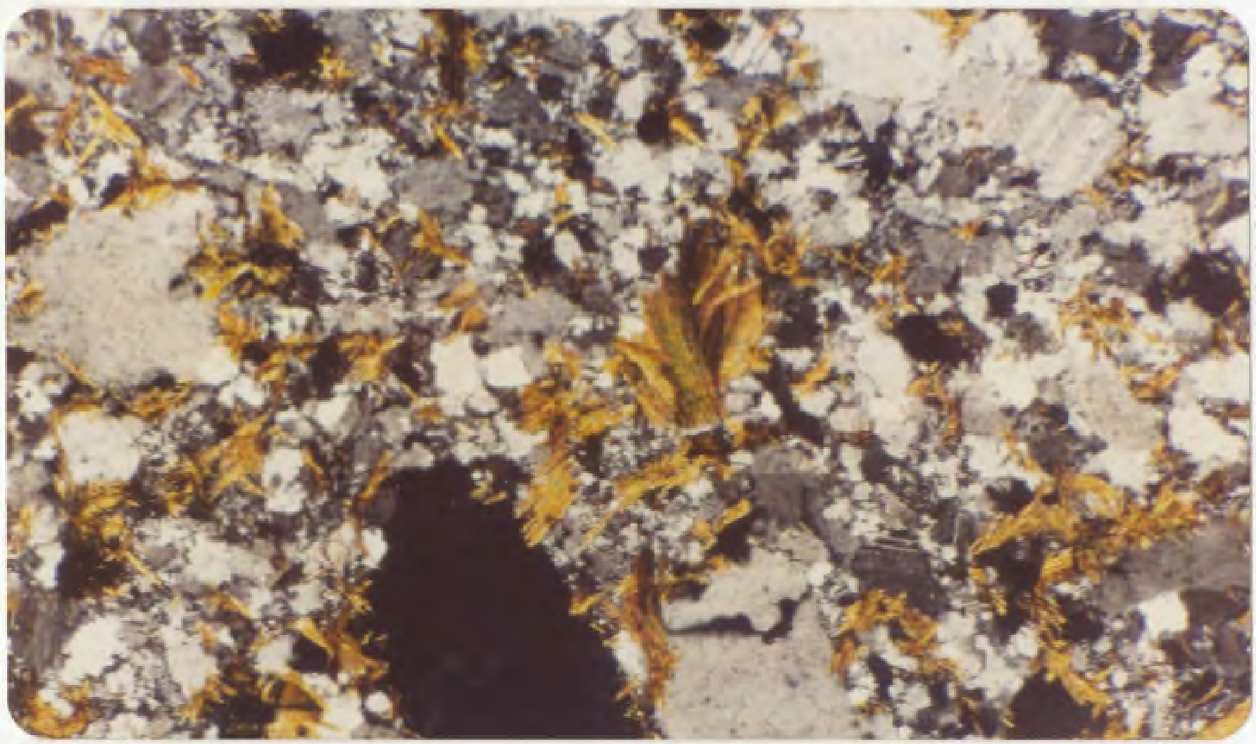


Plate 18

Photomicrograph of sandstone from gabbro contact aureole. Matrix sericite has been completely altered to radial aggregates of stilpnomelane. Note fine-grained recrystallized quartz in matrix also. Maiden Point Fm., Pigeon Cove (crossed polars). (Specimen #16-7-3)



leuco-gabbros. They locally contain small diffuse-edged pegmatitic pockets of plagioclase (e.g. at Grapnel Cove and Pigeon Point) (Plate 4b, facing p.28). The sill exposed at Grapnel Cove is approximately 7m wide and shows a strong compositional asymmetry. A coarsely crystalline, leucocratic hornblende/plagioclase assemblage is restricted to the east side of the sill and grades westwards into a coarse grained hornblendite. The leucocratic portion contains very well developed harrisitic textures with dendritic clinopyroxene, altered to hornblende, growing towards the centre of the sill, normal to the chilled margin (Plate 19). The compositional variation in the sill is probably a magmatic cumulate feature, where mafic minerals have settled towards the bottom of the sill, indicating that the top of the sill is to the east, conforming with the obsesved sedimentary way-up structures observed in this area. The gabbros at Colombier Cove and Cape Bauld are cut by rare veins of rhodocrosite with associated carbonate, similar to those seen in the pillow lavas on Sheep Island.

Petrography

The matrix material consists of medium- to coarse-grained plagioclase (An 28-32) with minor microperthite with grains up to 1cm across. This has been variably altered to clinozoisite and sericite or has been replaced

Plate 19

Harrisitic texture in gabbro sill at Grapnel Cove. Dendrites are of clinopyroxene. Maiden Point Fm.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by chlorite (which often has a fibrous decussate texture) and fine needles of actinolite and tremolite. The clinozoisite usually occurs as numerous scattered fine-grained anhedral to subhedral crystals. Plagioclase has commonly been recrystallized to fresh fine-grained aggregates. Numerous fine-grained anhedral crystals of sphene and fresh acicular subhedral crystals of apatite are common in the feldspar matrix of many thin sections together with minor carbonate and fine needles of stilpnomelane. The plagioclase matrix commonly contains fine- to medium-grained anhedral to euhedral crystals of skeletal opaques, now mostly altered to leucoxene/sphene.

The plagioclase matrix hosts medium- to coarse-grained crystals of anhedral to euhedral strongly pleochroic brown kaersutite. These have optically continuous epitaxial growths of acicular or needle-like actinolite. Minor pale green ferro-actinolite occurs adjacent to the kaersutite cores (Plate 20) (c.f. Jamieson, 1977). Kaersutite is often host to minor acicular crystals of apatite and small grains of sphene, and is partially replaced along fractures or almost completely pseudomorphed by actinolite or chlorite.

In many gabbros, pale pink anhedral to euhedral clinopyroxene is associated with or occurs instead of kaersutite (Plate 21). It is commonly altered to chlorite, fmne-grained sphene, which may occasionally be completely pseudomorphous, and tremolite, along fractures and as epitaxial growths. In two thin sections clinopyroxene is

Plate 20

Photomicrograph of phenocryst of magmatic kaersutite (dark brown) rimmed successively by optically continuous epitaxial growths of ferroactinolite (green) and colourless fibrous actinolite. Matrix mostly altered to chlorite. Maiden Point gabbro (PPL). (Specimen #9-7-3)

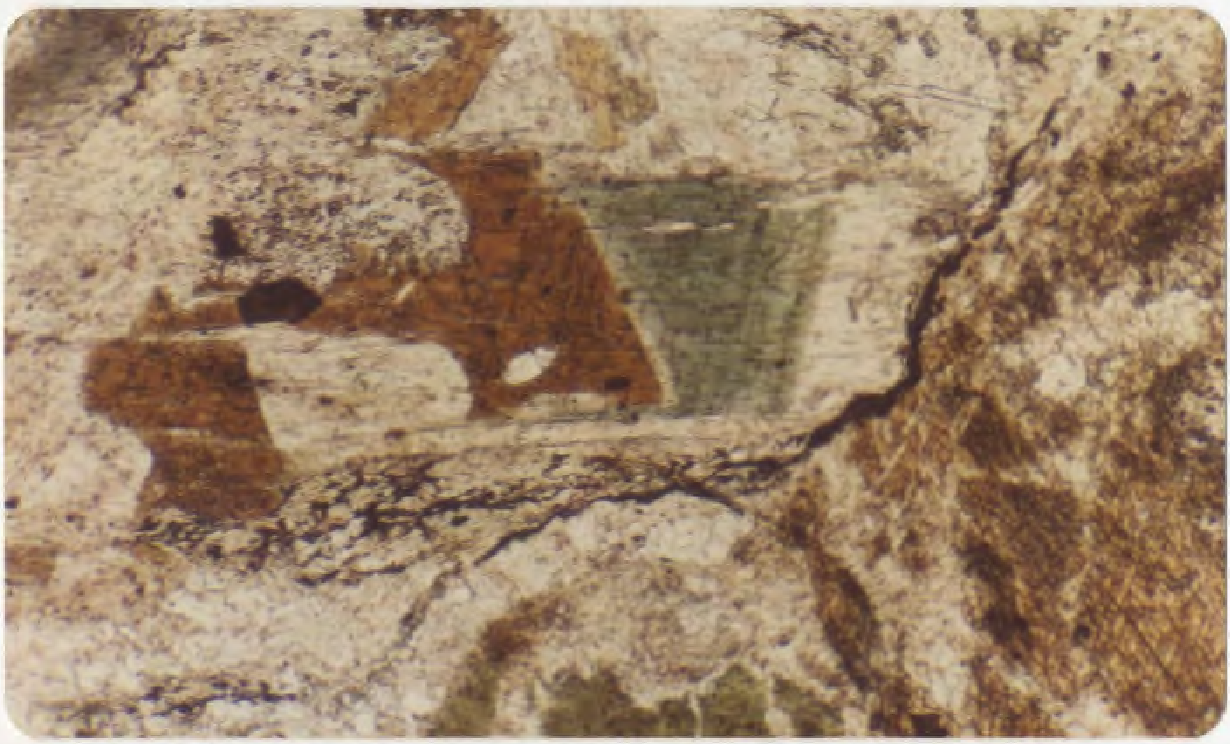
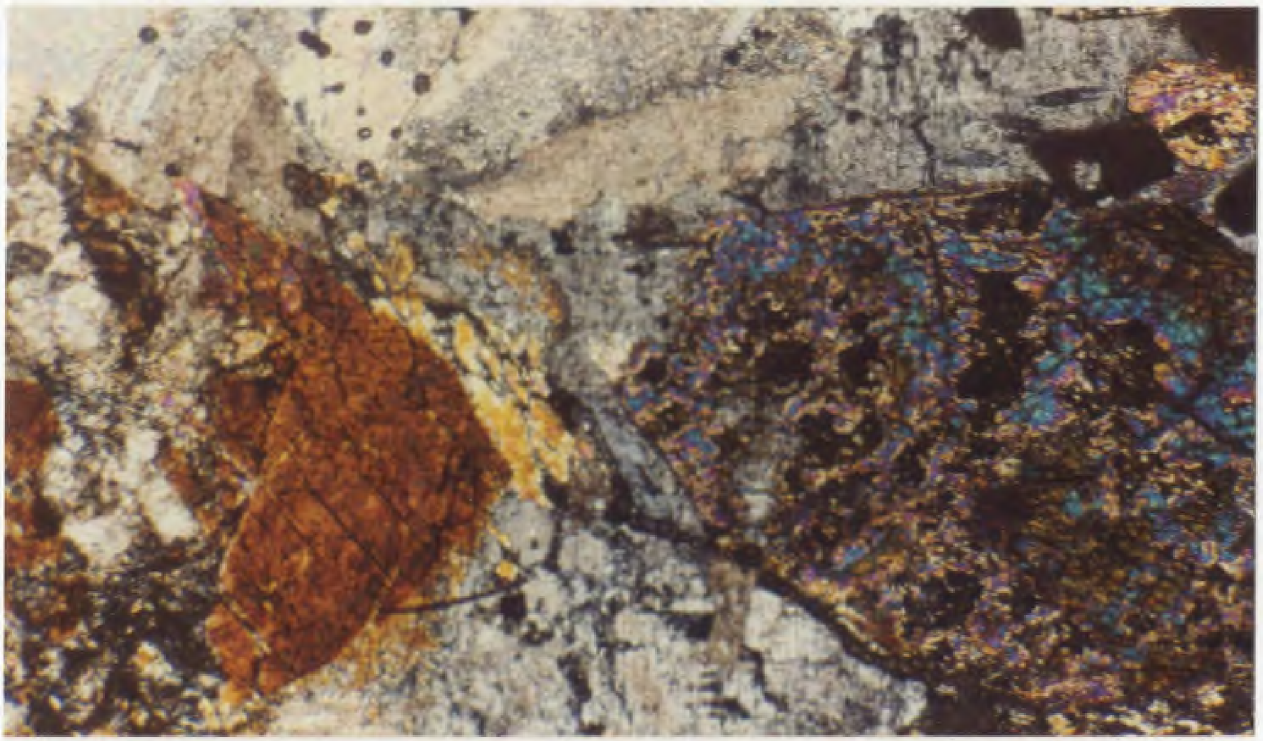


Plate 21

Photomicrograph of phenocrysts of magmatic euhedral clinopyroxene (blue) and anhedral kaersutite (brown) fractured and partially altered to actinolite (yellow) resting in a sericitized plagioclase/microperthite matrix, Maiden Point Fm. gabbro (crossed polars). (Specimen #16-7-1)

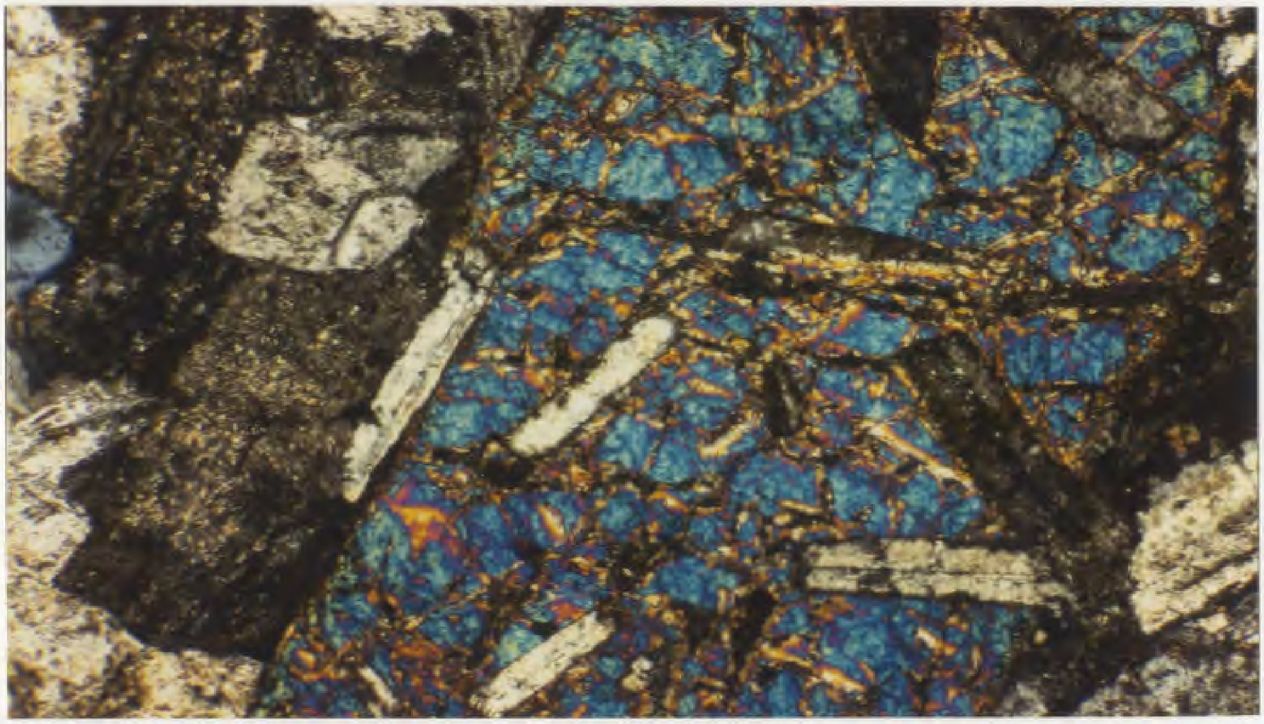


pseudomorphed by paramorphic brown hornblende with associated actinolite and chlorite.

The clinopyroxene occasionally develops a poor subophitic texture, but the plagioclase laths are never completely enclosed (Plate 22). Clinopyroxene may also occasionally host euhedral skeletal grains of ore minerals and acicular apatite may be interpenetrative with it. The geochemistry of the gabbros and pillow lavas of the Maiden Point Formation are compared with the Goose Cove Schist metagabbros in Chapter 7.

Plate 22

Photomicrograph of subophitic texture in gabbro. Randomly oriented laths of plagioclase are partially enclosed by a large euhedral crystal of clinopyroxene (blue). (Specimen #20-7-1)



Goose Cove Schist

Goose Cove Schist was the name used by Cooper (1937) to describe the greenschists that occur in the Pistolet Bay area and on the Fishot Islands. Tuke (1968) and Smyth (1971) used the name Goose Cove Formation and included all the metamorphic rocks beneath the White Hills Peridotite. Tuke (1968) estimated the thickness of the greenschists to be 150m, and Smyth described a section 110m thick at Fishot Island. Williams and Smyth (in press) used Cooper's (1937) name to describe only the greenschist member of Tuke's (1968) and Smyth's (1971) Goose Cove Formation. Williams and Smyth (in press) estimate the structural thickness of the unit to be 180m in its type locality at Goose Cove.

The Goose Cove Schist forms the highest allochthonous slice on Quirpon Island. It is an isolated part of the St. Anthony Group dynamothermal metamorphic aureole which lies beneath the ophiolitic White Hills Peridotite, south of the study area (Williams & Smyth, in press; Jamieson, 1979). On Quirpon Island actinolite schists form the predominant lithology of the Goose Cove Schist. The unit also contains sheet-like bodies of amphibolitized metagabbro which are exposed in a small klippe along Grands Galets Bay and as smaller bodies which lie subconcordant to the main foliation, S2, on Grands Galets Head. S2 is a penetrative cleavage defined by the preferred dimensional orientation of synkinematically-grown fine-grained actinolite neoblasts. The Goose Cove Schist is structurally separated from the underlying Maiden Point Formation by a major ductile thrust contact which is characterized by a jump in metamorphic grade and a change in structural style between the juxtaposed rocks.

Less deformed sediments and volcanic rocks have been recorded at the structural base of the Goose Cove Schist on Fishot Island (Smyth, 1973; Jamieson, 1979), but this situation is not seen at the structural base on Quirpon Island though metasediments do occur within the actinolite schists. In the Goose Cove area the Goose Cove Schist passes up into the higher metamorphic grade rocks of the Green Ridge Amphibolite (Williams, 1975). This unit in turn passes up into the White Hills Peridotite (Williams & Smyth, in press). However, at Quirpon Island the Goose Cove Schist does not pass up into either of these structurally higher units. The structural thickness of the Goose Cove Schist on Quirpon Island is at least 170m measured perpendicular to the attitude of S2 in a section from the contact with the Maiden Pont Formation and the summit of Grands Galets Head.

Actinolite schists

On Quirpon Island the Goose Cove Schist consists of finely cleaved (S2) green to grey, fine-grained, lustrous actinolite-chlorite-schists. Compositional layering on a centimetre scale is common and is developed by varying proportions of amphibole, quartz, epidote, chlorite and mica; in places minor carbonate layers occur. Coarser leucocratic and melanocratic bands are probably recrystallized remnants of diabase and /or gabbro. The actinolite schist adjacent to the interformational mylonite zone, which separates the Goose Cove Schist from the underlying Maiden Point Formation, southwest of Grands Galets Bay and at one place above White Point is characterized by buff weathering surfaces and contains small lenses of smokey quartz from a few cm to 20cm thick which lie sub-parallel to the foliation (Plate 23). These may be highly deformed and metamorphosed equivalents of Maiden Point sediments (see petrography of metasediments below). At one place in central Grands Galets Bay the quartz has not completely disaggregated and forms a 20-30cm thick band of white, foliated quartz schist parallel to S2 which is traceable for about 10m (Plate 24a).

Southwest of Clous Cove a fine-grained, uncleaved, light green volcanic body is in structural contact with the schist, and on Galets Head in two places boudins (approximately 2m x 4m) of uncleaved spotted volcanics

Plate 23

Photomicrograph of Maiden Point-like deformed sandstone within the Goose Cove Schist from the cliff base on the north side of Grands Galets Head. Recognizable grains of quartz and feldspar are present in the foliated sericite matrix. Foliation (S2) runs left to right (Specimen #25-8-5)

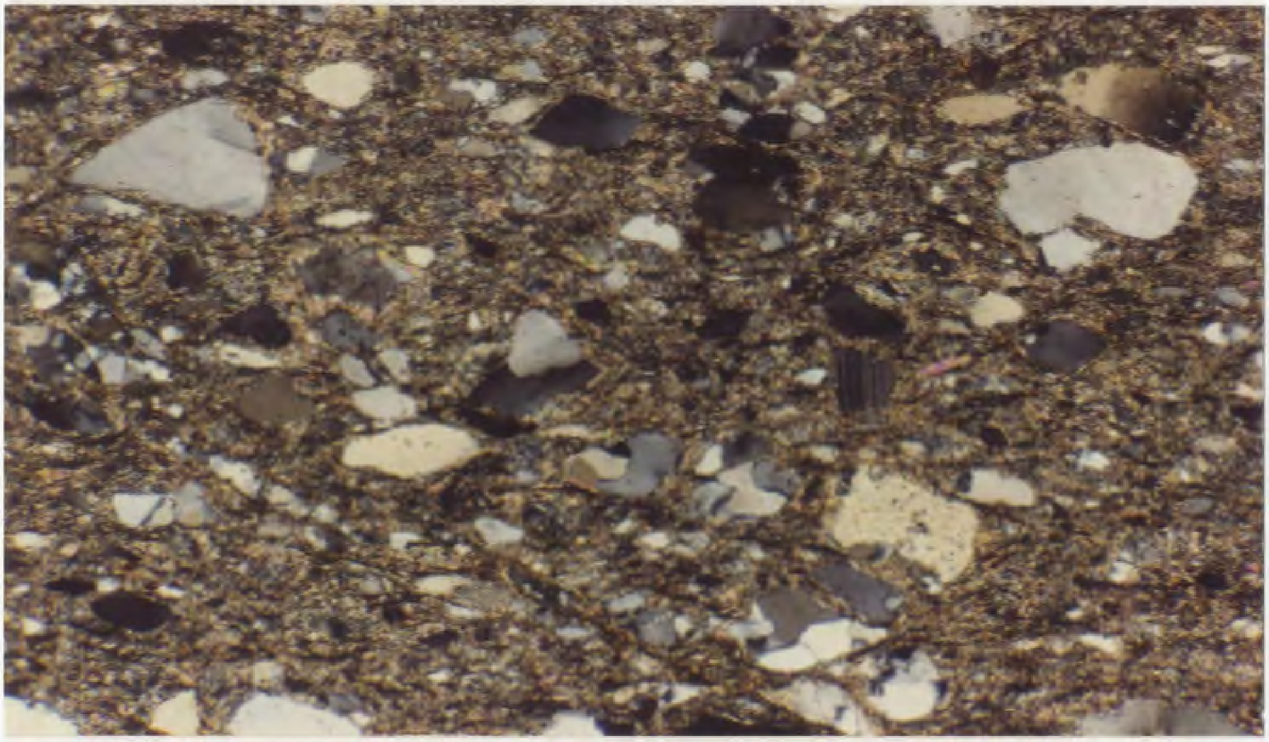
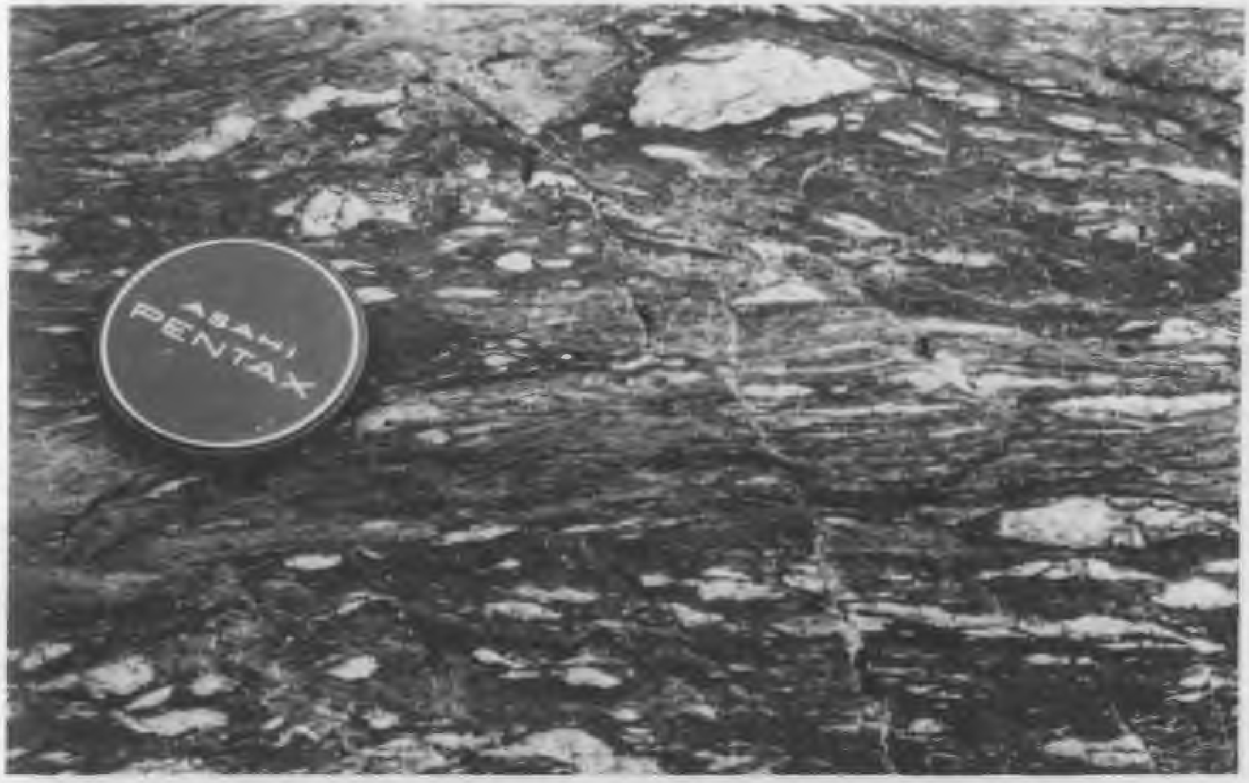


Plate 24a

Strongly foliated, disaggregated lenses of quartz in the actinolite schists of central Grands Galets Bay, Goose Cove Schist

Plate 24b

Disharmonically-folded and deformed grey marble exposed in an intraformational shear zone at the base of Grands Galets Head, Goose Cove Schist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occur which are cut by several carbonate veins. The spots are 1cm long, white, anhedral to euhedral pseudomorphs, probably after plagioclase, which have been completely sericitized and altered to clinozoisite.

Marble

Within the predominant lithology of actinolite schist are found minor but distinct units of calcareous metasediments that are restricted in occurrence to zones of intense deformation. Light grey and grey/black to green, highly deformed marble is exposed in intraformational shear zones on the east side of Clous Cove and at the base of the cliffs along Galets Head (Plate 24b). At Clous Cove the shear zone is a heterogeneous chaotic mixture of greenschist, metagabbro, calcareous sheared black shale and marble, that has been isoclinally folded on a small scale. Similar outcrops of finely laminated marble along the cliff base of Galets Head are intimately associated with the actinolite schists. These pass northwards into a massive nearly unfoliated green lithology which in one place contains well foliated Maiden Point-like sandstone with clearly recognizable grains (Plate 23).

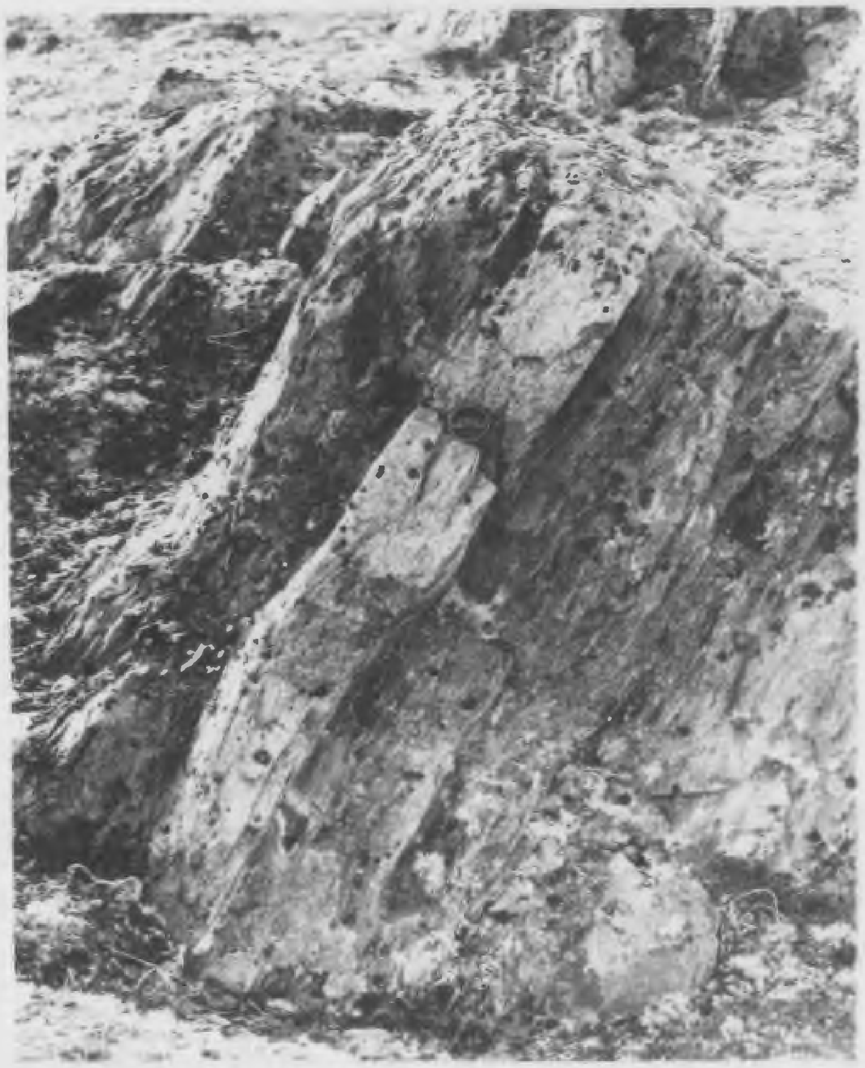
Metagabbro

Metagabbro occurs in the actinolite schists along Wild Cove as large, discordant, medium- to fine-grained bodies of leucocratic actinolite schist. These bodies commonly display compositional layering a few centimetres thick which may represent original igneous heterogeneities now transposed into parallelism with the main foliation (S2). The discordancy of these bodies with respect to S2 may represent an original intrusive relationship and may also partly be due to late faulting. Outcrop was insufficient to determine actual contact relationships. In several places late stage veins of rhodocrosite with quartz cut across S2.

Numerous sheets of fine- to medium-grained leucocratic actinolite schist, about 0.5m thick, also occur throughout the fine-grained schists. These sheets are always oriented sub-parallel to the main foliation (S2) and are compositionally homogeneous as a result of internal reworking by deformation associated with metamorphic differentiation. These bodies may represent parallel-sided recrystallized intrusive or extrusive sheets (Plate 25).

Plate 25

Sheet of leucocratic schist within the actinolite schist oriented sub-parallel to S2. Such bodies possibly represent original intrusive or extrusive sheets, Goose Cove Schist, Grands Galets Head



Petrography

Actinolite Schists

The actinolite schists contain a large proportion of fine- to medium-grained, acicular, green pleochroic actinolite (referred to as Act 2) which shows a preferred dimensional orientation that defines both S2 and the relict S1 cleavages. The actinolite often grows in epitaxial continuity around small dusty cores of actinolite porphyroblasts (referred to as Act 1). The actinolite is interlayered on a microscopic scale with greater or lesser amounts of sericitized and saussuritized plagioclase, epidote/clinozoisite, quartz, chlorite (often penninite), minor muscovite, and opaques with sphene alteration rims.

Metasediments

There is a good deal of compositional heterogeneity within the Goose Cove Schist which reflects changes in composition of the protolith. Rocks interpreted as metasediments contain little or no amphibole, the foliation (S2?) being defined by micas and streaks of opaque material. A compositional layering is usually observed parallel to the foliation and strained quartz is common as thin discontinuous lenses.

Calcareous metasediments consist of finely crystalline carbonate with streaks of opaque material and associated lenses of polycrystalline strained quartz. Alignment of fine-grained, sheaf-like orientation patterns of acicular tremolite define the foliation, together with parallel alignment of fine-grained dispersed laths of muscovite. The grey laminated marble at the base of the cliffs in Clous Cove and on the east side of Galets Head consists of tightly microfolded, polycrystalline layers of granoblastic-polygonal carbonate with varying proportions of fine-grained quartz. Randomly oriented fine-grained, euhedral, acicular actinolite is sparsely scattered throughout the carbonate groundmass. The massive green lithology exposed around White Point on Galets Head consists of variable proportions of fine grained sphene, penninite, quartz, epidote, needles of actinolite and minor carbonate, all without a tectonic fabric. A crude foliation is defined by dusty streaks of opaque material and lenses of penninite. Thin late stage anastomosing veins cutting this foliation contain fine-grained anhedral carbonate and quartz with scattered and matted needles of stilpnomelane. At the western contact of this lithology against the actinolite schists a single specimen of foliated medium-grained sandstone was recovered (Plate 25, facing p.65). The matrix of this specimen consists of colourless to pale green sericite with strings of fine-grained sphene. The constituent grains are of strained quartz with minor sericitized plagioclase and some bent laths of muscovite lying subparallel to the foliation. The original grain shapes have been modified by deformation so that the quartz has developed a crude shape fabric parallel to the foliation. Where grain shapes are preserved these range from sub-angular to sub-rounded. Pressure shadows are not present around the grains. One or two thin late stage veins lying parallel to the foliation contain fine-grained unstrained quartz with associated anhedral crystals of carbonate and fine-grained laths of penninite.

Actinolite/quartz/garnet schists

Other lithologies are characterized by very fine-grained heterogeneous banded matrix material consisting mostly of sericite or sericitized plagioclase, quartz, colourless to pale green muscovite and strings of opaques with alteration rims of sphene. This is associated with variable amounts of chlorite and scattered anhedral fine-grained epidote. Subhedral to euhedral medium-grained garnets are also found and contain inclusion trails of ore and penninite. These trails may be S-shaped, and indicate rotations of up to 55^{o} (Plate 26a).

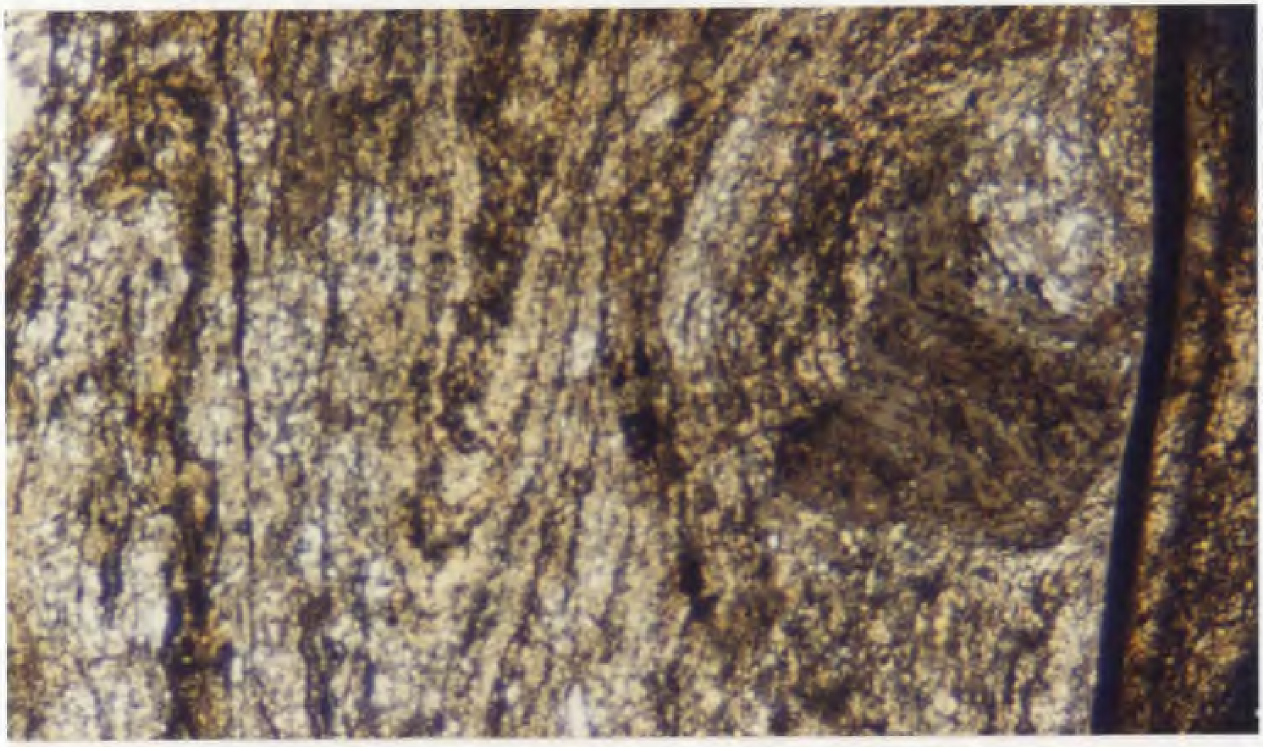
The opaques have been largely altered to sphene and cracks in the garnets are filled by chlorite and sericite (Plate 26b). Chlorite pressure shadows are poorly developed around the garnets. Small to medium-sized lenses of fine- to medium-grained quartz are common in the banded

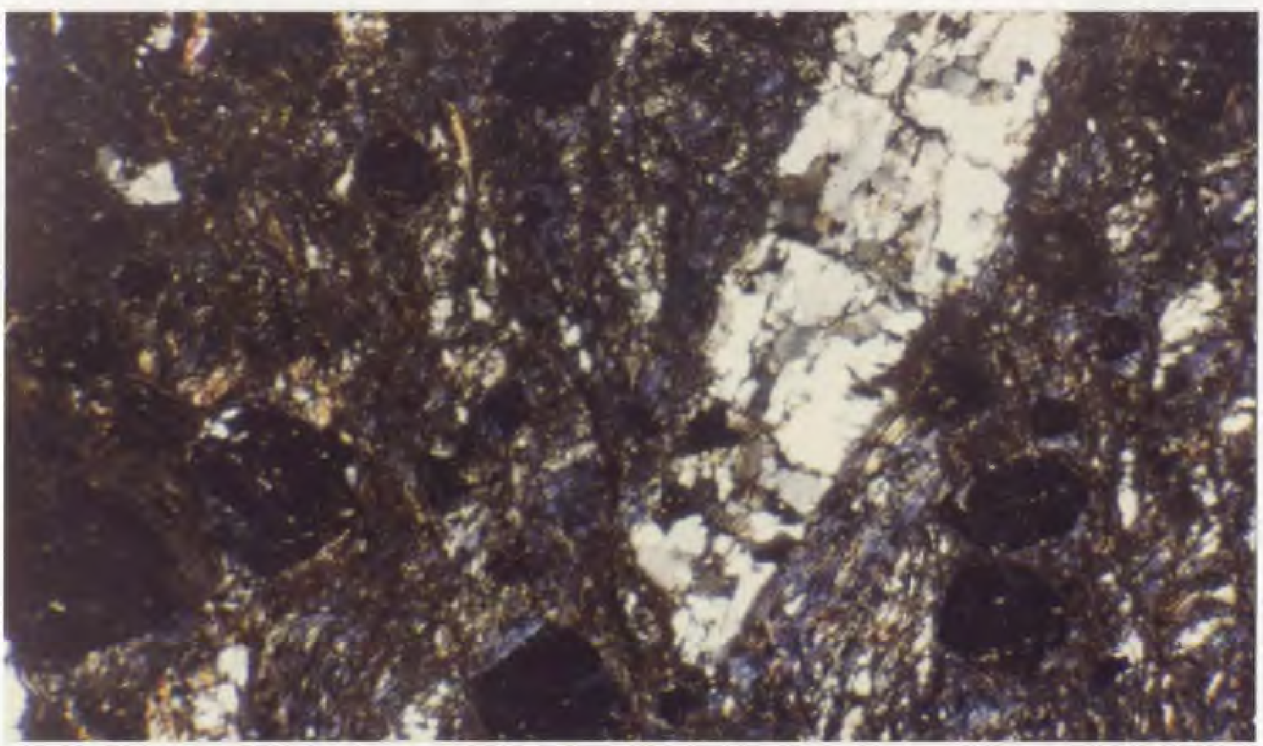
Plate 26a

Photomicrograph of medium-grained almandine garnet (right) containing sigmoidal inclusion trail of the relict S1 foliation continuous with the external foliation,- S2. To left of garnet is a rootless isoclinal F1 fold hinge which affects S1. Note that the anticlockwise sense of rotation of the garnet is not consistent with the isoclinal fold symmetry, placing garnet growth post S1 and probably syn-post F1. Goose Cove Schist (partially crossed polars). (Specimen #20-8-3)

Plate 26b

Photomicrograph of euhedral garnets in foliated (S2) penninite matrix (blue). Garnets mostly cracked and filled by penninite. Note large lens of polycrystalline strained quarz (centre right), Goose Cove Schist metasediment (crossed polars). (Specimen #20-8-6)





matrix. The quartz is usually in a foam texture with the unstrained grains in similar crystallographic orientations. It also occurs as strained polycrystalline aggregates with a strong shape fabric and strongly serrated grain and subgrain boundaries, and less commonly as strained ribbon quartz.

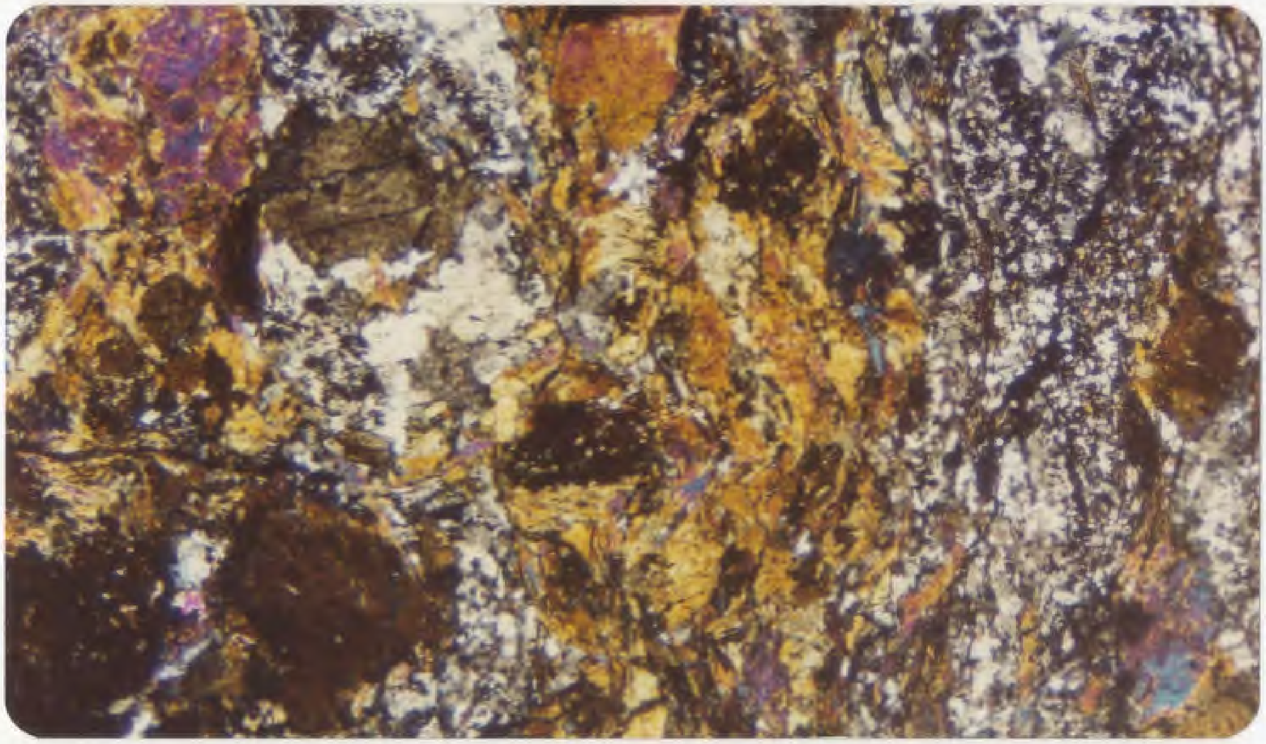
Metagabbro

The actinolite schists grade into or have sharp contacts, mostly subconcordant to S2, with medium- to coarse-grained bodies and lenses of metagabbro. The metagabbros have a very similar mineralogy to the actinolite schists and are distinguished from them by coarser grain size, greater proportions of plagioclase, the abundance of actinolite porphyroclasts, an amphibole L-S shape fabric and coarse compositional layering.

The metagabbros consist of sericite (after plagioclase) with associated actinolite, clinozoisite, and very minor amounts of chlorite in alternating compositional layers 2-5mm thick. The remnant plagioclase is largely finely recrystallized and subsequently sericitized. The sericite contains fine needles of tremolite/actinolite, fine grained sphene, and small anhedral to subhedral crystals of clinozoisite (Plate 27). The clinozoisite commonly has a strong preferred dimensional and crystallographic orientation, and the rims of the grains

Plate 27

Photomicrograph of differentiated layering in Goose Cove Schist metagabbro. Alternations between layers of fine-grained recrystallized and sericitized plagioclase (colourless) and layers of medium-grained acicular actinolite (yellow/green). Relict Act1 porphyroblasts are seen at top and bottom left, and smaller, cleaner-looking crystals are Act2 which define anastomosing cleavage films. Differentiated layering and alignment of acicular Act2 define the foliation, S2. (Specimen #31-7-3)

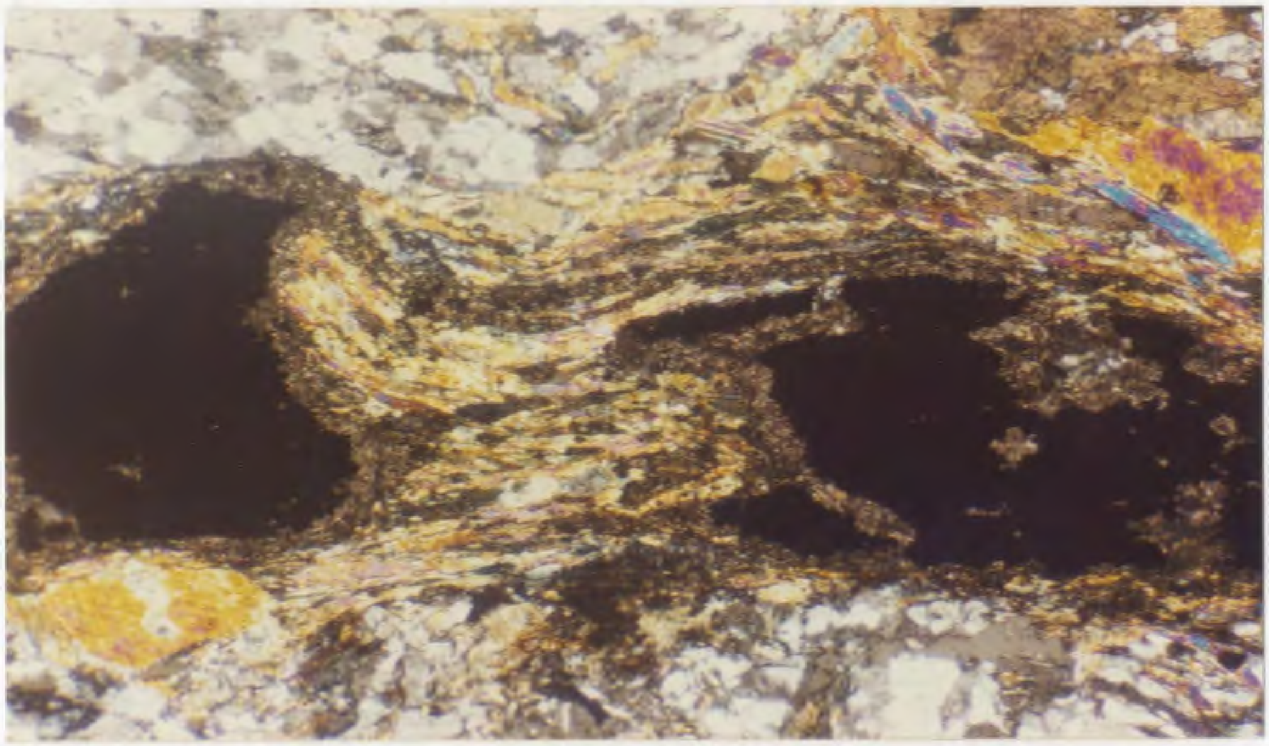


are often sites for the concentration of "dusty" microcrystalline sphene.

The actinolite-rich layers consist of relict medium-grained oval porphyroclasts of weakly pleochroic, pale green, strained actinolite (Act 1). The cores of these crystals are commonly "dusty", and may contain inclusions of fine grained sphene and ragged grains of ore with sphene alteration rims. The Act 1 porphyroclasts are flattened parallel to S2 and define a strong S-fabric. Occasionally porphyroclasts show "augen" or fish shapes; the latter have been rotated and lie at small angles oblique to S2 and may represent domains of an incompletely transposed earlier foliation (S1) (see actinolite/quartz/garnet schists above). Recrystallized fine-grained acicular actinolite (Act 2) always lies parallel to S2 and wraps around the Act 1 porphyroclasts . Films of acicular Act 2 crystals interconnect the Act 1 porphyroclasts and define the amphibole-rich layers (Plate 28). Commonly the Act 1 porphyroclasts are partially recrystallized to form fine grained domains of "dusty" acicular actinolite. The metagabbros are cut by thin post-S2 veins of fine grained clinozoisite in places associated with quartz and plagioclase with fine hairs of colourless amphibole.

Plate 28

Photomicrograph of differentiated layering in Goose Cove Schist metagabbro. Acicular Act2 actinolite interconnects two prophyroblasts of opaques which have alteration rims of fine grained sphene. An Act1 porphyroblast is visible top right. Colourless and grey material is recrystallized and sericitized plagioclase. Alignment of acicular Act2 and differentiated layering define the foliation, S2. (crossed polars) (Specimen #31-7-3)



CHAPTER 4

SEDIMENTARY PETROGRAPHY

Sandstone Compositions

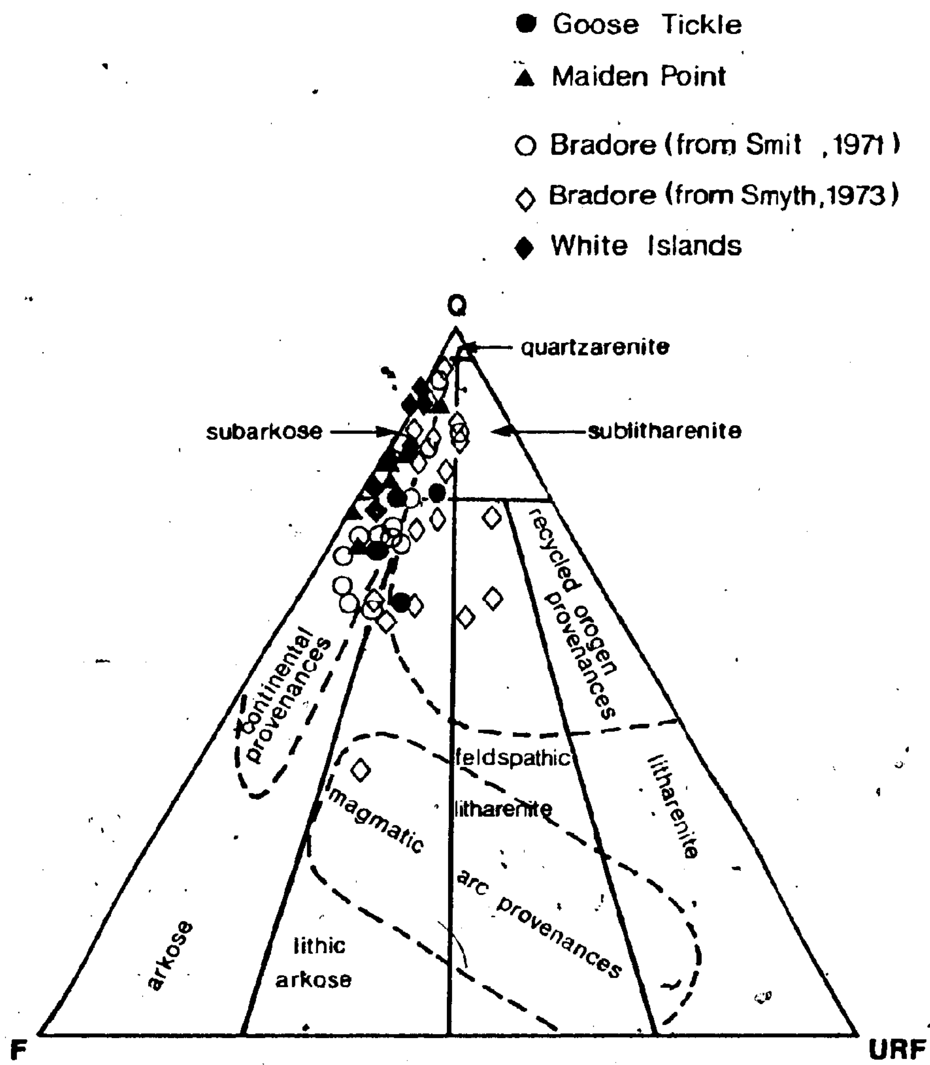
Analyses of sandstone components were made of samples collected from the Goose Tickle and Maiden Point turbidites. A single analysis was made of a specimen of mildly deformed sandstone taken from the Goose Cove Schist on Galets Head. It should be remembered in the following discussion that these sandstones were collected from different structural slices so that similarities do not bear a simple direct relationship.

Several different plots have been used to represent the data. The matrix data were used only in computing component percentages and are not included in the figures. The Q,F,URF triangular plot (Fig.3) shows all the sandstones and includes data from Smit (1971) and Smyth (1973) from the Bradore Formation.

Sandstones of the White Islands and Maiden Point Formations from the study area fall mainly in the subarkosic field. Data from Smit (1971) and Smyth (1973) have a large scatter into the lithic arkose and feldspathic litharenite fields probably reflecting a much broader sampling. The White Islands and Maiden Point sandstones from the study area all fall within the Continental Block

Figure 3

Q-F-URF (quartz-feldspar-unidentified rock fragments) triangular diagram



after Folk (1968) and Dickinson & Suczek (1979)

Sandstone Compositions

Provenances of Dickinson and Suczek (1979). Smit's (1971) data generally conforms to this but Smyth's (1973) distribution indicates a slightly greater lithic content.

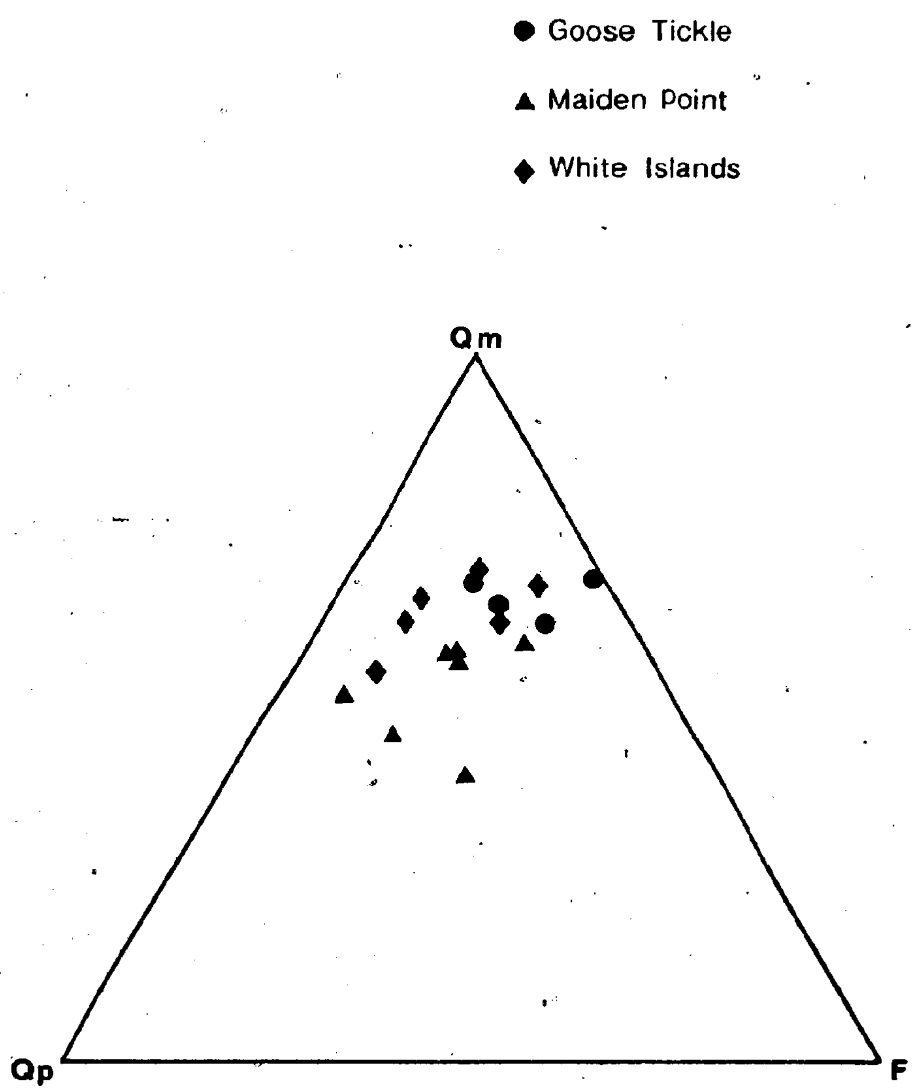
The Goose Tickle sandstones, sampled from massive beds, fall between the Continental Provenances and Recycled Orogen Provenance fields (Dickinson and Suczek, 1979) (Fig. 3). This spread supports the idea that the Middle Ordovician Goose Tickle Formation has been partly derived from recycled lower Cambrian continentally-derived prism sandstones and partly from the Allochthon during emplacement.

The Qm,Qp,F plot (Fig. 4) shows clearly that the Maiden Point Formation has a slightly higher feldspar content than the White Islands Formation. The Goose Tickle Formation contains slightly lower quantities of polycrystalline quartz than the other sandstones. This may simply be a reflection of smaller grain size.

The Perthite,F,Microcline plot (Fig.5) represents only the White Islands and Maiden Point Formations since the Goose Tickle Formation contains only plagioclase feldspar. It can be seen clearly that the White Islands Formation contains significant amounts of recognizable perthite and microcline whereas the Maiden Point Formation contains small amounts of perthite only. This may reflect loss of perthite and microcline during transport and deposition of the Maiden Point Formation by chemical weathering (and not by abrasion since much of the Maiden Point sandstones are

Figure 4

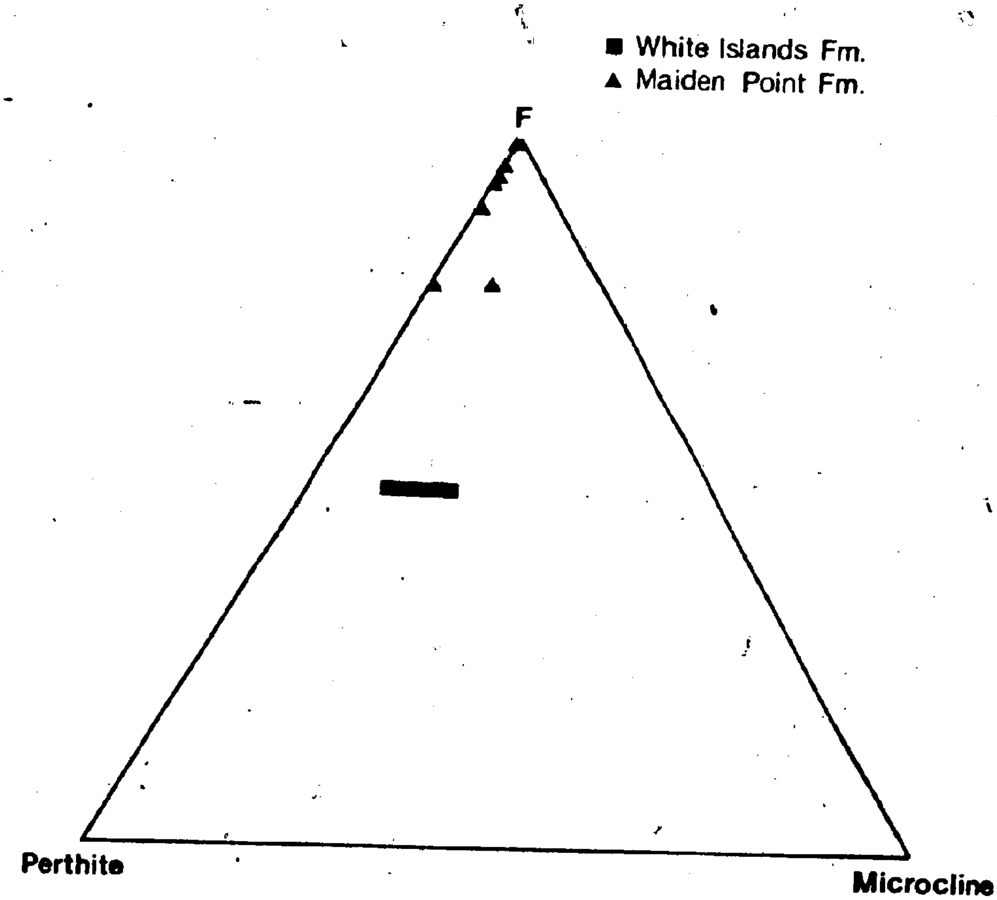
Qm-Qp-F (monocrystalline qtz. grains-polycrystalline qtz. grains-feldspar) triangular diagram



Qm – monocrystalline qtz ; Qp – polycrystalline qtz ;
F – total feldspar

Figure 5

, F-perthite-microcline triangular diagram


White Islands Fm.
Maiden Point Fm.
F
Perthite
Microcline

of similar grain sizes to the White Islands sandstones).

The histograms in Fig.6 show the percentage of all feldspars in the total rock from the samples used. It is interesting to note that the average feldspar content in the Maiden Point and Goose Tickle Formations is significantly higher than in the White Islands Formation. The differences in feldspar content between the White Islands and Maiden Point Formations perhaps suggest that the feldspars in the White Islands Formation have been preferentially removed by mechanical abrasion, possibly in a beach facies environment (see paragraph below).

Sedimentary facies interpretation

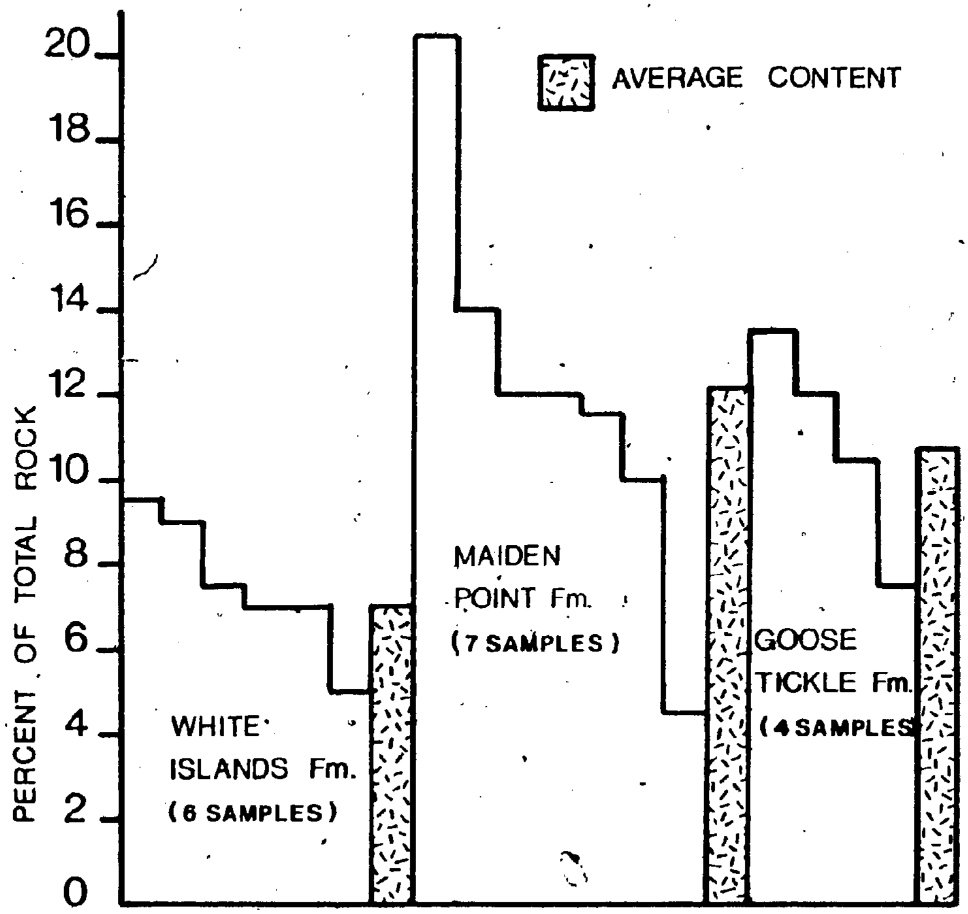
White Islands Formation

Because of disagreement over the affiliation of the White Islands Formation to a defined formation (see Chapter 2) comparisons with other sediments will not be made. However, Tuke (1968) who visited the White Islands interpreted the sandstones as a beach facies based on the existence of horizontal laminae and parting lineations. The author has no reason to disagree with this interpretation.

Figure 6

Percentage of total feldspars in the White Islands, Goose Tickle and Maiden Point Formations

FELDSPAR CONTENT OF SEDIMENTARY ROCKS



Maiden Point Formation

The Maiden Point Formation south of Hare Bay consists of sandstones and slates of which sandstones account for about 80% of the total sediment (Smyth, 1973) which is of similar proportions to the Maiden Point sediments on Quirpon Island. The Quirpon sediments have similar features to those south of Hare Bay but show considerably more compaction structures (Chapter 3). The Maiden Point sandstones on Quirpon Island are also similarly compositionally mature and texturally immature. Smyth (1973) concluded that the Maiden Point sediments showed features typical of proximal turbidites, however Stevens (1970), examining the lower quartzo-feldspathic flysch of the Curling Group (which includes Maiden Point Formation correlatives) concluded that the sediments were turbidites developed on a deep-sea fan. Both authors agree on a probable western (Stevens, 1970) to northwestern (Smyth, 1973) source. It is not obvious from the descriptions given by Stevens (1970) or Smyth (1973) or from work completed by the author, that the Maiden Point sediments can be simply classified as proximal or as deep-sea fan deposits. The latter is questioned because coarsening upwards sequences have not been recognized, and the former is queried because a deep water origin is not necessarily precluded on the basis of coarse grain size. The Maiden Point sediments appear to more closely fit the slope-wedge model developed by Parker (1977). This model facilitates Stevens' (1970) deep water origin and explains the lack of deep water fan facies and is favoured by the author.

Goose Tickle Formation

Both Tuke (1968) and Smyth (1973) described the Goose Tickle Formation as turbidites. Smyth (1973) noted that the rocks south of Hare Bay show partial Bouma sequences consisting of graded bases and upper cross- or parallel-laminated divisions. This is similar to the Goose Tickle Formation on Quirpon Island where more complete Bouma sequences are seen (Chapter 2).

Both Tuke (1968) and Smyth (1973) found graptolites in the sediments and concluded that the rocks represent a deep water facies which Smyth (1973) indicated was northeasterly-derived. The author agrees with this interpretation though no evidence for a northeasterly located source is found on Quirpon Island. Although the rocks in the Quirpon area are much deformed, coarsening upwards sequences are not found which suggests that a slope-wedge facies model (Parker, 1977) is valid for the Goose Tickle Formation.

CHAPTER 5

MELANGE AND MYLONITE ZONES

Previous work in melange terranes

Hsu (1968) stated that melanges are deformed rocks containing tectonically mixed blocks of both native and exotic origin in a pelitic matrix. He envisaged two distinct processes occurring during melange formation,

i) fragmentation, and

ii) mixing, with which he drew analogies to the mixing of ground moraine beneath a glacier.

Hsu (1968) also noted the previous use of the term "wildflysch" to describe melanges and olistostromes because of similarities in appearance, but stressed that the formational processes are different and that melange should be restricted to description of tectonic mixtures. However he acknowledged that the distinction between a melange and a deformed olistostrome is difficult and stated that rocks found in an olistostrome that are younger than the age of olistostrome sedimentation should indicate it is a melange.

Gansser (1974) noted the association of melanges with ophiolite belts and suggested the use of the term ophiolitic melange. He defined such melanges as resulting from both olistostromal and tectonic processes because they contain exotic blocks which could not be derived by a purely tectonic process. This is borne out by earlier observations by Stevens (1970) who described the major melange zone below the ophiolite in the Humber Arm Allochthon which he interpreted as an original olistostromal deposit subsequently overridden and deformed during emplacement. Gansser (1974) also made the observation that ophiolites are visible because they are obducted rather than subducted and that "ophiolitic melange may be explained through a mechanism related to obduction".

Bruckner (1975) preferred the purely descriptive term "zones of chaotic structure" because of confusion as to whether melanges are tectonic, sedimentary or both. He believed that the chaotic nature was primarily and dominantly the result of subaerial exogenic processes and that tectonic processes were secondary.

Melanges which define tectonic contacts between formations are referred to as interformational, those occurring within lithological units are termed intraformational melanges. Each type is described separately.

INTERFORMATIONAL SHEAR ZONES

Goose Tickle/Maiden Point melange zone

Melange zones mark the contacts between the Goose Tickle Formation and the Maiden Point Slice. A melange zone forms the boundary of the Grandmother's Cove inlier, and others are exposed on Jacques Cartier Island, at Lighthouse Cove and at Whale Point (Plate 29). The edges of the melange zone are defined where beds of the Maiden Point and Goose Tickle Formations cease to be boudinaged and intermixed. The melanges are characterized by a black, commonly pyritiferous, finely cleaved (S1) shale matrix. At the east side of Grandmother's Cove the melange zone is about 40m wide. It is full of sloughed off and boudinaged blocks of Maiden Point sandstone intermixed with calcareous Goose Tickle laminated sandstones and siltstones. Pods and boudins of Goose Tickle and Maiden Point lithologies become more profuse towards the contacts with their respective outcrops. A single piece of isotropic leucogabbro from the Maiden Point Formation was seen in the melange zone on the eastern side of the Grandmother's Cove inlier. The fine sandstones and siltstones of the Goose Tickle Formation in the melange zone are cut by the cleavage which is axial planar to several small scale folds. The limbs of these folds are sheared out but the beds preserved in the remaining hinges indicate younging to the south. It was

Plate 29a

The Goose Tickle Fm./Maiden Point Fm. melange zone. Relatively undeformed Maiden Point sandstones are located in the distance. Photograph taken standing on Goose Tickle Fm. The melange zone is shaly and full of subrounded clasts of pebble- to boulder-sized clasts of Goose Tickle Fm. and Maiden Point Fm. lithologies. Also present are probable clasts of peridotite. The shear zone is steeply east-dipping and carries a strong S2 cleavage. View looking west from the eastern contact of the Grandmother's Cove inlier

Plate 29b

The Goose Tickle Fm. (right)/Maiden Point Fm. (left) contact at Whale Point. The melange zone has been faulted out in this locality and the fault dips steeply west (left). Grands Galets Head (consisting of Goose Cove Schist) is visible in the background. View looking northeast

not possible to determine the orientation of the fold axes. The western limb of one small fold has been slightly refolded so that S1 cuts it twice. Northeast of Dumenil Point the black shale matrix is slickensided and contains subrounded gravel to cobble-sized grey/green clasts of serpentinite (Plate 29a). The clasts weather a characteristic orange-buff and some contain numerous euhedral orange-weathering crystals (of amphibole?) up to 4mm wide. This weathering is characteristic of peridotite.

The western contact of the Goose Tickle Formation with the Maiden Point Slice is sharp. The underlying rocks are strongly sheared and boudinaged close to the contact, but the sandstones of the Maiden Point Slice are more homogeneous and are not boudinaged or broken. Thus the melange zone is developed only in the Goose Tickle Formation lithologies here. The cleavage (S1) in the melange dips steeply southeast on both sides of the inlier.

The contact on Jacques Cartier Island is sharp but both formations have been disrupted and sheared. Disruption is greatest in the shale-rich Goose Tickle Formation where beds are boudinaged in a zone 1-5m wide adjacent to the contact. The cleavage, S1, is mostly sub-parallel to the contact but at the northwestern tip of the island the contact strikes northeast - southwest dipping southeast at 70° and is cut by the cleavage which strikes north-northeast - south-southwest.

A contact between the Goose Tickle and Maiden Point

Formations is exposed on the south side of Lighthouse Cove where a small inlier of highly sheared Goose Tickle sediments is exposed. The beds here have been severely disrupted and boudinaged as described previously and are considered to be part of the contact melange zone. The southern contact against the Maiden Point Formation is sharp and is marked by a 7m wide zone of finely cleaved black shale. The contact zone can be traced southwestwards within the Maiden Point for a distance of 0.5km as a discrete finely cleaved shale band that carries a fracture cleavage (S3). The zone runs into the northern tip of a large pillow lava body which occurs in this region. The pillow lavas are blastomylonitic in this zone and carry a locally developed L-S fabric.

The melange zone at Whale Point has been modified by a late stage fault which dips 75° to the northwest (Plate 29b, facing p.86). The Goose Tickle sediments have been strongly deformed adjacent to the fault where cobble to boulder-sized clasts of fine- to medium-grained sandstone rest in a finely cleaved black shale matrix (Plate 29b, facing p.86). West of the fault, the Maiden Point Formation is shale-rich and has been strongly deformed. The shale is pyritiferous in places and contains gravel to boulder-sized clasts of sandstone up to 1m across. Silty bands in the shale have been isoclinally folded on a small scale with S2 parallel to the axial planes of the folds. More competent sandstones mark the western edge of the melange zone.

The nature of the contact is not seen on The Whale, southwest of Cape Bauld, because it is submerged beneath low water level. The Goose Tickle Formation has been strongly deformed and boudinaged here, as described before, and is considered to be part of the contact zone. In this lithology, a small rootless fold hinge has been refolded by a second generation fold which carries an axial planar cleavage, S_1 (Plate 30).

Maiden Point/Goose Cove Schist mylonite zone

The tectonic contact between the allochthonous slices of the Maiden Point Formation and the overlying Goose Cove Schist is defined by a mylonite shear zone that has a structural thickness of about 30m measured normal to the tectonic foliation. The zone is developed in strongly banded and foliated Maiden Point sandstones. The zone everywhere dips steeply eastwards except on the east side of the Goose Cove klippe around Whale Point where it dips steeply to the northwest. The direction of dip of the zone at the southern end of the klippe where it strikes east-west cannot be determined.

The mylonite carries a strong wavy foliation parallel to thin discontinuous white mylonitic quartz bands in a buff-coloured matrix. The white quartz bands are the remnants of small scale similar style rootless intrafolial

Plate 30

Refolded small-scale isoclinal F1 fold hinge in the Goose Tickle Fm. affected by F2. Note the cleavage, S2, is axial planar to F2. Note dislocation of the sandstone band along S2 planes. The Whale

isoclinal folds with the sheared limbs lying parallel to the foliation (Plate 31).

The contact with the Goose Cove Schist is gradational but the transitional zone from mylonite to actinolite schist is very narrow so that the upper contact is fairly easily defined. The gradation between mylonitic sandstones in the contact zone and the less deformed sandstones of the Maiden Point Formation makes definition of the lower contact more arbitrary.

Late stage movement within the mylonite zone is indicated by the presence of several lenses of anastamosing ultramylonitic "crush zones" seen at Whale Point which truncate the mylonitic foliation (Plate 32). A small lens of undeformed Maiden Point gabbro intrudes the mylonite zone truncating the foliation, west of Grands Galets Bay and clearly post-dates movement in the zone.

Petrography and microstructures

Five representative samples were collected in a traverse across the mylonite zone southwest of Grands Galets Bay. Towards the contact with the Goose Cove Schist the Maiden Point sandstones become recrystallized (Plate 33a). Small detrital quartz grains are preferentially recrystallized leaving larger quartz porphyroclasts (Plate 33b). Pale green mica and chlorite are commonly associated. Carbonate is a minor but characteristic mineral

Plate 31

The Maiden Point Fm./Goose Cove Schist mylonite zone west of Grands Galets Bay. White lenses of deformed Maiden Point quartzite rest in a finely comminuted sheared and foliated actinolitic matrix. Note dismembered small scale fold hinges in the mylonitized quartzite. The mylonite zone in this region dips steeply east beneath the Goose Cove Schist

Plate 32a

Evidence of late stage movement along the Maiden Point Fm./Goose Cove Schist mylonite zone is indicated by the presenae of ultramylonite zones (dark grey) within ~~the~~ the mylonite zone. Grands Galets Point

Plate 32b

As above. Note truncation of the main foliation, S2, in the Goose Cove Schist (top left). Grands Galets Point


ASAHI
PENTAX

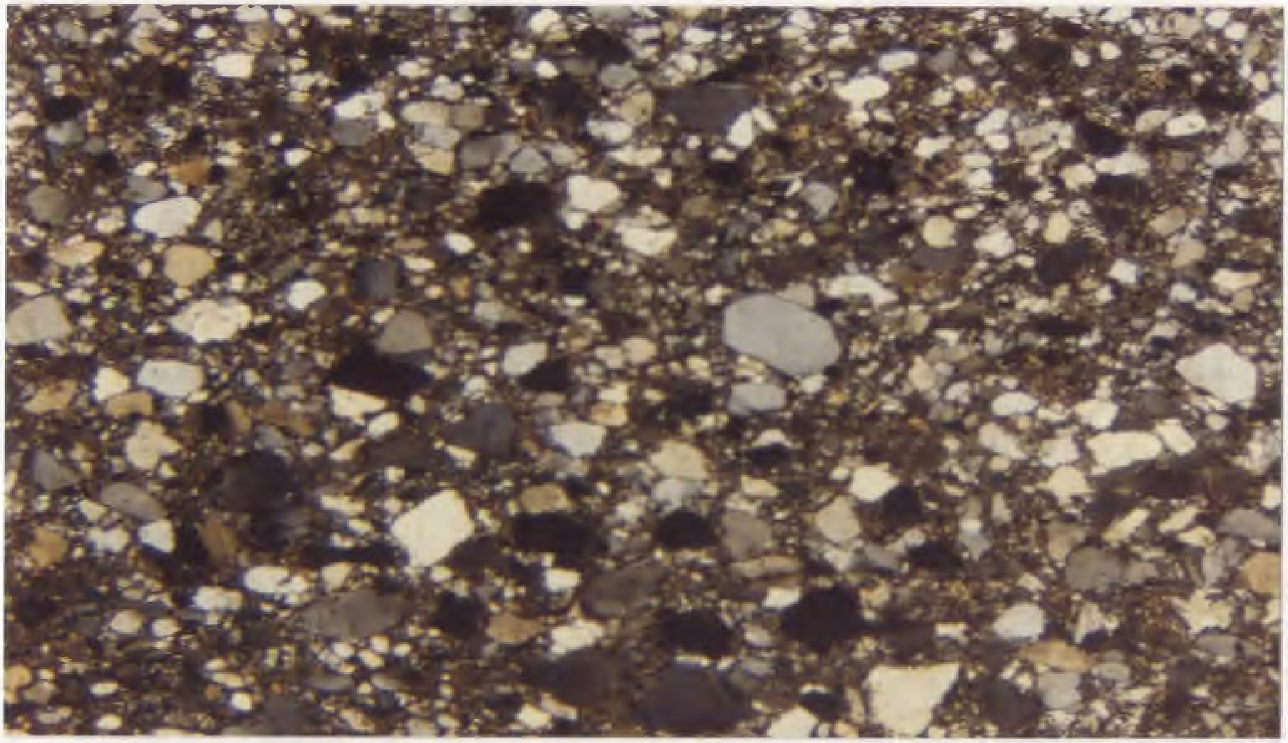

ASAHI
PENTAX

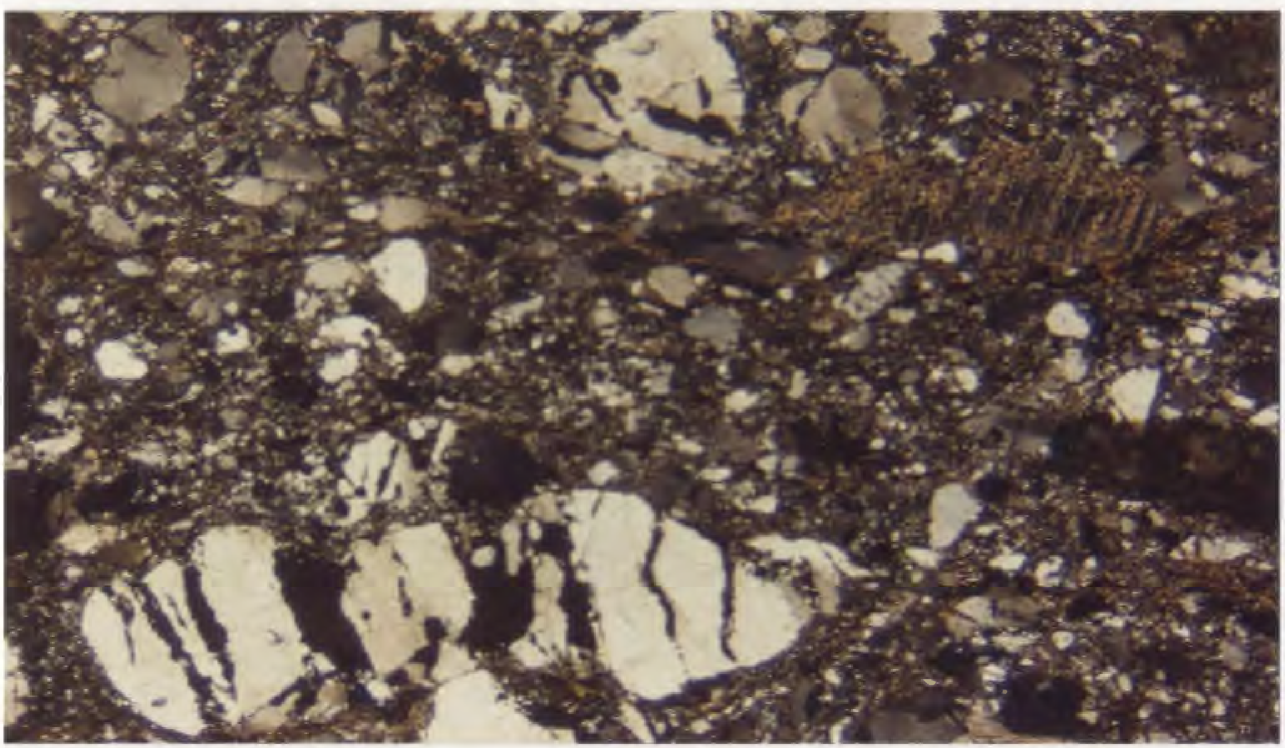
Plate 33a

Photomicrograph of slightly deformed Maiden Point Fm. sandstone near the Maiden Point side of the Maiden Point Fm./Goose Cove Schist mylonite zone. Detrital grains still recognizable. Southwest of Grands Galets Bay (crossed polars). (Specimen #9-8-3)

Plate 33b

Photomicrograph of specimen from closer to the Goose Cove Schist contact where the Maiden Point sandstones are more deformed. Small detrital grains are recrystallized and large grains (lower centre) are stretched in the plane of shearing (left-right). Note recognizable twinned grain of partially sericitized plagioclase (top right) (crossed polars). (Specimen #9-8-5)





throughout, occurring as fine anhedral grains.

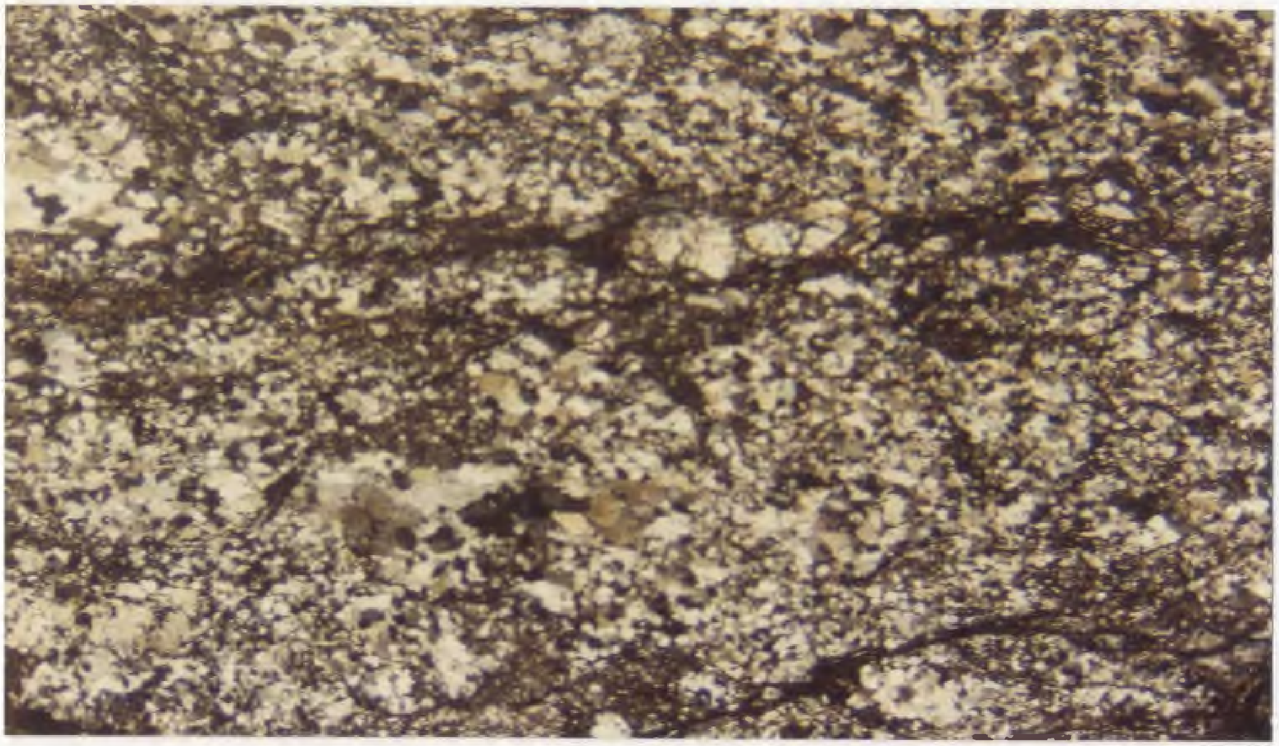
Recrystallization has homogenized the sandstone approximately 10m from the actinolite schists. Here the quartz forms a fine-grained polygonal texture with nearly hexagonal grains displaying 120^{o} triple point junctions. Evidence of the existence of original larger detrital grains is shown by areas of slightly coarser crystals that maintain a similar optic orientation distinct from the matrix quartz (Plate 34). The rock is almost pure quartz at this locality with little or no sericite and chlorite. The quartz matrix is cut by numerous anastamosing micro-shear zones of crypto-crystalline quartz. These are associated with concentrations of dusty opaque material and small amounts of chlorite. Minor relict grains of plagioclase are seen but these are small. At the approximate contact between the Maiden Point sandstones and Goose Cove actinolite schists the rock consists of colourless to pale green sericite containing inclusions of oval-shaped sphene with a strong (L-?) S fabric developed parallel to the foliation defined by the sericite. The sericite is interbanded with thin discontinuous lenses of fine-grained to microcrystalline quartz in a mortar texture. The sericite/quartz banding defines the foliation. The sericite carries a penetrative conjugate crenulation couple which may be related to the crenulations S3 and S4 described in Chapter 6.

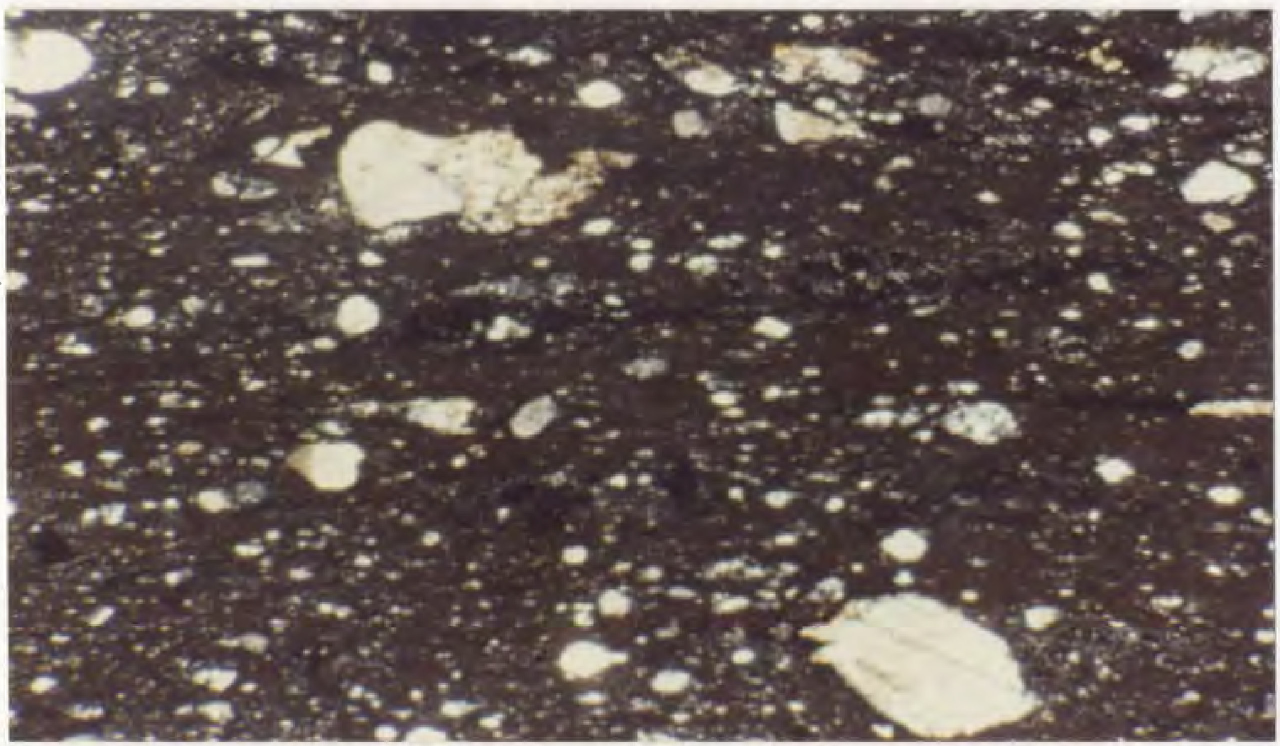
Plate 34a

Photomicrograph of sample from the centre of the Maiden Point Fm./Goose Cove Schist mylonite zone. The Maiden Point sandstone has become completely recrystallized and the quartz crystallographically reoriented. Domains of coarser grained quartz probably represent incompletely recrystallized large detrital grains. Lenses of fine-grained opaque and micaceous material define the mylonitic foliation. Southwest of Grands Galets Bay (crossed polars). (Specimen #9-8-6)

Plate 34b

Photomicrograph of quartz-rich blastomylonite within the Goose Cove Schist adjacent to the Maiden Point Fm./Goose Cove Schist mylonite zone. Original sandstone lithology completely destroyed and quartz grains lie in a finely comminuted opaque matrix. Mylonitic foliation runs left to right. Southwest of Grands Galets Bay (crossed polars). (Specimen #25-8-4)





INTRAFORMATIONAL MELANGE ZONES

Maiden Point Formation melange zones

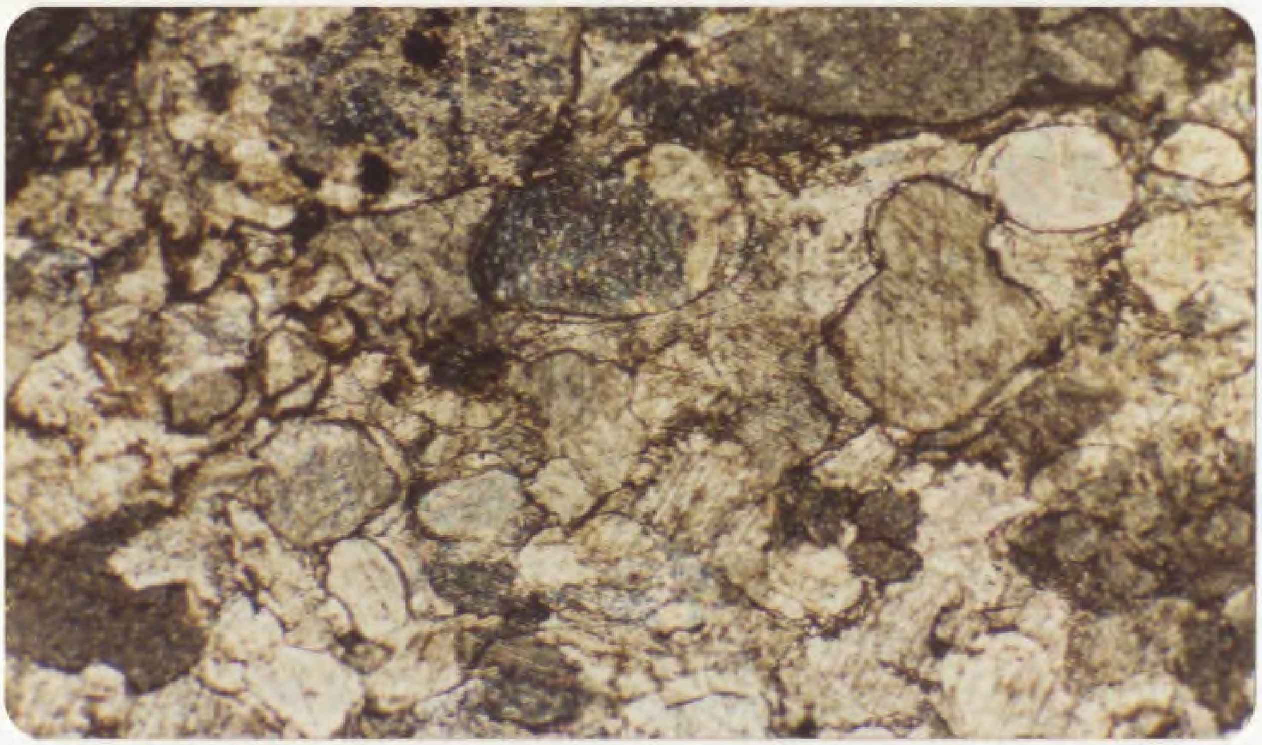
The melange exposed in Degrat Harbour contains blocks of similar lithologies to those seen along strike at the south tip of Quirpon Island but are generally larger in size. The blocks consist of calcareous laminated brown-weathering siltstones and calcareous silty volcaniclastic rocks which in one specimen contain echinoderm fragments (Plate 35). Other blocks consist of Maiden Point sandstones and pillow lavas which are in places so intensely cleaved that original structures are obliterated. Sheep Island and Degrat Island probably represent large pillow lava and sandstone lenses in the melange. The pillow lavas on Degrat Island are characteristically amygdaloidal and non-variolitic and are cut by small discontinuous dykes of diabase. The calcareous siltstones and volcanic rocks are exotic lithologies because they are not found elsewhere in the Maiden Point Formation.

Discussion

Smyth (1973), working in the southern part of the Hare Bay Allochthon noted that melange zones occurred at the contacts between all of the allochthonous slices. He also found melange zones in the Maiden Point Formation at Deep

Plate 35

Photomicrograph of echinoderm plates in limestone pebble from the intra-formational melange zone in the Maiden Point Fm. at Degrat Harbour. Each plate consists of a single calcite crystal, and several plates show epitaxial growth of calcite. (Crossed polars). (Specimen #22-7-3)



Bay and Little Canada Harbour which are similar in all respects to the intraformational melange described above, and which contain exotic blocks of brown-weathered calcareous siltstone and a block of diabase. He considered that these blocks were probably derived from the Northwest Arm Formation and were included in the melange by a process of either gravity sliding or tectonic incorporation. Following Smyth's (1973) argument it is also likely that the source for the exotic blocks in the Maiden Point intraformational melange at Degrat harbour was also the Northwest Arm Formation. Smyth (1973) interpreted the melange zones as having formed during the final emplacement by gravity sliding of the Hare Bay Allochthon. It is the authors opinion that the melanges on Quirpon Island are tectonic in origin with the possible exception of the Degrat Harbour melange and the interformational melange which bounds the Grandmother's Cove inlier. These melanges contain exotic blocks which may have been incorporated by processes of initial sedimentary slumping followed by tectonic incorporation and deformation as the allochthonous slices rode over these terranes.

Smyth (1973) found that the basal contact of the Goose Cove Schist on Fishot Island consisted of a melange zone. This is in contrast to the observed contact on Quirpon Island which, as described above, consists of a well defined ductile mylonite zone.

CHAPTER 6

STRUCTURE

Introduction

Each unit that has been defined in the Quirpon Island area displays a characteristic, unique structural signature relating to fundamental differences in the deformation histories of the units. Additionally, each unit consists of unique lithologies which may have behaved differently under the same stress regime.

The rocks in each structural slice probably underwent different deformational and metamorphic histories before their final tectonic incorporation into the Hare Bay Allochthon and emplacement onto the continental margin of eastern North America. The structures in the autochthonous and allochthonous units must therefore initially be considered separately.

This chapter deals with the description of:
1) the geometry of observed and inferred large scale structures in each unit;
2) mesoscopic structures (folds, foliations, lineations etc. that are observed in the field); and
3) microstructures (mostly from thin section analysis).

The deformation schemes for each unit are summarized in tabular form (Fig.7, located in back pocket).

White Islands Formation

The sandstones exposed on the White Islands carry a well developed heterogeneous slaty cleavage, S1, which dips steeply eastwards and is always steeper than the constantly dipping and facing beds which it cuts (Plate 36 and Fig. 8). No small, mesoscopic or large scale folds that might be associated with the cleavage were observed in the sandstone. In the slate band on the east side of the main island however, numerous small scale prolate lenses of deformed quartz define a strong rodding lineation that plunges steeply east in the plane of the cleavage (Fig. 8). The lineation thus appears to be related to the cleavage and may indicate the stretching direction or the relict boudinaged axes of small scale fold hinges.

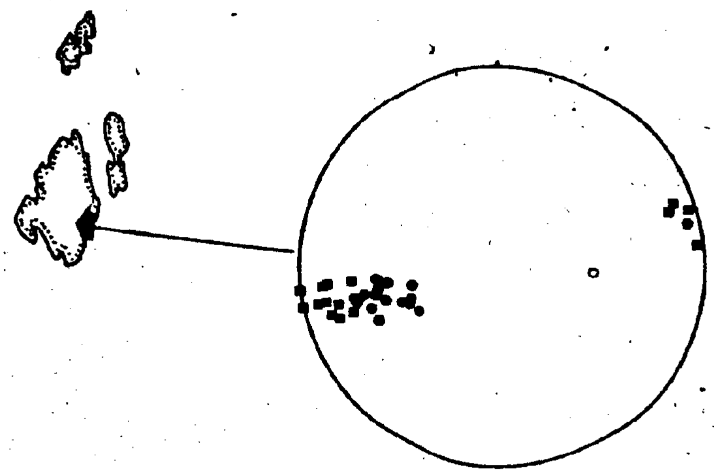
The bedding and cleavage relationships could not be measured in the field, but from stereonet construction it can be shown that the intersection lineation trends north-northwest - south-southeast and is approximately horizontal (Fig. 8). From this can be inferred the existence of a large scale north-northwest - south-southeast-trending, horizontal fold with the main island lying on the east limb of an antiform.

Plate 36

Bedding, dipping steeply to the right (east), and cleavage (vertical) relationship in the coarse-grained sub-arkosic white sandstones of the White Islands Fm. There is a lack of younging directions in the sandstone but beds are interpreted to young consistently to the east. View from north side of main island

Figure 8

Stereonet of bedding, S1 cleavage, and rodding lineation in the White Islands Formation



■ cleavage 15

● bedding (tops unknown) 17

○ rodding

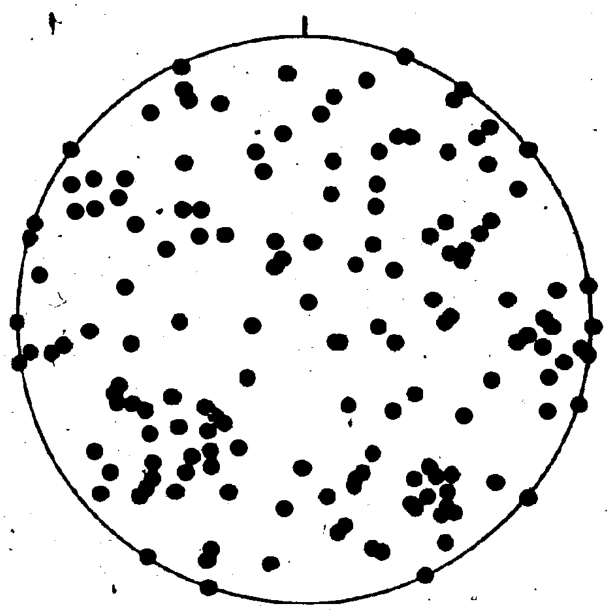
Microstructures

In the rock matrix S1 is defined by parallel alignment of fine-grained sericite which forms a strong foliation of anastomosing films wrapping around the constituent grains. Recrystallized quartz forms fine-grained blebs in the pressure shadows of some detrital quartz grains. In the pressure shadows of the old grains and where these blebs are still in optical contact, grain boundary migration normal to the foliation has been restricted by the plate-like sericite so that the recrystallized quartz forms digitate-like structures in the foliation plane which define an S fabric in the S1 plane. Where detrital grains touch the grain boundaries are commonly embayed, the contacts being sites for the recrystallized grain material or sericite, indicating that pressure solution has operated (White and Knipe, 1978). A quartz c-axis study was completed on the sedimentary grains of one specimen using a standard four-axis universal stage but revealed no preferred crystallographic orientation (Fig. 9). Unlike the quartz, feldspars appear fresh and undeformed.

These microstructures suggest that cleavage development may have occurred to some extent in relation to pressure solution processes (e.g. the quartz pressure shadows). Development of crystallographic preferred orientation in quartz is not likely to occur in association with such a deformation mechanism (Paterson, 1973; Nicolas

Figure 9

Stereonet of random quartz c-axis fabric of sedimentary grains from the White Islands Formation sandstones. Orientation of bedding unknown



195 points

& Poirier, 1976). Further, the c-axis study indicates that the internal deformation of the strained grains probably occurred before they were incorporated into the sandstone.

Goose Tickle Formation

Structural elements

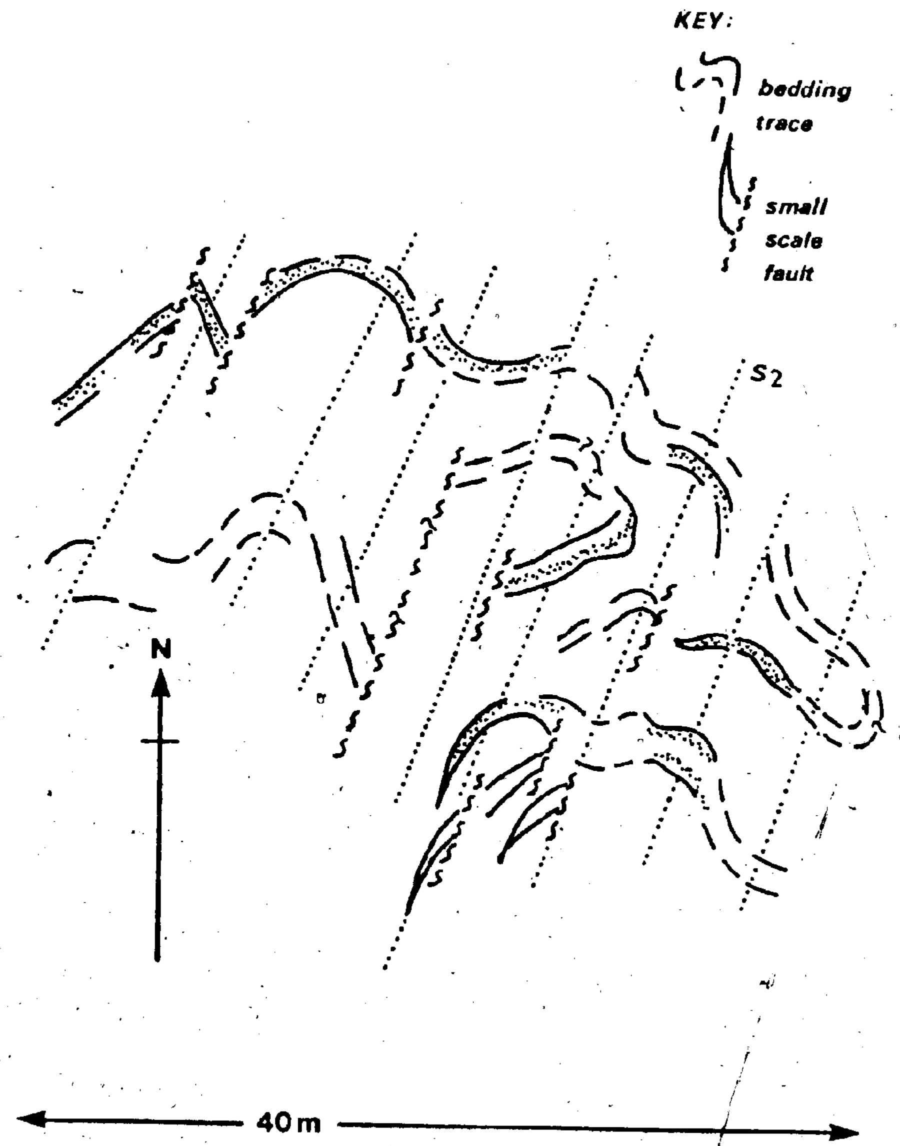
The different structural elements of the Goose Tickle Formation are introduced in this section followed by the detailed descriptions of structures in the different subareas.

F1 folds

Two generations of folds can be recognized in certain parts of the Goose Tickle Formation on the basis of mesoscopic overprinting criteria. The earliest fold generation includes a set of pre-cleavage isoclinal folds (F1) that are recognized only in the large inlier in Grandmother's Cove and in the smaller inliers located in Lighthouse Cove, and also on the Whale, southwest of Cape Bauld and on rock D. of the Islets. Fold style and scale cannot be directly observed since complete fold sections are not exposed, except on rock D. of the Islets where a partial hinge domain is exposed (Fig. 10) and on The Whale (Plate 30, facing p. 90). Instead F1 folds are recognized on the basis of facing reversals in bedding that is in constant angular relationship with respect to the later-developed cleavage. The axial surfaces of F1 folds, S1, are

Figure 10

Sketch map of the Islets rock D. showing F1 isoclinal fold and F2 folds



PLAN VIEW (approx. to scale)

not seen.

F2 folds and S2 cleavage

The second generation includes a set of mesoscopic tight, similar folds (F2) which occur throughout the unit and which also affect both the Goose Tickle and Maiden Point Formations and their tectonic contacts and are associated with an axial planar cleavage, S2 (Plates 37b & 38a). S2 is developed in the shales and in the sandstones as a fissile slaty cleavage and a non-penetrative fracture cleavage, respectively. Cleavage fans are observed in the slates in many F2 fold hinges, the cleavage being divergent in the pelitic layers. Cleavage fans are not observed in the sandstone beds and instead the cleavage traverses the beds as sub-parallel sets in the plane of the axial surface.

Small scale F2 fold hinges, seen only in sandstone beds, are mostly sheared out and lost along small scale faults that develop parallel to S2. However, complete small scale folds were observed in the field varying in size from a few centimeters to 4-5m across the hinge zone. It was not possible to discern fold wavelength, because in nearly all cases where fold hinges are preserved, the fold limbs have been either greatly thinned or faulted out.

Plate 37

Detail of typical mesoscopic asymmetric similar style F2 fold in the Goose Tickle Fm., Grandmother's Cove inlier. The shale carries a very strong penetrative slaty cleavage, S2, which is developed in the sandstones as a fracture cleavage. Note differential movement along S2 surfaces at base of thick sandstone bed and more severe disruption of thinner sandstone beds below. Shearing along S2 is characteristic and fold hinges are often completely dismembered from the limbs

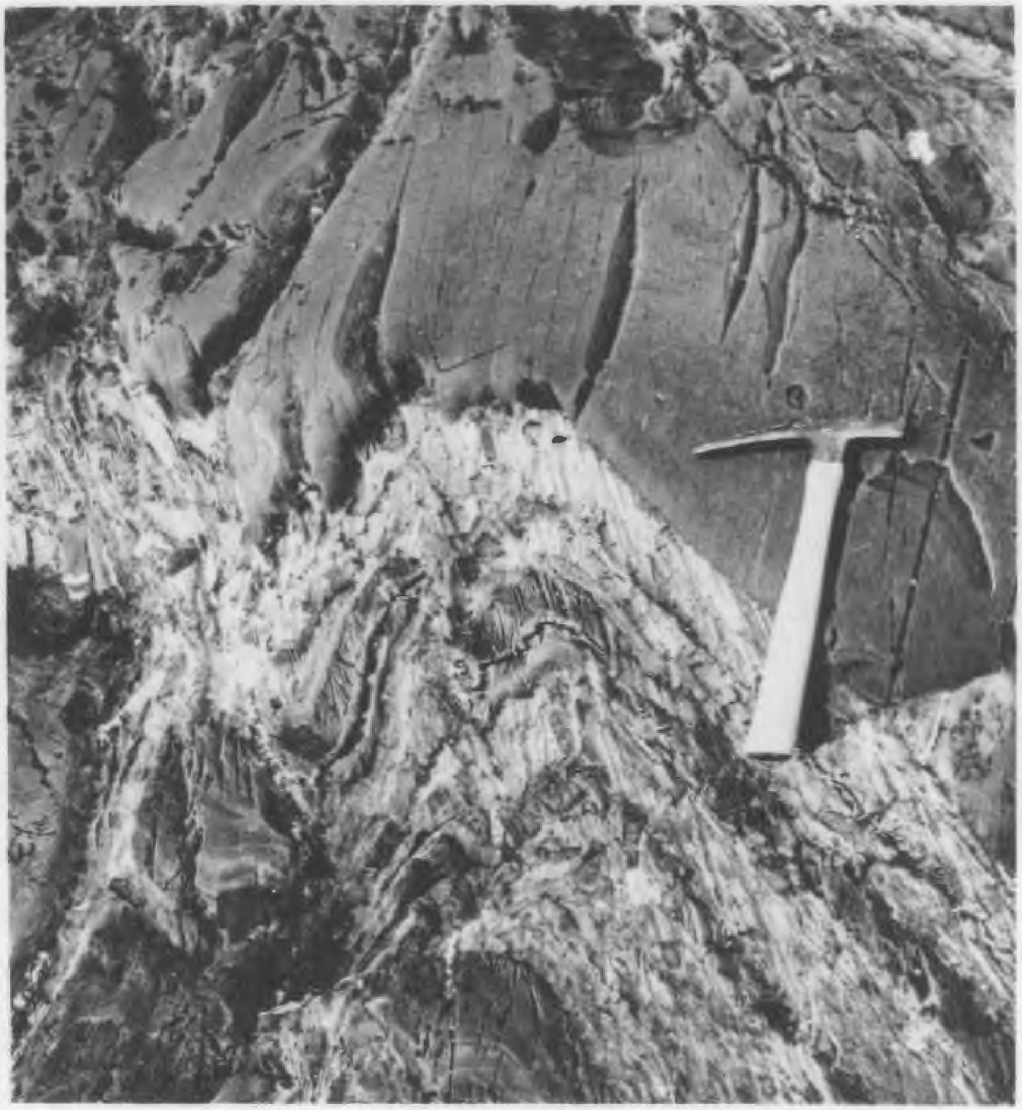


Plate 38a

Mesoscopic F2 fold in the Goose Tickle Fm. on the west coast of Jacques Cartier Is. (map case on fold for scale). Note the chaotic nature of the shaly lithology which is due to its proximity to the thrust contact with the Maiden Point Fm. several metres east (right) of picture. Fold is asymmetric, S-shaped when viewed from the northeast and plunges steeply southeast (see Fig.12c). Note well developed S2 axial planar cleavage

Plate 38b

Detail of structures in the Goose Tickle Fm. at Lighthouse Cove. Bedding laminae are horizontal, S2 slaty cleavage dips steeply to the left and the sparsely developed S3 crenulation cleavage dips to the right


ASAHI
PENTAX

F3 folds and S3 cleavage

A third generation of very small scale open folds, (F3), can be distinguished at only one locality on Chain Rock. Elsewhere, evidence of deformation is restricted to the presence of a cleavage (S3) which is developed only in the slate lithologies. Most commonly S3 has the morphology of a fracture cleavage, and is defined by closely-spaced (few mm) fracture-like planes separating microlithons which show a straight internal fabric. Rarely S3 is developed as a crenulation cleavage causing microfolding of the bedding and S2 surfaces (Plate 38b).

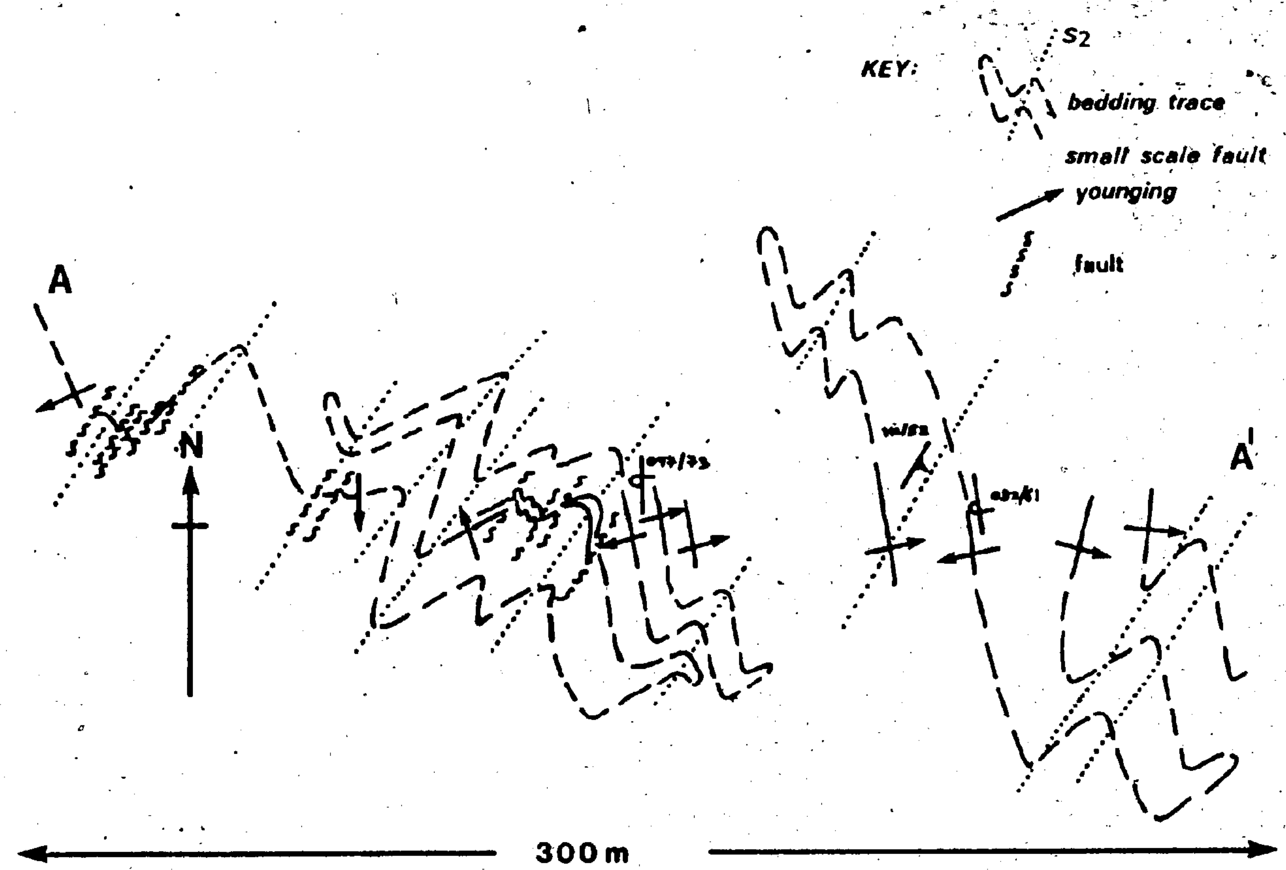
Structural geometry of subareas

Grandmother's Cove

A detailed coastal section A-A' was made across part of the large inlier exposed between Herring Cove Head and north of the the Islets in Grandmother's Cove (Fig. 11). Beds strike north-northeast and are cut by the cleavage which strikes more to the east. The asymmetry of small scale, tight, similar F2 folds in this area indicates that a large scale F2 antiformal structure is situated to the west (Fig. 11). Near the western contact against the Maiden Point Formation there is a predominance of massive, largely unbedded slatey lithologies so that no fold hinges

Figure 11

Plan section A-A' in the Goose Tickle Fm. showing F1 and F2 folds. Younging symbols indicate that observed and assumed bedding are interpreted as fold surfaces



PLAN VIEW (not to scale)

are observed. However, the cleavage in this locality now strikes anticlockwise of the beds indicating that the large scale antiformal fold hinge lies to the east and thus occupies the central area of the inlier. Thus from small scale F2 fold geometry and bedding and cleavage relationships the Grandmother's Cove inlier is inferred to be a major F2 antiformal structure.

Few younging directions were determined, but most beds on the eastern limb of this structure are right way up, and dip east-southeast between 30° and 70°. However, several beds, though maintaining the same attitude and bedding and cleavage relationships, are downward facing. This observation indicates the existence of an older fold set, F1, now refolded by F2 folds. The hinge zones of F1 folds are not observed in this region.

F1 fold style can be indirectly inferred from these observations. Because facing reversals (with respect to S2) occur in sets of parallel beds in the limbs of F2 folds, F1 folds are inferred to be isoclinal. Also, because F1 hinge zones are not observed in this area, F1 fold amplitudes are inferred to be large (Fig. 11). Though it is not possible to define the scale of F1 folds the fact that facing reversals vary in occurrence from a few metres to tens of metres, suggests that fold scale also varies. The S3 crenulation and fracture cleavage is developed sparsely throughout the inlier where it is essentially at a horizontal attitude.

The Islets

Facing reversals with respect to S2 were observed on rocks A. and D. of the Islets. On rock D. this condition can be shown to be the product of refolding of F1 folds. Here a southeasterly-closing recumbent F1 fold has been refolded by a medium scale (15-20m) F2 fold. Both limbs of the F1 fold are cut by the main cleavage, S2, which is axial planar to the F2 fold (Figs. 10, facing p.108 & 12a).

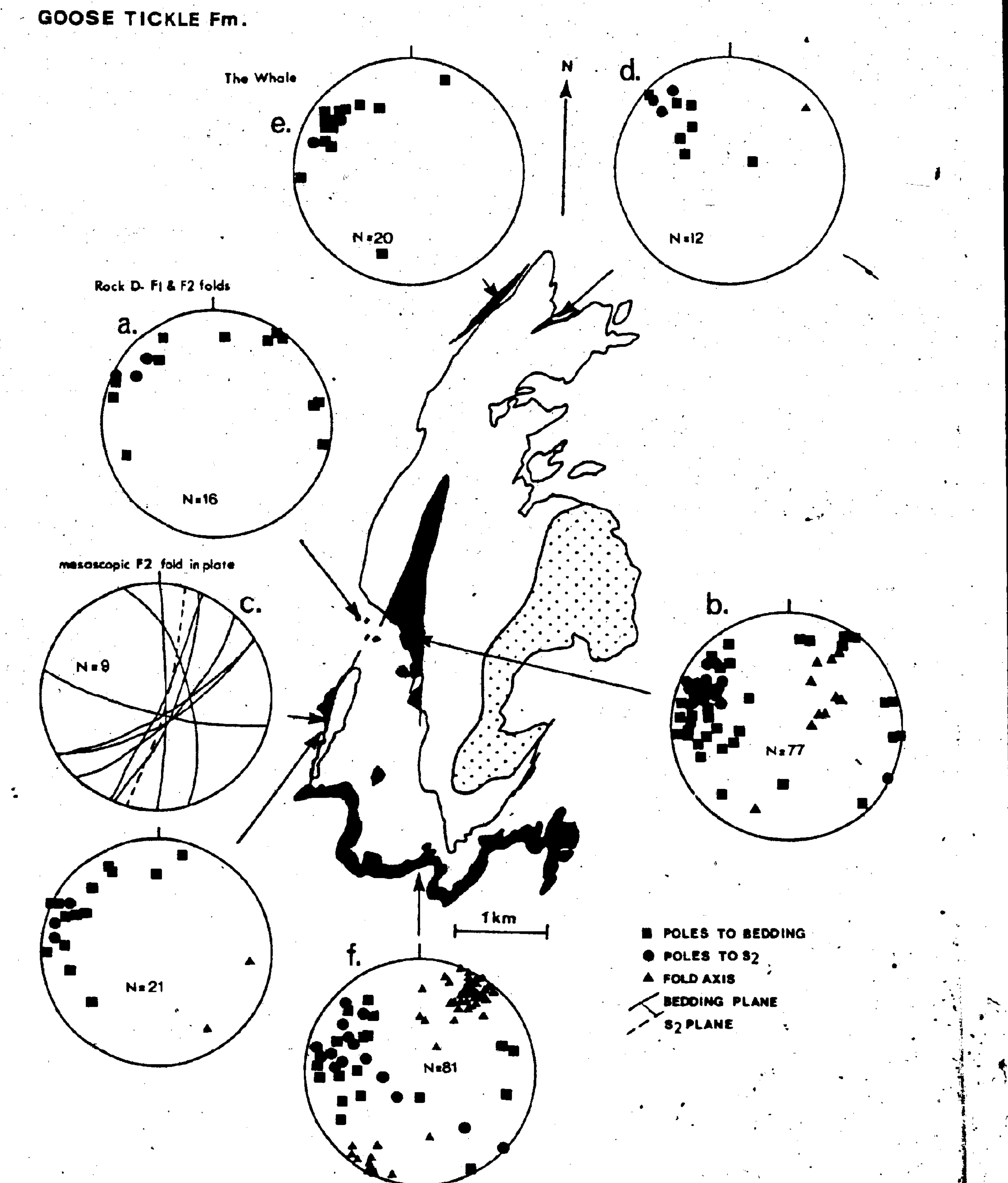
The F2 fold axes on rock A. plunge steeply south-southeast at about 75° (Fig. 7, back pocket). Measured F2 fold axes from the Grandmother's Cove inlier, though having a scattered distribution, indicate a variable plunge to the northeast between 20° and 80° (Fig. 7, back pocket). The stereoplot of bedding and cleavage attitudes shows domainal variation, and a general intersection point indicating the overall hinge plunge of the F2 folds is not apparent (Fig. 12b). It is therefore likely that on a large scale the F2 structures are non-cylindrical.

Jacques Cartier Island

The Goose Tickle Formation is exposed along a narrow strip on the west coast of Jacques Cartier Island where it is in structural contact with the Maiden Point Formation to the east. The sediments here are intensely deformed and disrupted so that the beds are broken up and boudinaged in

Figure 12

Structural stereonets for the Goose Tickle Fm.



GOOSE TICKLE Fm.
The Whale
e.
N=20
N
d.
N=12
Rock D- F1 & F2 folds
a.
N=16
mesoscopic F2 fold in plate
c.
N=9
b.
N=77
N=21
1km
f.
N=81
POLES TO BEDDING
POLES TO S_2
FOLD AXIS
BEDDING PLANE
S_2 PLANE

a finely cleaved rubbly black shale. Only two complete folds were seen, these having hinge zones from 1-5m across but with their limbs sheared out. Several readings were taken from the hinge zone of one of these folds which is shown in Plate 36a. The fold has an S-asymmetry when viewed down the steeply (~75^0) southeast-plunging axis (Fig. 12c). The short limb dips steeply southeast and is overturned, and the long limb, where beds are right way up, dips to the east. The fold is a reclined, tight, anticline (Fig. 12c and Plate 38a, facing p.111). S3 is sparsely developed in this locality and has a horizontal attitude.

Lighthouse Cove and the Whale

The small inlier of Goose Tickle Formation rocks at Lighthouse Cove is intensely deformed adjacent to the contact with the Maiden Point Formation. Beds are boudinaged into discrete pods of sandstone and siltstone in a less competent shale matrix and dip steeply southeast (Fig. 12d, facing p.116). In this locality S3 is developed as a domainal crenulation cleavage occurring in spaced parallel lamellae which affects S2 and bedding (Plate 38b, facing p.111).

The Goose Tickle Formation is also exposed on The Whale, a small tidal rock situated southwest of Cape Bauld. The beds here are also much deformed and boudinaged because of their juxtaposition with the Maiden Point Formation.

Boudinaged sediments young eastwards and lie sub-parallel to S2 which dips steeply east-south-east at about 75° (Fig. 12e). A single small scale F1 fold hinge was observed at this locality that has been refolded by F2 and cut by S2 (Plate 30, facing p.90).

Whale Point

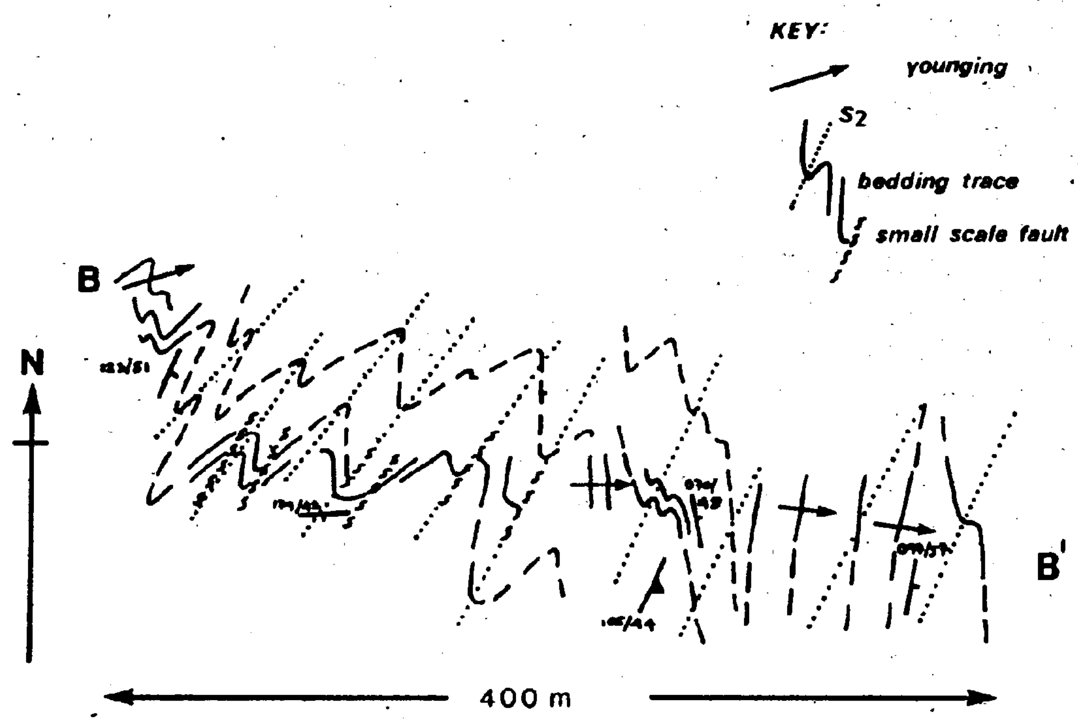
The Goose Tickle Formation is also exposed on the tidal reef at Whale Point. The beds are disrupted similarly to those seen adjacent to the Maiden Point Formation elsewhere and are cut by S2. Though bedding plane readings could not be taken, beds strike roughly northeast - southwest and are affected by small scale F2 folds, the limbs of which are sheared out. S3 is sparsely developed in the slates here. It shows some variation in dip but maintains a fairly constant northeast-southwest stike.

Point Vert to Chain Rock

A detailed coastal section, B-B', was made between Point Vert and Chain rock, on the mainland south of Quirpon Island (Fig. 13). The sediments in this area reveal similar bedding and cleavage relationships to those seen in the Grandmother's Cove inlier. However the beds have consistent younging directions, and facing reversals with respect to S2 were not found. F1 folds could not therefore

Figure 13

Plan section B-B' in the Goose Tickle Fm. showing F2 folds



PLAN VIEW (not to scale)

be inferred (Fig. 13). The folds are identical in style to F2 folds in the Grandmother's Cove inlier. They vary from small scale folds with wavelengths of a few centimeters to about 1.5m and the cleavage lies at a similar attitude to S2 elsewhere. From the outcrop pattern of small and mesoscopic scale folds it is possible to delineate the existence of a large scale F2 anticlinal structure. Most of the folds are asymmetric to the northwest indicating an anticlinal hinge zone in this direction. Folds closer to B in Figure 13 are less asymmetric, indicating that the anticlinal hinge zone is probably slightly west of B.

The stereoplot for bedding and cleavage is similar to that from the Grandmother's Cove inlier but does not reveal a mean F2 fold axis plunge direction. Bedding and cleavage intersection lineations are also extremely variable. This may be a function of undersampling of bedding and cleavage orientations. However, measured fold axes reveal a regional north-northeast - south-southwest trend with a gentle mean plunge of a few degrees to the north-northeast (Fig. 12f, facing p. 116). On the basis of similarities in style and orientation patterns these folds are interpreted to belong to the F2 fold set.

At Chain Rock the second cleavage, S3, is sub-vertical and axial planar to small scale (10-15cm wavelength), symmetric, open folds (F3) which affect gently northward-dipping bedding and associated S2 cleavage.

Microstructures

S2 cleavage

The first cleavage, S2, is a heterogeneous, domainal-type of slaty cleavage defined in the matrix material by the preferred orientation of metamorphic chlorite, the parallel alignment of small shale clasts, and by streaks of opaque minerals. Gray (1979) states that opaques may represent residues in seams related to the operation of pressure solution processes. Minor rigid body rotation of inequidimensional quartz grains lends a weak shape fabric to the sandstones in places, but this was observed in the field at only one locality.

S3 cleavage

S3 was not observed in thin section because the slaty lithologies which carried this cleavage could not be sampled. Also, no F1, F2 or F3 microfolds were observed in thin section analysis.

Deformation history and large-scale structures

It has been demonstrated that the deformation history for the Goose Tickle Formation includes the formation of three generations of structures which are believed to represent three phases of deformation. It has been shown that the rocks on the mainland part of Quirpon harbour and on Quirpon Island have undergone different structural histories.

F1 folds have been inferred for the Grandmother's Cove inlier and have been demonstrated on the Whale (Plate 30, facing p.90) and on rock D. of the Islets (Fig. 10, facing p.108). Though it cannot be unequivocally demonstrated, it is likely that all of the remaining Goose Tickle Formation inliers (i.e. Lighthouse Cove, Whale Point, rock A. of the Islets and Jacques Cartier Island) have been affected by F1 folds because of their similar structural proximity to the Maiden Point Formation. This point is discussed further in Chapter 8.

F1 folds predate the formation of the axial plane cleavage (S2) in the rocks. They are isoclinal, probably with large amplitudes and exist on different scales, though microfolds were not observed. It is possible deformation occurred whilst the sediments were only partially consolidated, though soft-sediment deformation does not necessarily imply that a foliation or some other type of internal fabric will not develop (e.g. Gill, 1979).

Evidence for post-F1 deformation is found throughout the Goose Tickle Formation. F2 folds are associated with an axial planar cleavage, S2, and are observed at most localities as small- to mesoscopic-scale, tight, similar folds. Small-scale faulting within the plane of S2 is characteristic of this fold set, and fold hinges are commonly faulted out so that fold limbs and partial fold hinges are often observed.

Large scale antiformal and anticlinal structures have been inferred in the Grandmother's Cove inlier and in section B-B' respectively. Other large scale structures could not be inferred because the remaining outcrops of Goose Tickle rocks are small and widely separated. Also they have suffered considerable deformation because of their proximity to thrust contacts with the Maiden Point Formation and consequently large scale structures cannot be discerned.

Maiden Point Formation

Structural elements

F1 folds

The earliest fold set, F1, consists of pre-cleavage folds which, though not directly observed, can be inferred from reversals in facing directions of bedding which is in constant angular relationship with respect to the first cleavage, S2 (related to F2 folds). F1 folds have been inferred in an F2 fold section at Lighthouse Cove, and possibly along the southwest coast of Quirpon Island. F1 fold style varies from tight to isoclinal but fold symmetry and scale cannot be inferred because complete fold sections are not seen. Similarly to the Goose Tickle Formation the axial surfaces of F1 folds, S1, are not seen.

F2 folds and S2 cleavage

F2 folds are related to an axial planar foliation, S2, a pervasive, anastomosing slaty cleavage. S2 cuts the shales, but is developed in the sandstones as a fracture cleavage. In areas where the dip of the sandstone beds and the cleavage are sub-parallel, foliation and bedding mask each other.

F2 folds are similar in style and they have tight to open fold geometries. Fold scale ranges from 1-2m to several tens of metres, and on the basis of fold asymmetries and bedding and cleavage relationships, very large scale regional fold structures can be inferred. This fold generation affects the Goose Tickle Formation/Maiden Point Formation contact.

F3 folds and S3 cleavage

F3 folds affect S2 and are observed at only one locality. The folds are small scale, very open and similar in style and are not associated with a cleavage. A cleavage (S3), which may be related to F3 folds is more sparsely developed than the Goose Tickle Formation S3 cleavage and is only observed in the intraformational melange at Degrat Harbour.

Structural geometry of subareas

Lighthouse Cove

At Lighthouse Cove immediately north of the contact with the small inlier of Goose Tickle Formation rocks, structural relationships indicate the existence of an F1 fold structure. Here, beds are overturned and dip between 70°-87° to the northeast, and 40 to 50m north of this they are also overturned but dip between 75°-82° to the south and all the beds are downward facing with respect to the first cleavage, S2 (Fig. 14a, located in back pocket).

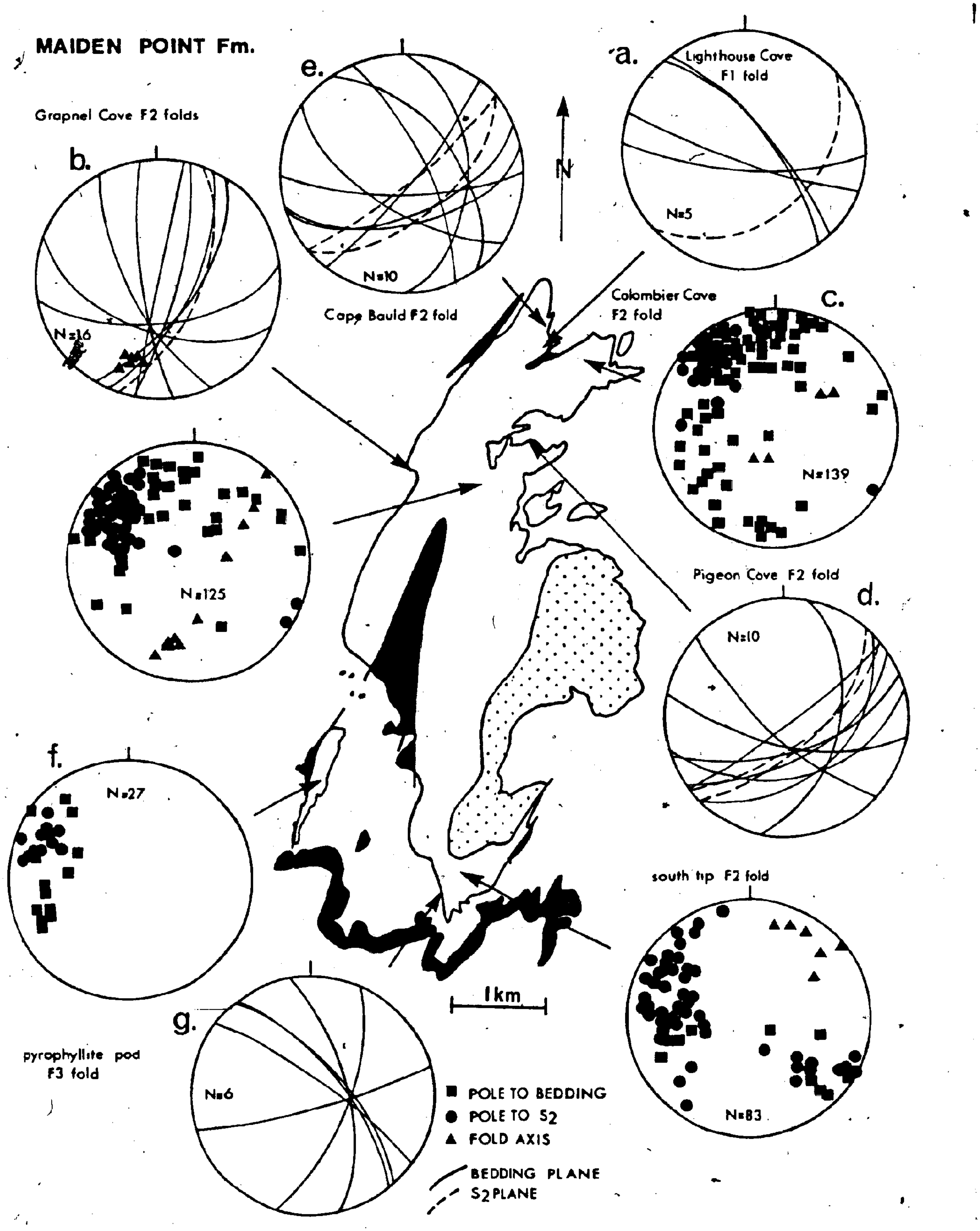
Though the hinge of this structure is not seen, the sense of convergence of the beds suggests the fold closes to the northwest. If this is the case then the structure must be interpreted as an overturned anticline because the fold axis plunges steeply southeast (Fig. 15a). However, in order for this to be true the beds must have been overturned prior to F1 because both limbs of the F1 stucture are downward facing. This implies a pre-F1 folding event in order to overturn the beds, and there is no evidence to suggest this. Instead it is interpreted that the F1 fold was originally an anticline that was rotated and overturned during F2 folding to become a downward facing structure. The F1 axis is contained in the S2 plane of the F2 folds (Fig. 15a) supporting this theory. The deformation is pre-cleavage in age and it is possible that they may have been periods of soft-sediment deformation.

Herring Cove Head to south tip of Quirpon Island

Structural relationships along the southwest coast between Herring Cove Head and the south tip of Quirpon Island may indicate the presence of F1 folding. Beds are mostly overturned to the west against the Goose Tickle Formation, though in a few localities they are right way up. Beds dip steeply east-northeast and are cut by S1 which dips about 65° east-southeast. The bedding and cleavage

Figure 15

Structural stereonets for the Maiden Point Fm.


MAIDEN POINT Fm.
Grapnel Cove F2 folds
b.
N=16
e.
N=10
Cape Bauld F2 fold
a.
Lighthouse Cove
F1 fold
N=5
N
Colombier Cove
F2 fold
c.
N=139
N=125
Pigeon Cove F2 fold
d.
N=10
f.
N=27
pyrophyllite pod
F3 fold
1km
south tip F2 fold
N=83
g.
N=6
POLE TO BEDDING
POLE TO S2
FOLD AXIS
BEDDING PLANE
S2 PLANE

relationships are constant but there are reversals in facing directions with respect to S1. These reversals suggest that the region has been affected by F1 folds though complete fold sections are not found.

Grapnel Cove

S2 is axial planar to tight, asymmetric mesoscopic F2 folds, 1-3m in wavelength, observed at Grapnel Cove (Plate 39). The structures exposed here are very tight northwesterly-inclined similar folds that have long, normal limbs, and short, overturned limbs that dip east-southeast between 65° and 80°. The fold axes plunge south at about 30° (Fig. 15b, facing p.127) and the folds have Z-shaped asymmetries when viewed down the plunge of the axes. Asymmetries of these folds indicate that this area is part of the western limb of a northwesterly-inclined anticline which closes to the northeast (Fig. 10, facing p.108).

Colombier Cove and Pigeon Cove

In the Colombier Cove area, the hinge zones of F2 folds vary in width from 60m at Pigeon Cove to 350m at Colombier Cove. The large scale F2 fold at Colombier Cove has a long normal limb which dips southeast at between 60° and 80° and an o verturned short limb which dips between 45° and 70° to the east and northeast (Fig. 14b, located in

Plate 39

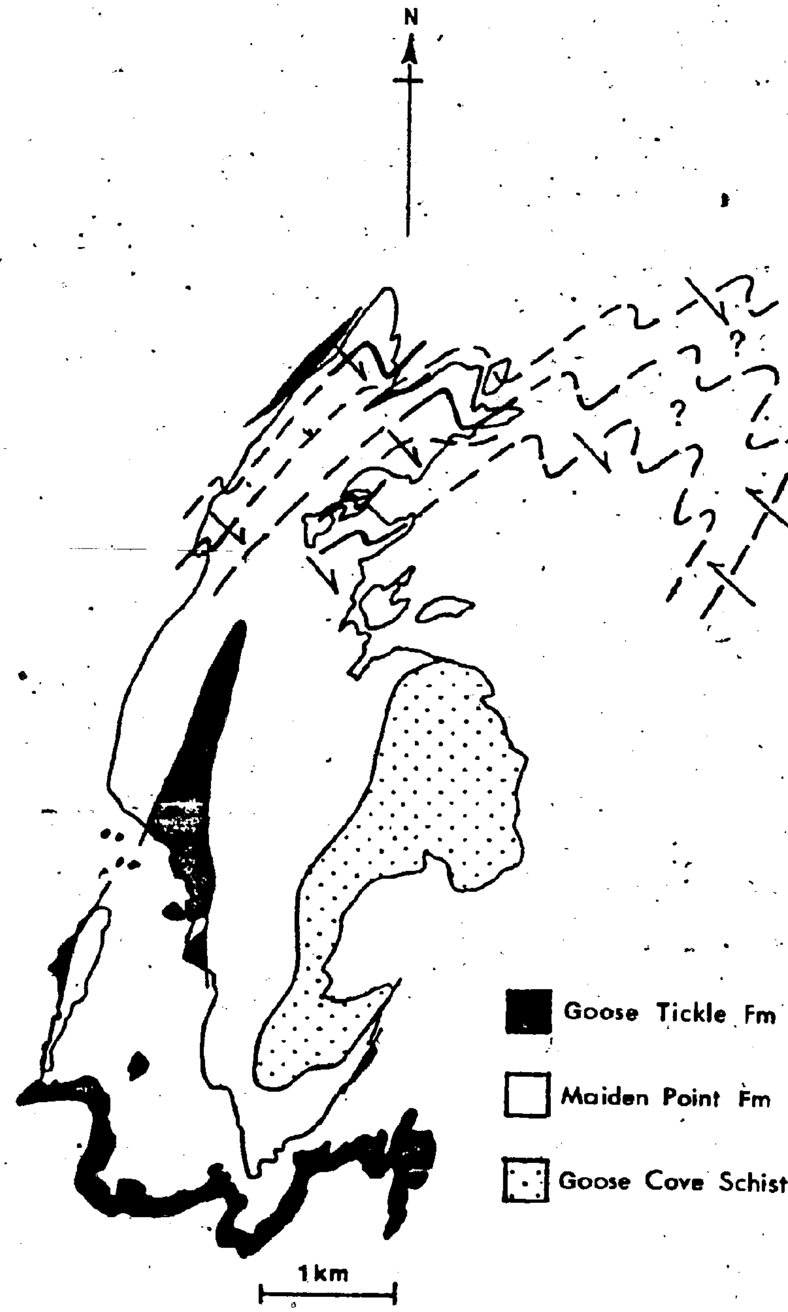
View to south of part of a tight, asymmetric, northwesterly-inclined mesoscopic F2 fold in the Maiden Point sandstones at Grapnel Cove. Long, upright limb is to the right (west), and short, overturned limb is to the left (east). Fold axis plunges south away from camera at about 30° (see Fig. 16b)

back pocket and Fig. 15c, facing p.). The axial plunge of the fold, though variable, is about 45° slightly north of east, and the structure has a Z-shaped asymmetry when viewed down the plunge of the axis. The hinge line of the smaller F2 fold at Pigeon Cove plunges southeast at about 70° (Fig. 15d, facing p.127), and also has a Z-shaped asymmetry when viewed down the plunge of the axis (Fig. 14b back pocket).

These large scale folds may be parasitic to even larger scale regional fold structures. S2 is axial planar to both the Colombier Cove and Pigeon Cove folds and the outcrop pattern clearly indicates that they both lie on the same limb of a larger scale fold structure (Fig. 16). The asymmetry of the Colombier Cove fold indicates that it lies on the northwestern limb of a northeasterly-plunging, northwesterly-inclined synclinal antiform. On the other hand the asymmetry of the Pigeon Cove fold seems to indicate that it forms part of the northwestern limb of a southeasterly-plunging, northwesterly-inclined syncline. However, the change in plunge direction of the axes of both folds explains this apparent inconsistency. Thus it appears that in this area F2 folds, though similar in style, are non-cylindrical.

Figure 16

The geometry of observed F2 folds (drawn in heavy black) and the inferred large scale F2 fold in the Maiden Point Formation


N
Goose Tickle Fm
Maiden Point Fm
Goose Cove Schist
1km

South Pigeon Cove

The sandstones on the south side of Pigeon Cove form a large scale asymmetric open F2 fold structure similar in style to the Colombier Cove fold. The western, normal long limb of this structure dips southeast at about 65° and passes through the gently curving hinge zone into the short overturned eastern limb which dips at about 72° north-northeast. Stereographic projection shows that the axis of this structure, though not seen or measurable in the field, plunges slightly south of east at about 60°. The fold has a Z-shaped asymmetry when viewed down the plunge of the axis.

Cape Bauld

Another large scale F2 fold was mapped around Cape Bauld where the axis also plunges slightly south of east at about 45° (Fig. 15e, facing p.127) and has a Z-shaped symmetry looking down the plunge of the axis. Both the south Pigeon Cove and Cape Bauld structures are east-southeasterly-plunging inclined to almost reclined synclines, and lie in the same domain of the larger scale structure that also includes the Pigeon Cove and Colombier Cove folds.

Grands Galets Point to the south tip of Quirpon Island

Along the southeast coast of Quirpon Island, between Grands Galets Point and the south tip, the effects of differential movement have obscured structural relationships. Because of the paucity of well exposed sandstone compared with more common pillow lavas in this region, only two younging directions were determined and these are overturned to the west. S2 along this coast strikes northeastwards and dips northwest at about 45°. The bedding and cleavage relationships here suggest that the beds form part of the eastern limb of a southwesterly-closing F2 synform located around the south tip of the island. It should be noted that the attitude of S2 alters from an orientation of about 65° east-southeast on the other limb of this structure, between Herring Cove Head and the south tip of Quirpon Island, to a northwesterly dip in this region.

Jacques Cartier Island

The Maiden Point Formation is also exposed in an incomplete large scale fold section on Jacques Cartier Island where it is in structural contact with the Goose Tickle Formation on the west coast. Along the northeast coast beds are overturned to the west and southwest and dip steeply east and northeast at about 60° (Fig. 15f, facing p.127). They are cut by S2 which strikes to the north-northeast, indicating that these lie on the eastern limb of a northwestward-closing synclinal structure. On the west side of the island and west of the large body of pillow lavas, adjacent to the contact with the Goose Tickle Formation, some beds are right way up and dip at about 60° east-southeast. S2 dips steeply eastwards indicating that beds here form the corresponding western limb of the syncline. The fold axis plunges steeply east at about 65° and is a reclined southeast-facing structure, the core of which is occupied by the pillow lava (Fig. 17).

A comparison of the cross section derived from these data differs from an interpretation of the same section given by Jamieson (1979) (Figs. 17 & 18). Jamieson (1979) interprets the Maiden Point Formation on Jacques Cartier Island as an overturned large scale thrust nappe resting above the Goose Tickle Formation on a sub-horizontal basal thrust which extends east to Quirpon Island. (Fig. 18). The author's interpretation is different in that the Maiden Point Formation has been shown to represent a large scale reclined fold, and the thrust dips steeply east. Although Daly's (1903) cross-section of Jacques Cartier Island offers no structural interpretation it is included for comparison (Fig. 19).

Figure 17

Geology of Jacques Cartier Island

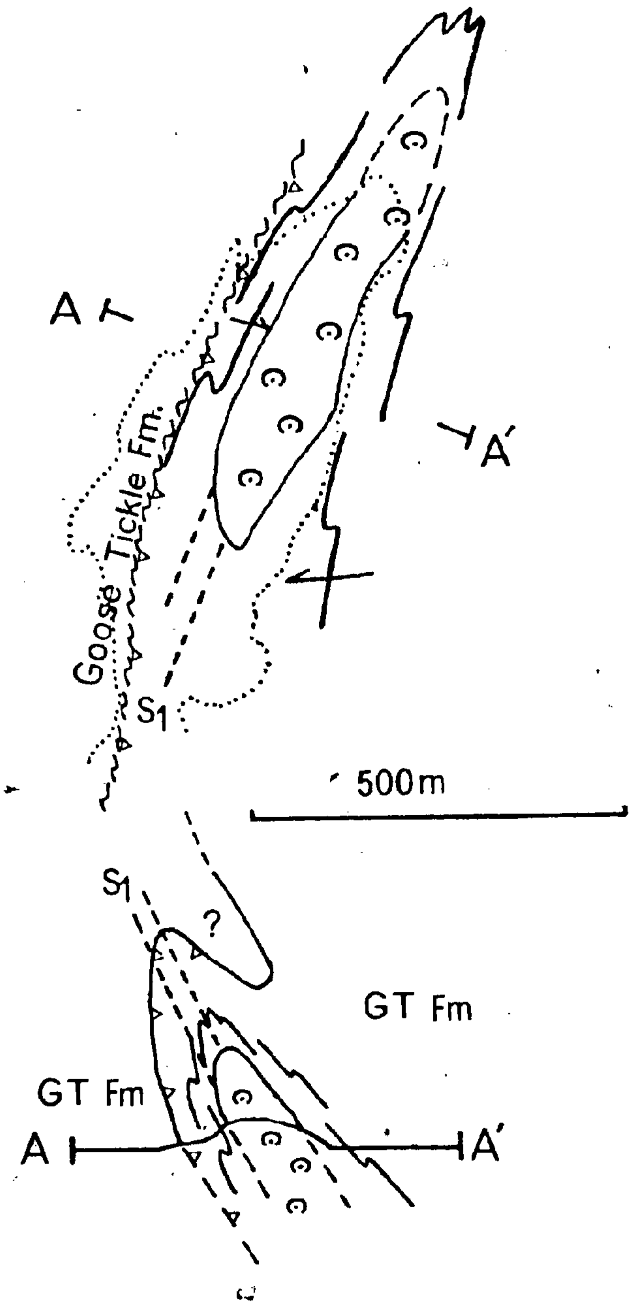

A
A′
Goose Tickle Fm.
S1
500m
S1
?
GT Fm
GT Fm
A
A′

Figure 18

Geology of Jacques Cartier Island, after Jamieson (1979)

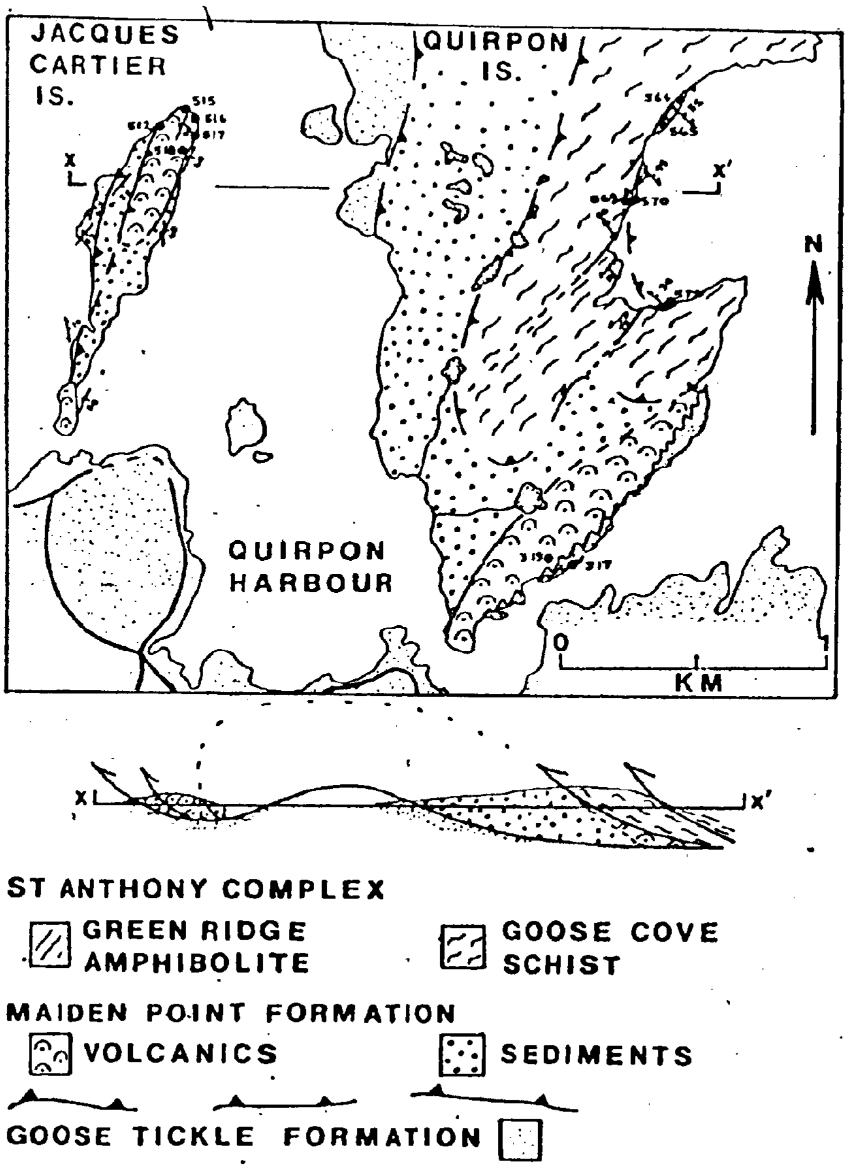
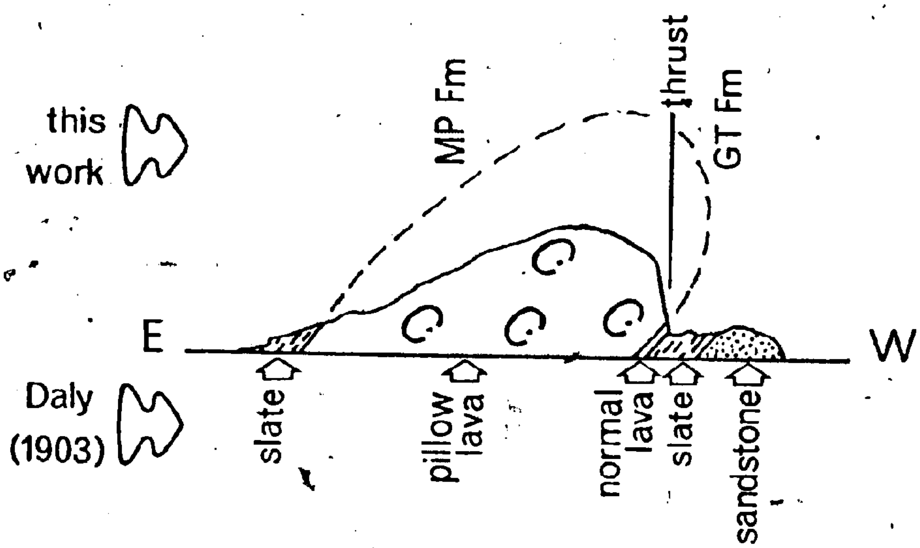

JACQUES
CARTIER
IS.
QUIRPON
IS.
X
X'
N
QUIRPON
HARBOUR
0
KM
X
X'
ST ANTHONY COMPLEX
GREEN RIDGE
AMPHIBOLITE
GOOSE COVE
SCHIST
MAIDEN POINT FORMATION
VOLCANICS
SEDIMENTS
GOOSE TICKLE FORMATION

Figure 19

Cross-section through the north end of Jacques Cartier Island, after Daly (1903)



this work
Daly (1903)
E
W
MP Fm
thrust
GT Fm
slate
pillow lava
normal lava
slate
sandstone

Regional F2 fold geometry

Though there is some degree of variability in fold axis plunge, all the F2 folds described above lie on the northwestern limb of a major east to southeasterly-plunging partially reclined to upright synclinorial structure (Fig. 16, facing p.131).

F3 and S3

F3 folds are observed south of Alun Point in a (ultramafic?) talc/pyrophyllite pod. The folds are very open, small scale and similar in style and affect S2. It is possible that these folds may be related to F2, but because of the effects of the unique lithology in which they are developed they do not carry an axial plane foliation and the style and scale may differ from other F2 folds. Stereographic projection of the folded cleavage reveals that the fold axes plunge due east at 65° which is similar to F2 fold axis plunges (Fig. 15a, facing p.127).

A sparsely developed cleavage (S3) is observed only in the shale matrix lithology of the Degrat Harbour intraformational melange. S3 has the morphology of a fracture cleavage, and is defined by thin (few mm), spaced fracture-like planes separating microlithons which show a straight internal fabric. S3 is not seen as a crenulation cleavage unlike S3 in the Goose Tickle Formation (see above). The orientation of S3 is not known because of inadequate outcrop.

Goose Cove Schist

Actinolite schists

Introduction

The Goose Cove Schist consists predominantly of a monotonously-appearing green actinolite schist which, however, shows evidence of a complex polyphase deformation history. Though no mesoscopic structures are observed the deformation history can be derived from field analysis of small scale structures and from microscopic scale structures identified from thin section analysis. Because of structural complexities a special structural nomenclature has been developed and is given below;

Foliations	porphyroclasts	folds	deformation phase
S1	Act1		1
S2	Act2	F1	2
S3 & S4		F2	3

S1 foliation, S2 foliation and F1 folds

In the greenschists a penetrative schistosity (referred to as S2) is defined by a preferred dimensional orientation of fine-grained synkinematically-grown actinolite grains. It can be shown in thin section that these grains represent neoblasts (referred to as Act 2) derived from recrystallization of considerably coarser-grained, optically strained metamorphic amphiboles occurring now as relict porphyroclasts (referred to as Act 1) which defined a pre-existing planar fabric (referred to as S1). Folds related to S1 are not found. S1 is affected by rare small and microscopic scale tight to isoclinal similar style folds (referred to as F1) which lie in the plane of S2 (see Plates 40 & 41).

S1 is defined as a fine-scale compositional layering formed from alternating layers of leucocratic and melanocratic material and may be the remnant of an early amphibole foliation. The melanocratic layers contain porphyroclasts of metamorphic amphibole (Act 1). S1 has been almost completely transposed into the plane of the regional schistosity, S2, and is preserved only in relict F1 fold hinge domains. F1 folds were identified in the field from one outcrop on Grands Galets Head where a single small scale rootless fold was seen (Plate 40). They have been identified elsewhere on a microscopic scale from thin section analysis.

In summary, an original compositional layering (S1) can be defined. S1 is affected by F1 folds which are thus second generation structures.

Plate 40

Small scale intrafolial F1 fold affecting an earlier foliation, S1. F1 fold lies parallel to the main foliation S2. These folds are extremely rare. Goose Cove Schist, Grands Galets Head

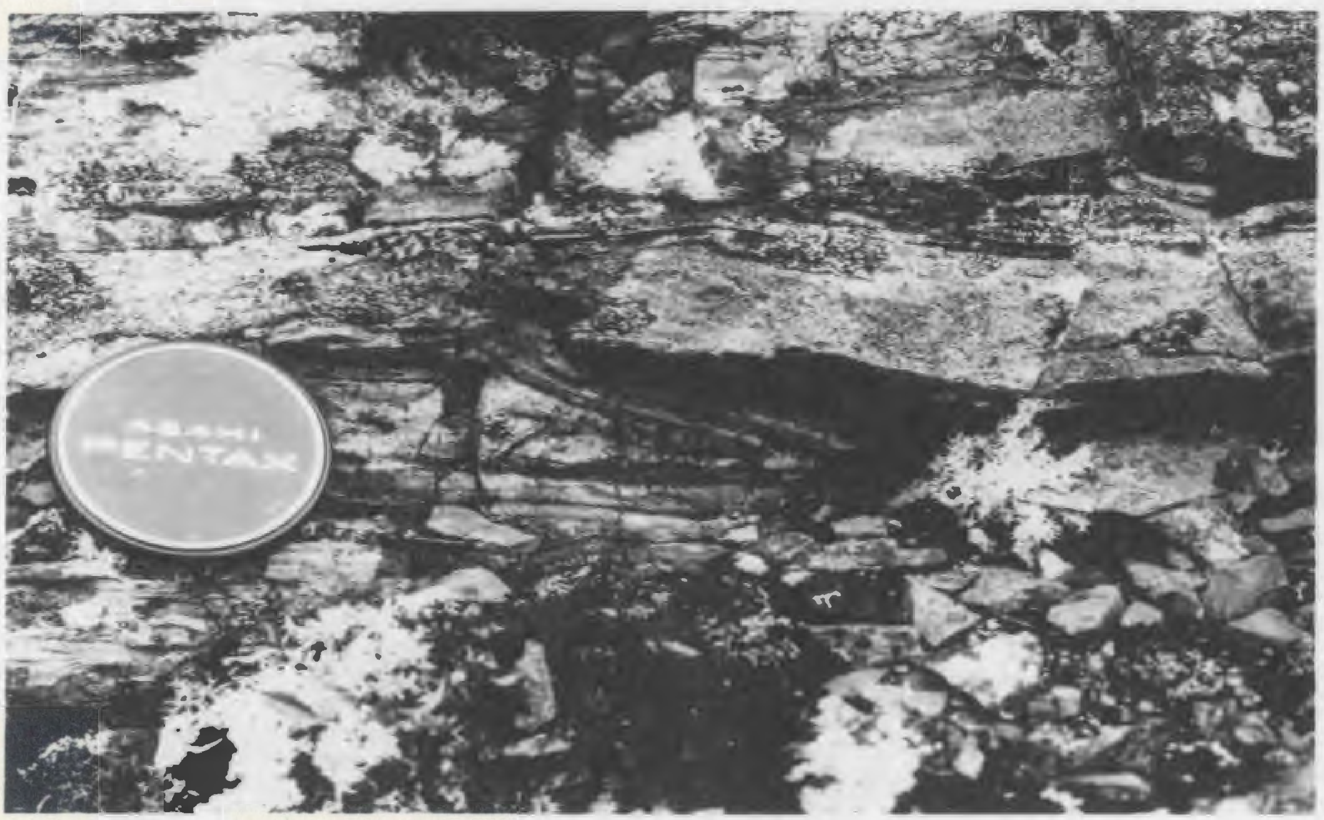
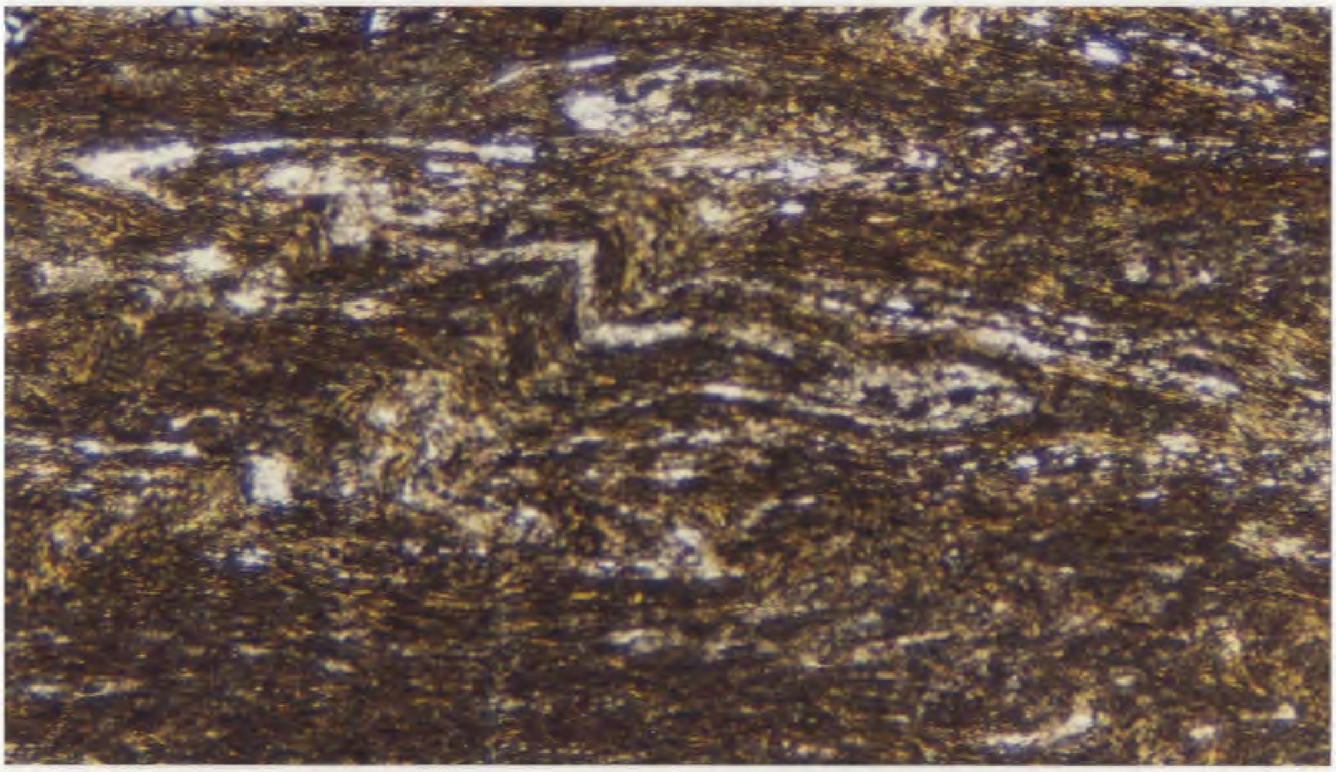

ASAHI
PENTAX

Plate 41

Photomicrograph of isoclinal F1 microfold cut by S3 crenulations in the hinge zone of an F2 fold, Goose Cove Schist (crossed polars). (Specimen #20-8-2)



Crenulation (S3) and mineral lineation (L3)

In both the actinolite schists and metagabbros, S2 is cut by a pervasive but weakly developed non-fissile crenulation S3, which has an associated intersection crenulation lineation, L3a, that is developed on S2 surfaces. S3 is not observed in the field except where L3a is developed on some S2 surfaces. In thin section the microscopic S3 crenulations have very small amplitudes and wavelengths of about 0.5mm with very round hinge zones. The axial traces are commonly at high angles to S2. Large scale folds that can be associated with this crenulation are not seen. In the coarser-grained metagabbros a well developed mineral lineation, L3, is orientated parallel to L3a and is developed by the preferred dimensional orientation of actinolite grains in the S2 plane. Though not seen in association it is likely that L3a and L3 are related but that differences in grain size between the actinolite schists and the metagabbros have influenced the development of different L-fabrics.

F2 folds

S2 is affected by F2 folds which range from 1-10cm in wavelength (Plate 42) and vary morphologically from close to tight. They may be disharmonic in style with no apparent consistency in orientation of axial surfaces and axes or in

Plate 42

Small scale non-symmetric F2 folds which affect the main foliation, S2. The crenulation Ss and the F2 axial planar foliation S4 are not present in this locality. Goose Cove Schist, south Grands Galets Bay

sense of asymmetry, to less common, asymmetric folds with northwesterly-closing hinges. An axial planar chevron-style crenulation with angular hinge domains, S4, is developed in most of the F2 fold hinge zones but is not found elsewhere (Plate 43). An intersection crenulation lineation, L4a, is sometimes associated with S4 and is sub-parallel to the F2 fold axes. When observed together S3 and S4 are always inclined to one another.

It is not clear that S3 is older than S4 because definitive overprinting relationships are not seen. Plate 44 shows the relationship between S3 (small crenulations) and S4 (large crenulations) in a small scale F2 hinge zone. S3 is developed preferentially on one limb (left of S4 axial surface in Plate 44) of the F2 fold and is associated with the S4 crenulations but is not developed on the other. This relationship is found wherever S3 and S4 are associated. In these instances it is likely that S3 and S4 are conjugate kink sets (Hobbs _et al_., 1976) and can thus be related to the same phase of deformation. The strong finely developed schistosity and fine grain size of the actinolite schists make a good medium for the development of conjugate kink sets (Hobbs _et al_., 1976).

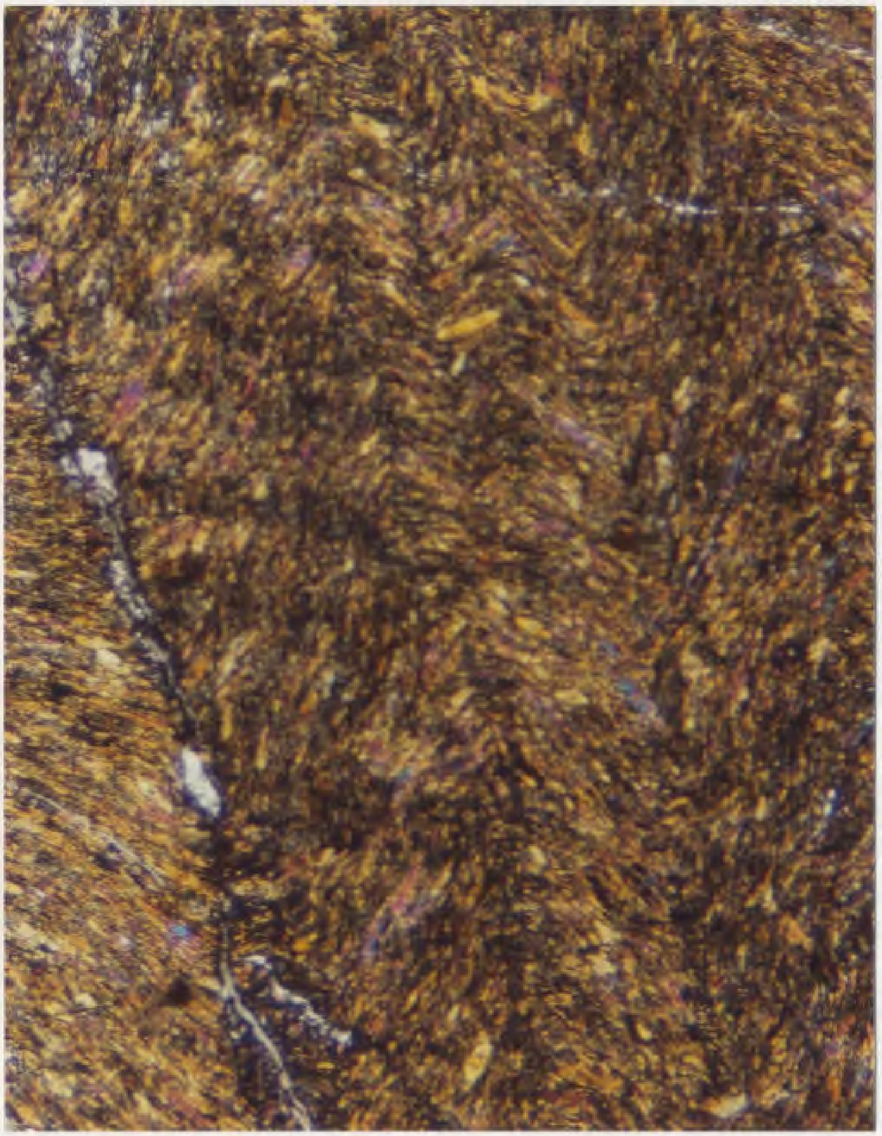
Plate 26a (facing p.) shows a syntectonic almandine garnet porphyroblast that has overprinted an early foliation, probably S1. The garnet has been rotated, as have others which show similar rotational internal fabrics, in an anticlockwise direction in response to localized

Plate 43

Small scale asymmetric F2 folds affecting the main foliation, S2. The axial planar foliation, S4, is discernable in the hinge zones of the folds. Goose Cove Schist, south Grands Galets Bay

Plate 44

Photomicrograph of S3 (smaller amplitude) and S4 (right of picture) conjugate crenulations. S3 is developed as a wavy crenulation of S2, and has characteristically rounded hinges. S3 is always observed at high angles to S2. Goose Cove Schist (crossed polars.) (Specimen #9-8-1)



shear along foliation planes during growth. The rootless isoclinal fold adjacent to the garnet does not appear to be related to garnet growth and rotation because the sense of rotation has produced an S-shaped fabric of the inclusion trail (Plate 26a, facing p.69). It is possible that this may be an F1 fold related to the development of S2. It is not known what relative ages the garnet and the fold have with respect to each other though both are clearly post-S1. The hinge domain of the fold, like the garnet, preserves the original S1 foliation. The fold closure is not continuous along the fold trace indicating that the remainder of the original S1 foliation in the hinge zone has been completely rotated and transposed into the S2 plane.

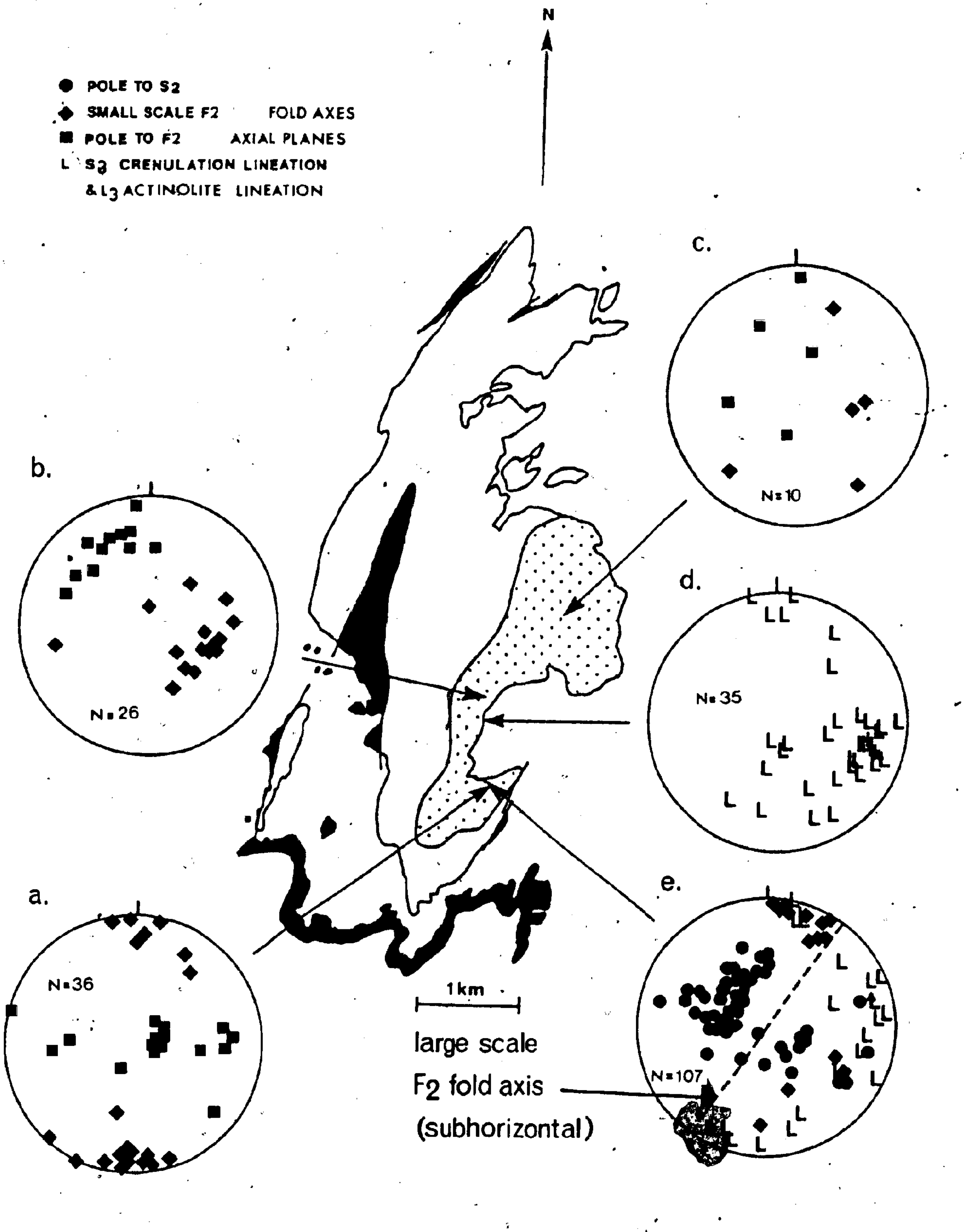
Orientation data

Stereographic examination of the orientations of fold axes and axial planes reveals an overall preferred orientation. F2 fold axes have plunges that lie on a great circle which dips east-southeast at about 55° and contains two point concentrations, one horizontal and one steeply southeast plunging which belong to two different domains within the Goose Cove Schist (Figs. 20a & b). This distribution may indicate that two fold populations representing different generations can be distinguished but this cannot be proven from field evidence. South of Grands

Figure 20

Structural stereonets for the Goose Cove Schist

GOOSE COVE SCHIST



Galets Bay, F2 fold axes are mostly sub-horizontal, trending north-northeast - south-southwest (Fig. 20a). The axial planes of these folds have a very shallow eastward dip at about 15°, though there is considerable variation in the attitudes of some planes (Fig. 20b & c). This coincides well with the similarly orientated L3 mineral lineation in the metagabbros in Grands Galets Cove (Fig. 20d).

L3 has been shown to correlate with L3a, and S3 and S4 have also been shown to be related as possible conjugate kinks. Because St is axial planar to the F2 fold set which affects S2 then this group of structures may correlate with a single phase of deformation. In Grands Galets Bay, fold axes generally plunge southeast at about 50° (Fig. 20b). Axial plane attitudes are variable striking from east-west to north-northeast - south-southwest and with easterly dips between 50° and 70° (Figs. 20a, b & c).

Fold hinges measured on Grands Galets Head have variable plunges which lie on a great circle which dips east-southeast at about 55° (Fig. 20c). No axial plane data are available for these folds.

Though S2 is affected by small scale F2 folds these are not found in conjunction with larger scale structures. However, the data from measured S2 do show the existance of a large scale fold structure in the area south of Grands Galets Bay, west of Whale Point. Here S2 dips towards the northwest becoming sub-horizontal westwards and finally returning to a moderate southeasterly dip characteristic of S2 elsewhere (Fig. 20e). This variation indicates the presence of a large scale open synformal structure in this region with a sub-horizontal to slightly northeastwards-dipping axis that trends northeast-southwest (Fig. 20e, facing p.). This synform also affects the contact between the Goose Cove Schist and the Maiden Point Slice and is therefore of post-emplacement age. There is strong correlation between orientations of small scale F2 fold axes in this region with the orientation of this large scale fold structure (Figs. 20a & e, facing p.150). The asymmetry and sense of overturning of the eastern limb are also similar. On this basis it is concluded that the large scale structure is an F2 fold and that therefore, the small scale F2 folds and their associated structures (S3, S4, L3a, L4a and L3) are of post-emplacement age.

The crenulation lineation, L3a, associated with S3 on S2 surfaces, has a variable plunge concentrating in a great circle that trends north-northeast - south-southwest and dips east-southeast between about 20° and 55° (Figs. 20d & e, facing p.150).

Metagabbros

S2 is observed in the metagabbros as a coarser, non-fissile foliation defined by differentiated layering of coarse-grained hornblende/actinolite porphyroclasts (Act 1) with fine-grained recrystallized actinolite (Act 2) and sericitized plagioclase. A mineral lineation, L3, is associated with S2. The lineation is defined by a preferred dimensional orientation of the Act 1 amphibole porphyroclasts. Sections normal to S2 and L3 show a few crystals of acicular actinolite (Act 2) in association with the large porphyroclasts, but in sections normal to S2 and parallel to L3, acicular grains are more numerous and are seen linking the porphyroclasts in actinolite-rich bands. L3 may also be defined by preferred dimensional and crystallographic alignment of finely crystalline euhedral clinozoisite neoblasts oriented with b-axes parallel to the actinolite lineation, L3 (Plate 45). One section examined carried an indistinct crenulation of S2, which may be equivalent to S3 or S4 in the actinolite schists. This is defined as a preferred dimensional orientation of actinolite neoblasts (Plate 46).

Orientation data

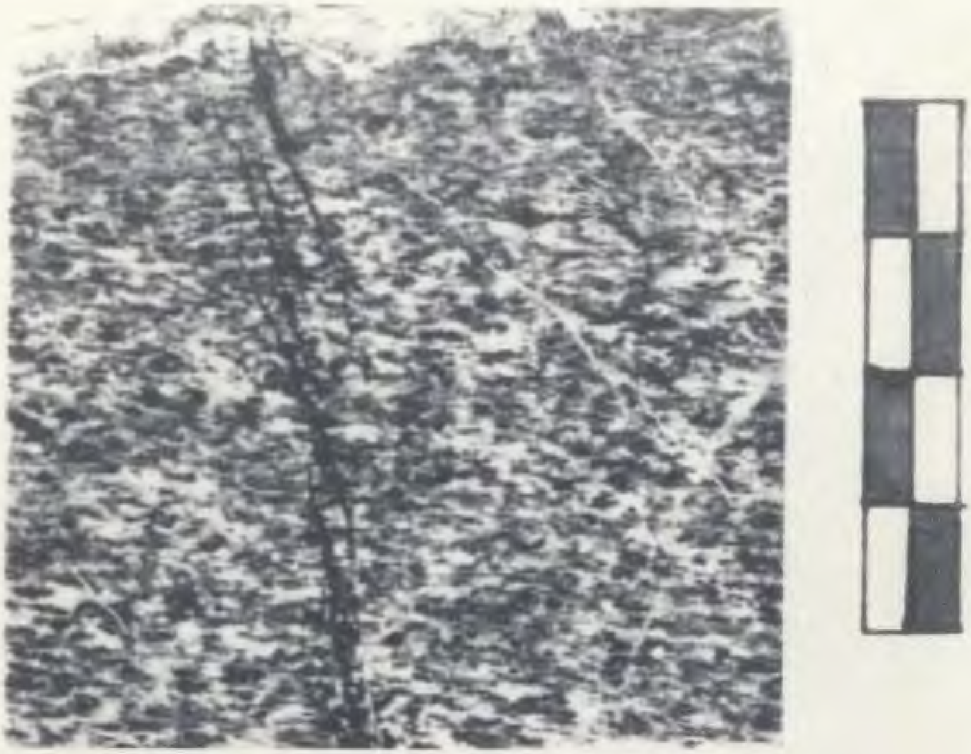
The actinolite mineral lineation, L3, in the metagabbros shows a concentration of points plunging to the southeast (Fig. 20d, facing p.150). Measurements from south of Grands Galets Head also show a concentration to the southeast but with some wide scatter (Fig. 20e, facing p.150). All but two of these measurements were taken from the large metagabbro body exposed along Grands Galets Bay.

Plate 45a

Slab of Goose Cove Schist metagabbro cut normal to the main foliation, S2, and normal to the mineral lineation, L3. S2 is poorly developed in this section. L3 is defined by the preferred dimensional orientation of actinolite neoblasts and the preferred dimensional and crystallographic orientation of clinozoisite. Scale is 4 cm long. (Specimen #31-7-5)

Plate 45b

Same specimen as above but section cut normal to S2 and parallel to L3. S2 well developed in this section. Scale is 4 cm long. (Specimen #31-7-5)



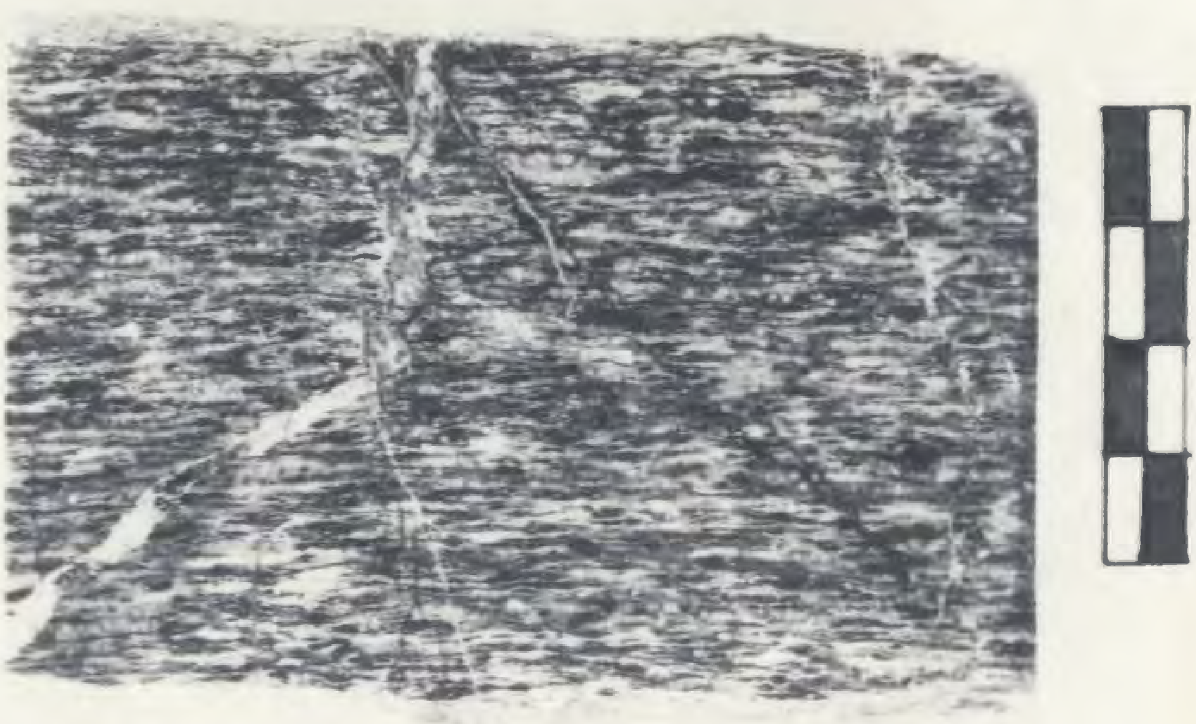
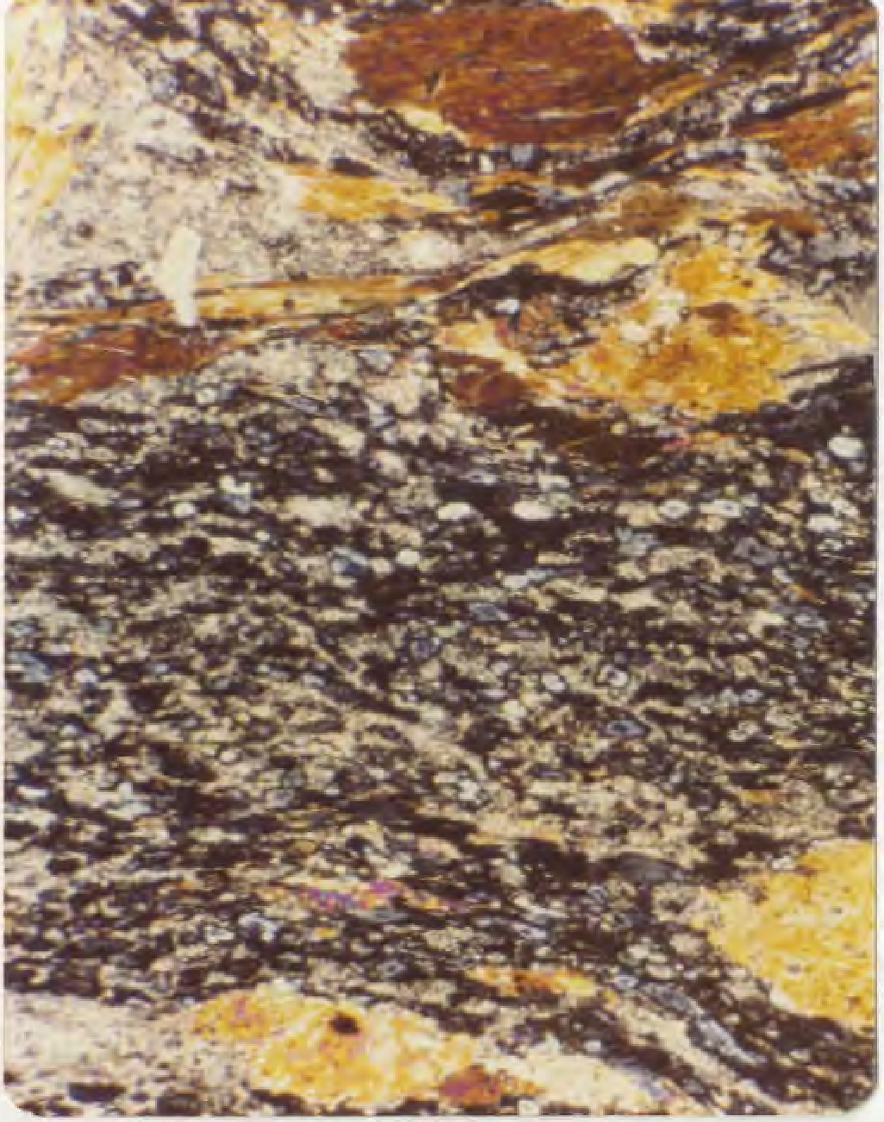


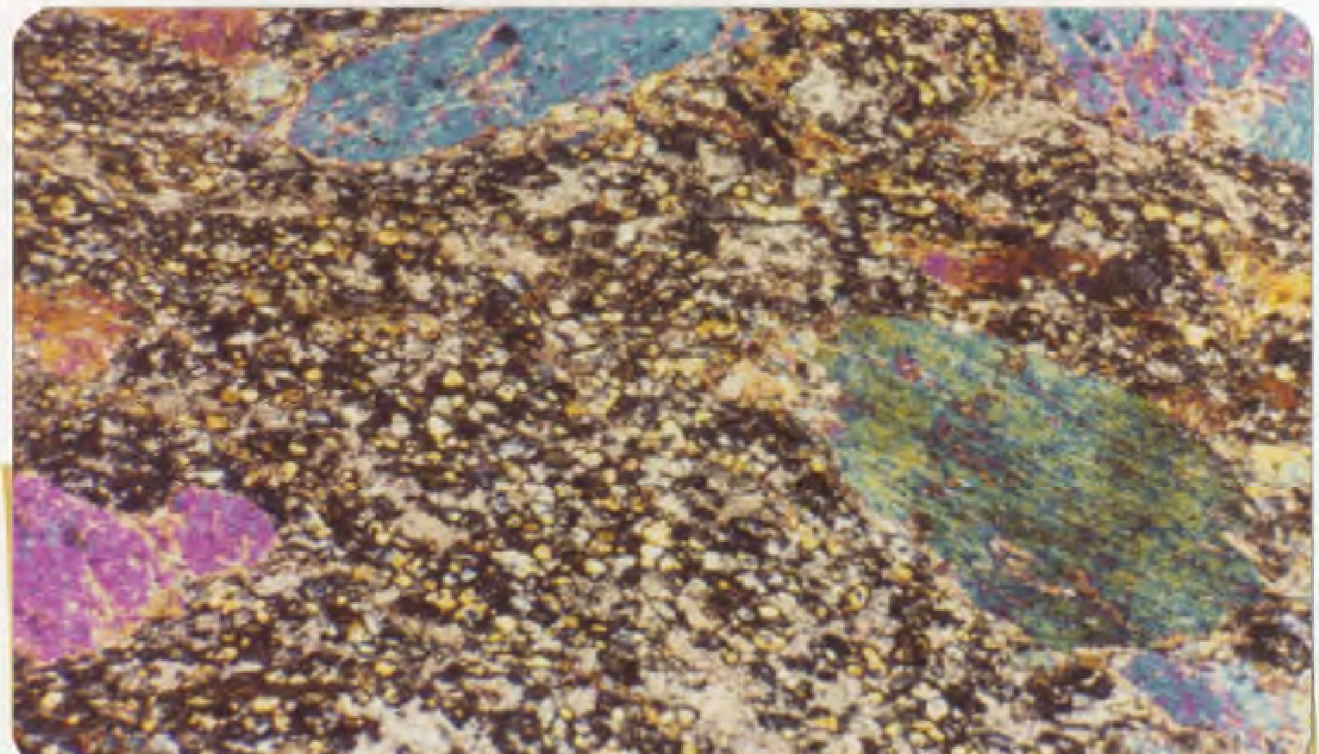
Plate 46a

Photomicrograph of Goose Cove Schist metagabbro cut parallel to L3 and normal to S2 (L-R). Long axes and crystallographic b-axes of clinozoisite neoblasts (blue) lie parallel to the plane of the photograph. Clinozoisite and acicular actinolite (yellow/brown) lie in a fine grained sericitized plagioclase matrix (crossed polars). (Specimen #31-7-2a)

Plate 46b

Photomicrograph of same specimen as above but cut normal to L3 and normal to S2 (left-right). Note clinozoisite has no shape fabric and interference colours are mostly yellow (b-axes normal to plane of photograph). Note also large strained Act1 actinolite porphyroblasts. Act2 links Act1 only in the L3 direction and thus does not appear here (crossed polars) (Specimen #31-7-2b)





A few readings taken from Grands Galets Head show variable orientations with a very minor concentration of points plunging steeply south. S2 has been affected by a sparse and weakly developed crenulation cleavage which may be either S3 or S4.

Metasediments

Protolith heterogeneity is reflected by the development of S2 as an undulose non-fissile cleavage. The earliest fold structures are numerous disharmonic small scale similar style folds which affect the cleavage and are seen in the grey marbles around Grands Galets Head and at Clous Cove. These characteristics are similar to the F2 folds seen in the actinolite schists with which they are tentatively correlated. Unfortunately it was not possible to measure fold orientations. No large or mesoscopic scale structures exist that can be correlated with the folds. Although S3, L3a, L3 and S4 are associated with F2 folds in the actinolite schists they do not occur in the metasediments.

There is no evidence of earlier structures that can be correlated with the early foliation (S1) or F1 folds. This may be a function of eradication of earlier structures by complete transposition of these into the S2 plane and by recrystallization of the calcareous groundmass (see Chapter 3).

CHAPTER 7

METAMORPHISM

Introduction

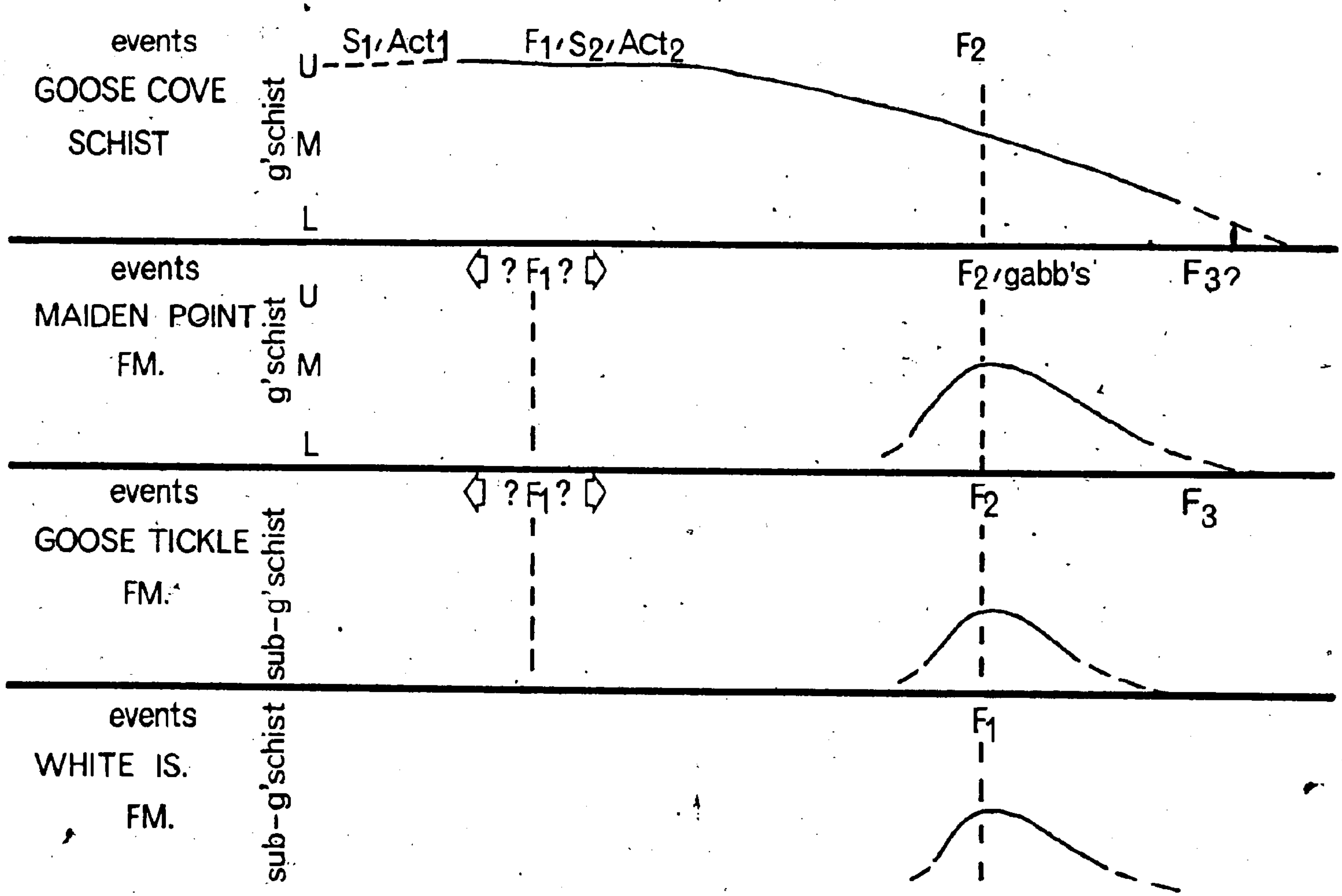
This chapter will deal with the metamorphic histories of each unit and rocks are placed into metamorphic zones according to Winkler's (1974) classification. Because sandstones are of little use in defining metamorphic grade, microstructural evidence from them will be discussed in relation to the metamorphic regime during which these structures developed. The metamorphic history is summarized in Figure 21.

White Islands Formation

Deformation of the sub-arkosic sandstones has caused the recrystallization of smaller quartz (and feldspar?) grains to form a fine-grained matrix with a developing foam texture. The clay minerals have been altered to fine-grained sericite which defines the foliation, S1. Thin, narrowly-spaced parallel layers of sericite restrict grain boundary migration in the matrix quartz. This has caused a poorly developed preferred dimensional orientation of the quartz particularly in the pressure shadows of the sandstone grains where it forms digitate-like structures.

Figure 21

Metamorphic history of the Quirpon area



events
GOOSE COVE
SCHIST
g'schist
U
M
L
S1/Act1
F1/S2/ACt2
F2
events
MAIDEN POINT
FM.
g'schist
U
M
L
? F1 ?
F2/gabb's
F3?
events
GOOSE TICKLE
FM.
sub-g'schist
? F1 ?
F2
F3
events
WHITE IS.
FM.
sub-g'schist
F1

Goose Tickle Formation

The characteristic paragenesis of the pelitic fraction of the greywackes is granoblastic "dirty" calcite with interstitial minor chlorite and relict quartz which is associated with dispersed anhedral crystals of stilpnomelane. The matrix paragenesis of the sandstones is the same but the calcite is anhedral and some of the feldspar grains are altered to fine-grained sericite with minor stilpnomelane.

Stilpnomelane is the index mineral of the assemblage and develops at approximately the same conditions as pyrophyllite and paragonite in other parageneses from other metamorphic terranes (Winkler, 1974) which places the Goose Tickle Formation within the very-low-grade zone of the sub-greenschist facies. This paragenesis appears to have developed post-tectonically because the granoblastic texture of the metamorphic minerals partially overprints the tectonic fabric. During deformation the sheet silicate minerals in the clay fraction were rotated into sub-parallelism to form the main cleavage, S2. S2 is poorly developed in the sandstones as a fracture cleavage, the clay minerals refracting around constituent grains. Pressure solution occurred in the sandstones during deformation and grains are seen in contact associated with thin whispy lenses of opaque material oriented parallel to the foliation.

Maiden Point Formation

Pillow lavas

The characteristic paragenesis of the devitrified matrix of the pillow lavas consists of actinolite, chlorite (largely penninite) and hornblende with rare cores of piemontite, much sphene, clinozoisite (which is usually concentrated in subhedral masses in discrete pockets), carbonate, minor green biotite and rare zoisite. Amygdales are filled with radial and commonly deformed calcite with chlorite. The variolitic structures generally contain variable parageneses of quartz, chlorite, clinozoisite, carbonate and minor sphene. The massive flows have similar parageneses but small phenocrysts of augite are seen altered to actinolite and chlorite. These are commonly rimmed by brown/green/colourless hornblende and actinolite, similar to the altered pyroxenes in the gabbros. These assemblages place the rocks in the low-grade zone (greenschist facies) and the coexistance of metamorphic hornblende with actinolite indicates a temperature around 500°C (Winkler, 1974). The preponderance of sphene is indicative of the high Ti-content of the basalts which is presumably contained in ilmenite. The parageneses do not carry a tectonic fabric that can be related to the main cleavage, S2, and metamorphism is thus assigned a syn- to post-S2/F2 age.

Gabbros

The characteristic mineral assemblage of the gabbros is the association of clinopyroxene and kaersutite but with considerable variation in proportions of each. The amphibole is often rimmed by, or has cores of a deep blue-green amphibole associated with later overgrowths of colourless amphibole. Jamieson (1977) in examining the similar Partridge Point gabbro at St. Anthony found dioritic pockets within kaersutite phenocrysts and thus considered both the amphibole and clinopyroxene to be magmatic in origin.

Metamorphism has caused minor but pervasive alteration of plagioclase (An 28-32) to clinozoisite and sericite, minor calcite and stilpnomelane and small amounts of chlorite. The skeletal opaques (probably ilmenite) have all been replaced by leucoxene/sphene. The amphiboles and clinopyroxene have undergone pervasive but relatively minor alteration to chlorite (penninite). Thus the association clinozoisite + sericite + calcite + chlorite (in plagioclase) and chlorite (in amphiboles and clinopyroxene) characterizes the metamorphic minerals of the gabbros placing them in the low-grade-zone (greenschist facies). The age of metamorphism appears to be syn- to post-tectonic because of the absence of metamorphic fabrics and because field relationships suggest this age of intrusion (see Chapter 3).

Sandstones.

Chlorite and lesser sericite form the major intergranular metamorphic minerals in the sandstones and also define the foliation, S2. Deformation and very low grade metamorphism of the matrix clay minerals were thus apparently contemporaneous. Post-tectonic intrusion of the north Pigeon Point gabbro caused extensive but minor alteration in the adjacent sandstones. Here chlorite and sericite have been recrystallized into delicate radially-grouped needles of stilpnomelane.

Minor pressure solution causes the development of embayed contacts where grains touch. Minor strain in the quartz is associated with this and subgrains may be seen developing at the points of contact.

Goose Cove Schist

Actinolite Schists

Protolithic minerals have been completely altered during metamorphism of the schists. Actinolite is the dominant phase and occurs as early-formed pale green/blue porphyroclasts (Act 1), that commonly show undulose extinction and subgrain formation and contain "dirty" inclusions. Act 1 porphyroclasts are uncommon and are set in a matrix of very fine-grained actinolite (Act 2), which defines a strong S-fabric, S2.

Actinolite is finely interbanded with sericitized plagioclase with clinozoisite/epidote, lesser quartz and chlorite and minor muscovite. Fine-grained opaques with sphene alteration rims are scattered throughout the rock. The long axes of these grains lie within the plane of S1. The actinolite does not appear to be strained in the hinge zones of either the S3 or S4 crenulations but this could be due to late stage recrystallization or crystalline recovery processes.

This mineral assemblage is characteristic of greenschists derived from mafic rocks (Winkler, 1974) and falls in the (albite)-actinolite-chlorite zone in the low temperature part of the low grade zone. The absence of plagioclase (albite?) is probably due to minor late stage retrogression to sericite.

Early growth of syntectonic[1] almandine garnets in minor actinolite/quartz/garnet schist bands overprint S1, and in places contain S-shaped inclusion trails (see Chapter 3). The garnets, which are indicators of increased pressure (Winkler, 1974), may indicate a peak in pressure during greenschist facies metamorphism as S1 was developing, and may be related to increased burial depth during stacking of the allochthonous slices prior to final emplacement.

Metagabbros

Act 1 porphyroclasts are numerous and well developed in the metagabbros. They occur as large (up to 0.5cm) single, and less commonly polycrystalline colourless/pale green crystals. They are characteristically filled with "dusty" inclusions which may be so numerous as to make the porphyroclasts appear brown. Act 2 actinolite is fine grained and defines S2. This second period of actinolite growth is related to dynamic recrystallization of Act 1 during F1 folding. The actinolite is interbanded with sericitized feldspar (plagioclase and microperthite occasionally recognizable), clinozoisite and sphene.

The mineral assemblage is similar to that of the actinolite schists and the metagabbros thus also fall in the same low grade albite-actinolite-chlorite zone of the greenschist facies. Partial sericitization of the feldspars likewise appears to be a late stage retrogressive feature.

A similar metamorphic history to the actinolite schists is suggested by the growth of early Act 1 porphyroclasts followed by later recrystallization to form Act 2 actinolite which defines S2 in both lithologies.

Summary of metamorphic and structural history

A three-phase metamorphic and structural history can be defined in the Goose Cove Schist (Fig. 21, facing p.158). During the first phase (prograde?) greenschist facies conditions caused almost complete recrystallization of an early (original?) mineral assemblage to coarse-grained greenschists (Fig. 21, facing p.158). This is seen from the existence of relict Act 1 porphyroblasts found in both the actinolite schists and metagabbros. This was probably contemporaneous with the development of the earliest recognizable tectonic foliation, S1, now preserved in microscopic and small scale F1 fold hinge domains. During the development of S1, growth of syntectonic almandine garnets was also occurring and may indicate a peak in pressure during stacking of the allochthonous slices prior to final emplacement.

During the second phase S1 was affected by F1 folds and the development of the now dominant S2 fabric was initiated (Fig. 21, facing p.158). This phase coincides with a reduction in grain size from a second period of recrystallization in the actinolite schists and metagabbbros. This caused the eradication of Act 1 and generated the Act 2 actinolite which defines S2. This phase of metamorphism and deformation was probably prolonged and intense because no mesoscopic or large scale pre-S2 structures are seen.

The third phase is characterized by waning greenschist facies metamorphism and the development of a suite of small scale structures which include F2 folds and associated conjugate crenulations (S3 and S4) in the actinolite schists, and a mineral lineation (L3) in the metagabbros, all of which are of post-F2 age (see Chapter 6). This final phase of metamorphism is post-emplacement in age because the F2 folds are correlated with the folded contact between the Goose Cove Schist and Maiden Point Formation (see Chapter 6).

GEOCHEMISTRY

Introduction

Samples of Maiden Point gabbro and Goose Cove Schist metagabbro were analyzed for major and trace element content. The Maiden Point pillow lavas were not sampled because Jamieson (1979) has analyzed these. The purpose of analyzing samples is to determine if there is a genetic link between the Goose Cove metagabbros, the Maiden Point gabbros and the associated pillow lavas. It was expected that there might be no link between the gabbros and the basalts since the former appear to be intruded into the Maiden Point syn-to post-tectonically. Also, no feeder dykes were seen connecting the gabbros to the basalts. Jamieson (1977) however, suggested a link between the gabbros and pillow lavas on petrographic and geochemical evidence though noting field evidence similar to that observed on Quirpon Island.

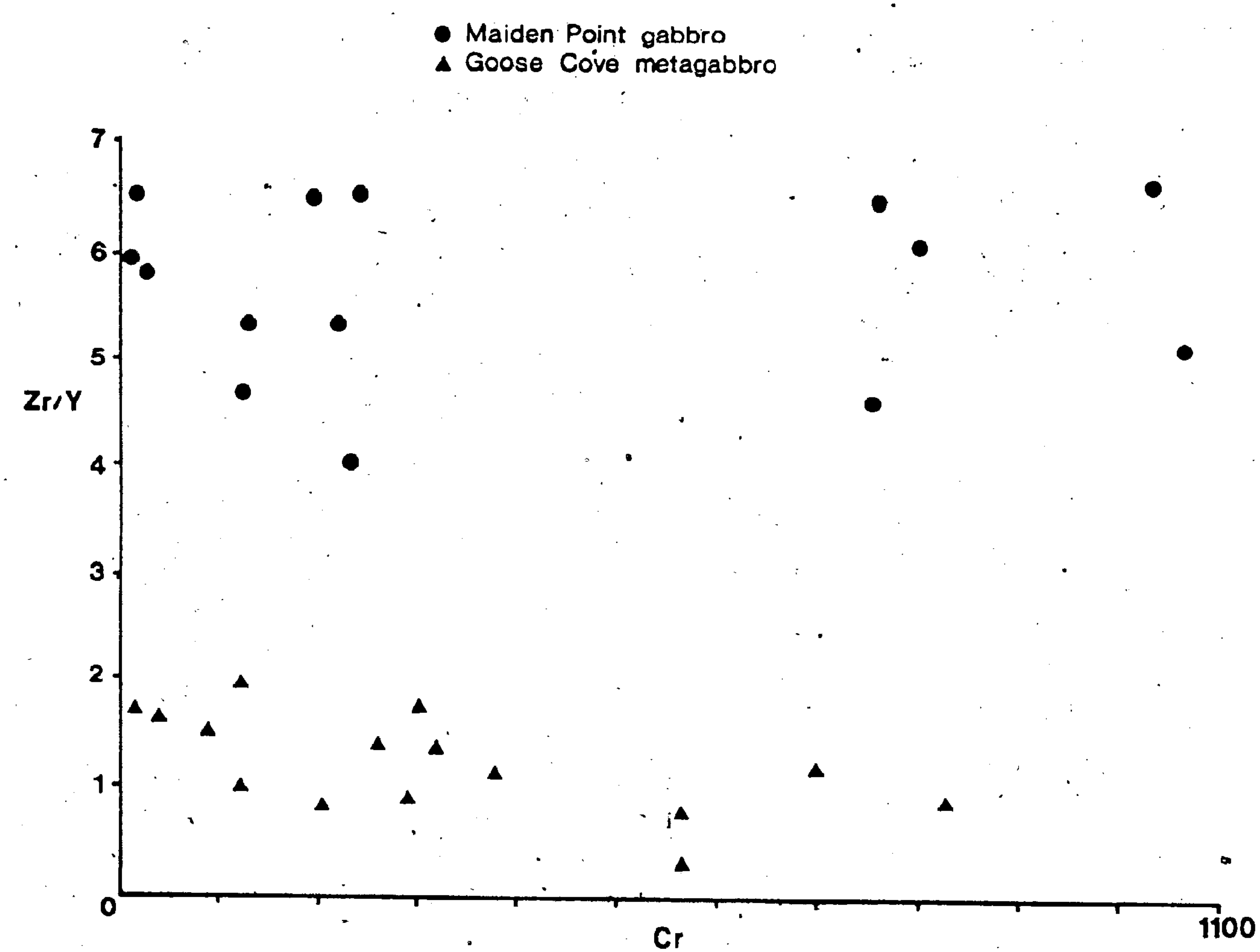
Characteristic associations of major and trace elements can be used to classify volcanic rocks. However, because many of the elements are mobile during metamorphism only those which are known to be immobile (mostly trace elements) are used here (e.g. Winchester & Floyd, 1976; Jenner & Fry, 1980). Several types of plots were used to present the data but only those which show significant trends are presented here.

Discrimination diagrams

It was found that the Zr/Y ratio was constant in both gabbros and metagabbros so this was plotted against elements that varied in abundance. Thus Zr/Y-Cr (Fig. 22) and Zr/Y-V (Fig. 23) show two distinct parallel non-convergent trends. Cr is lost easily during fractionation, and together with V is usually concentrated in an oxide phase (presumably ilmenite in gabbros), thus both show good fractionation trends. TiO2-V was also plotted to show parallel but distinct fractionation trends (Fig. 24). It should be noted that the gabbros are unusually rich in Ti which may be held in the amphiboles (probably kaersutite).

Figure 22

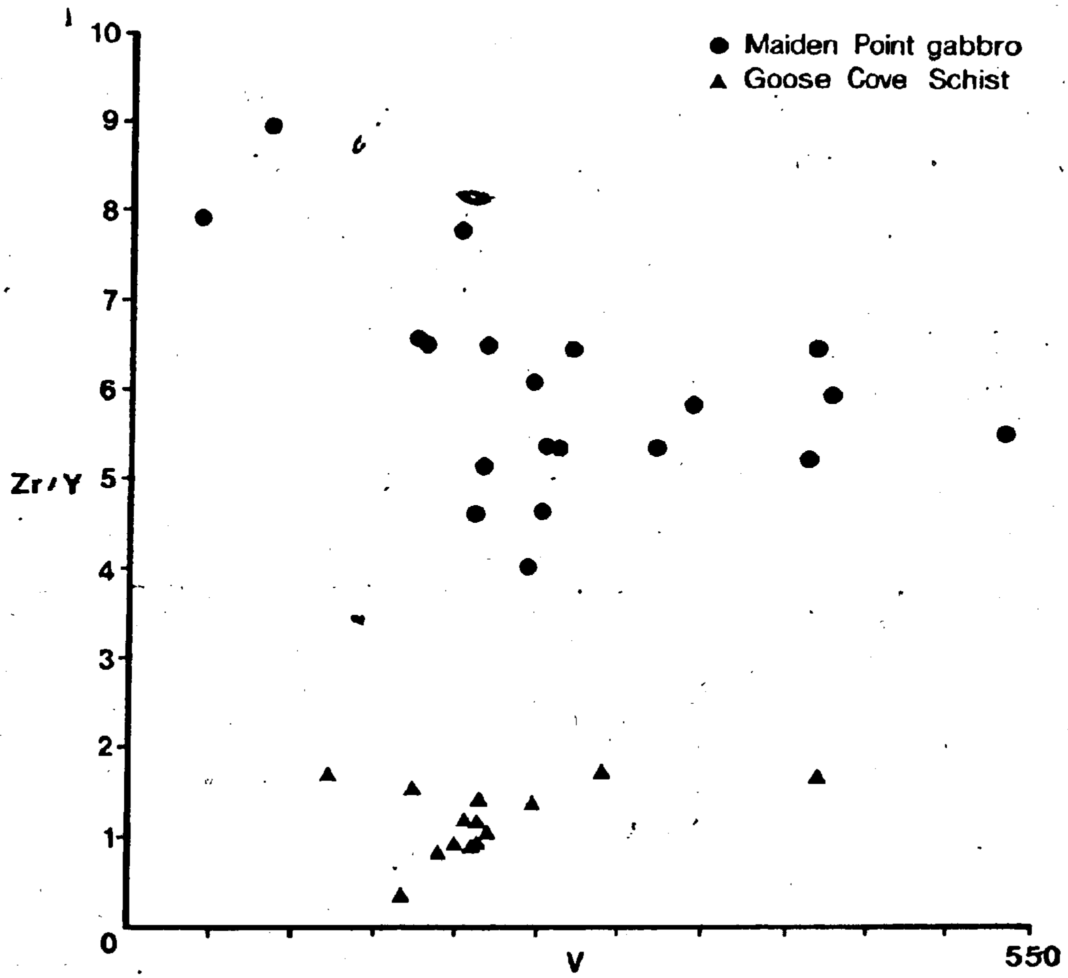
Zr/Y-Cr discrimination diagram



Maiden Point gabbro
Goose Cove metagabbro
Zr/Y
Cr
0
1
2
3
4
5
6
7
1100

Figure 23

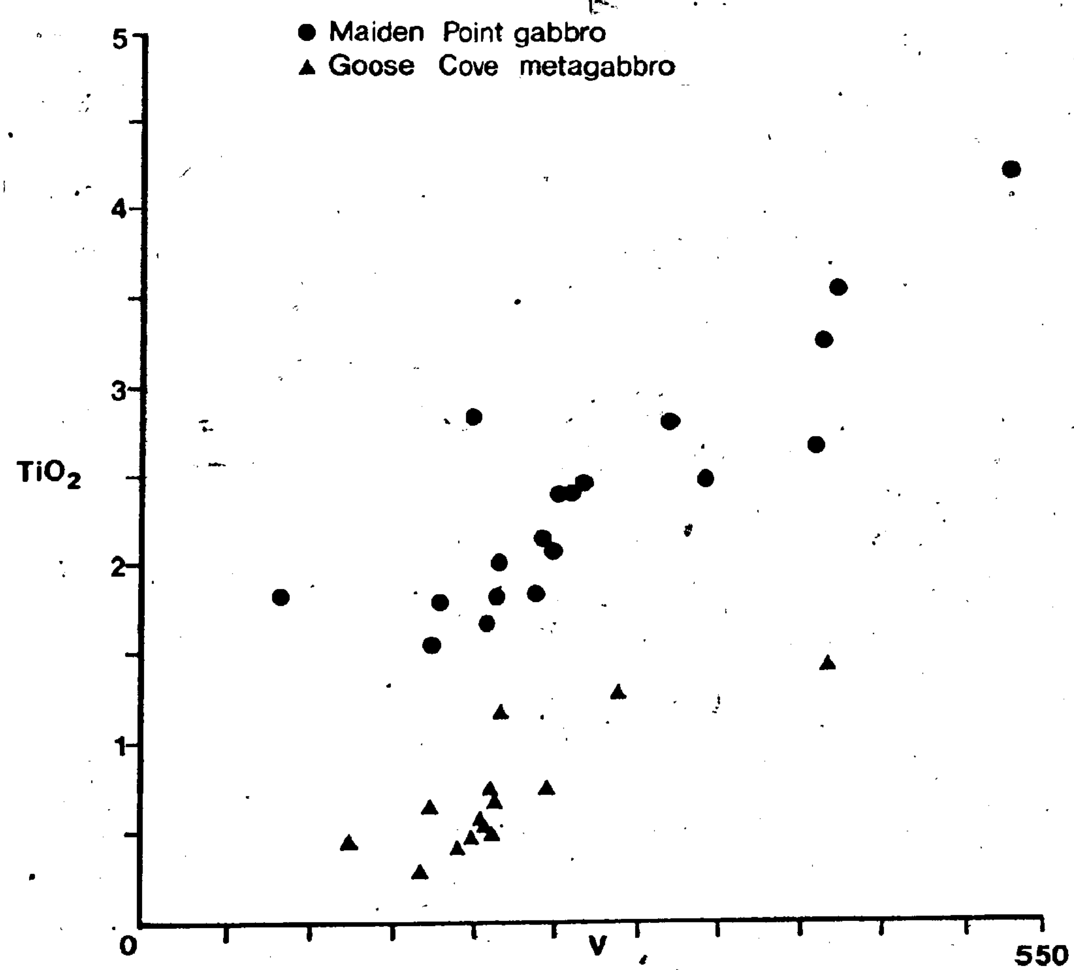
Zr/Y-V discrimination diagram



Maiden Point gabbro
Goose Cove Schist
Zr/Y
V
0
1
2
3
4
5
6
7
8
9
10
550

Figure 24

TiO2-V discrimination diagram



Maiden Point gabbro
Goose Cove metagabbro
TiO2
V
0
1
2
3
4
5
550

Triangular Diagrams

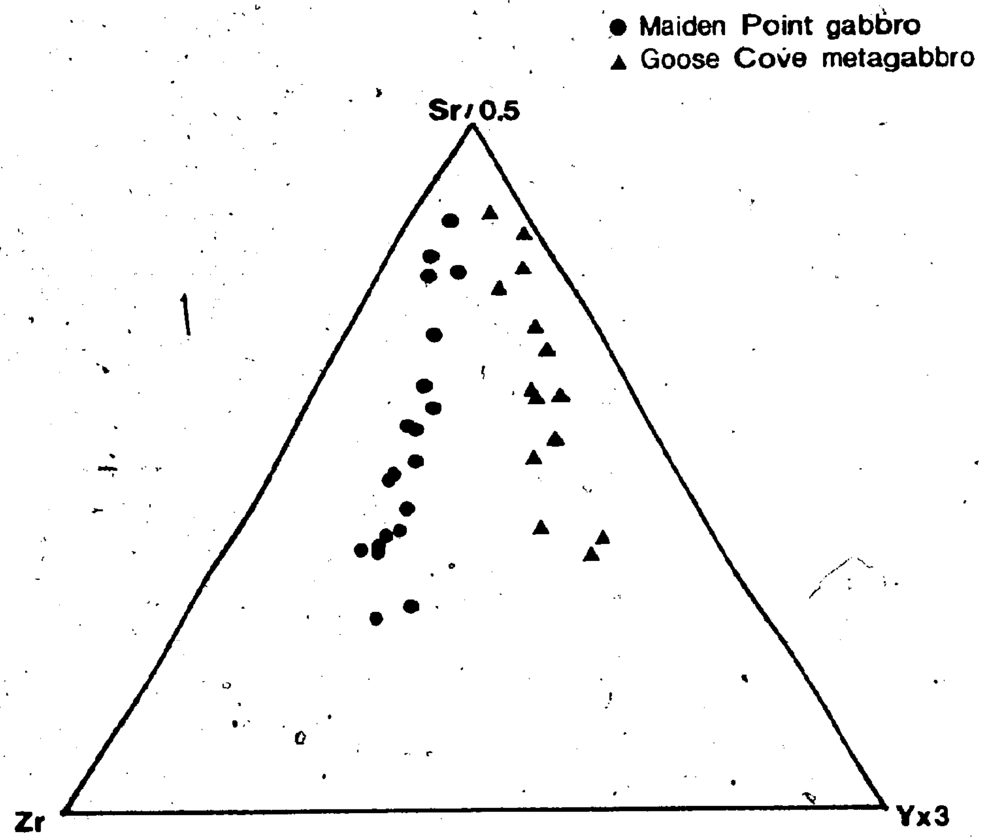
Separate trends are well shown in the Sr/0.5-Zr-YX3 diagram (Fig. 25) where a strong divergence away from Sr is marked. Sr is a fractionation index element being taken up by plagioclase. The data were also plotted on a Ti/100-Zr-YX3 (Fig. 26) diagram. These elements do not show fractionation trends and the points cluster in two distinct groups. The gabbros, except for two points, all fall inside the "within-plate" field whereas the metagabbros fall mostly outside the "low potassium tholeiite" field. An AFM diagram is given in Figure 27 and shows a characteristic calc-alkali trend in the gabbros, but the metagabbros tend to cluster centrally. This latter observation may reflect homogenization of the metagabbros during prolonged metamorphism.

Discussion

The diagrams show distinct and separate fractionation trends and the Ti/100-Zr-YX3 diagram (Fig. 26) place the two groups in separate genetic regimes. It can be concluded from these distinctions that the Maiden Point gabbros and the Goose Cove metagabbros originated from different parent magmas and are not geochemically related.

Figure 25

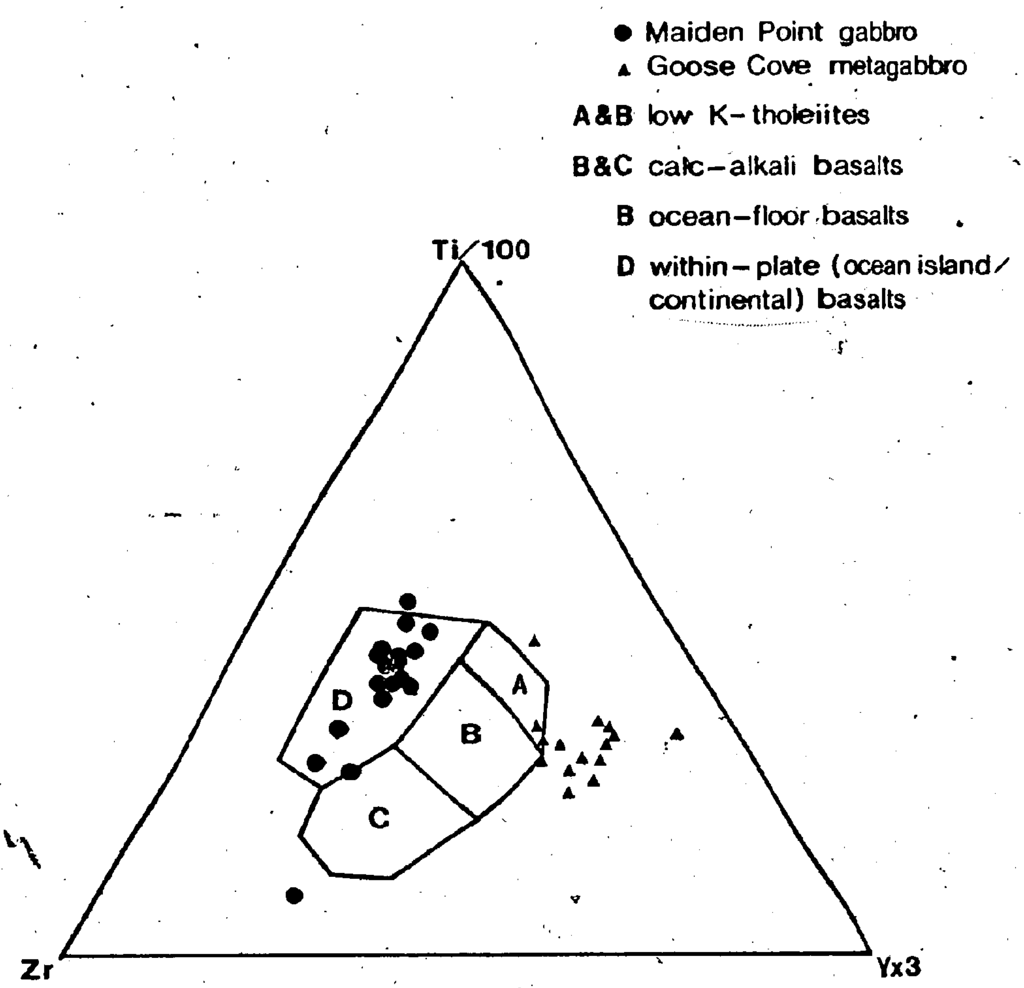
Sr/0.5-Zr-Yx3 triangular diagram



Maiden Point gabbro
Goose Cove metagabbro
Sr/0.5
Zr
Yx3

Figure 26

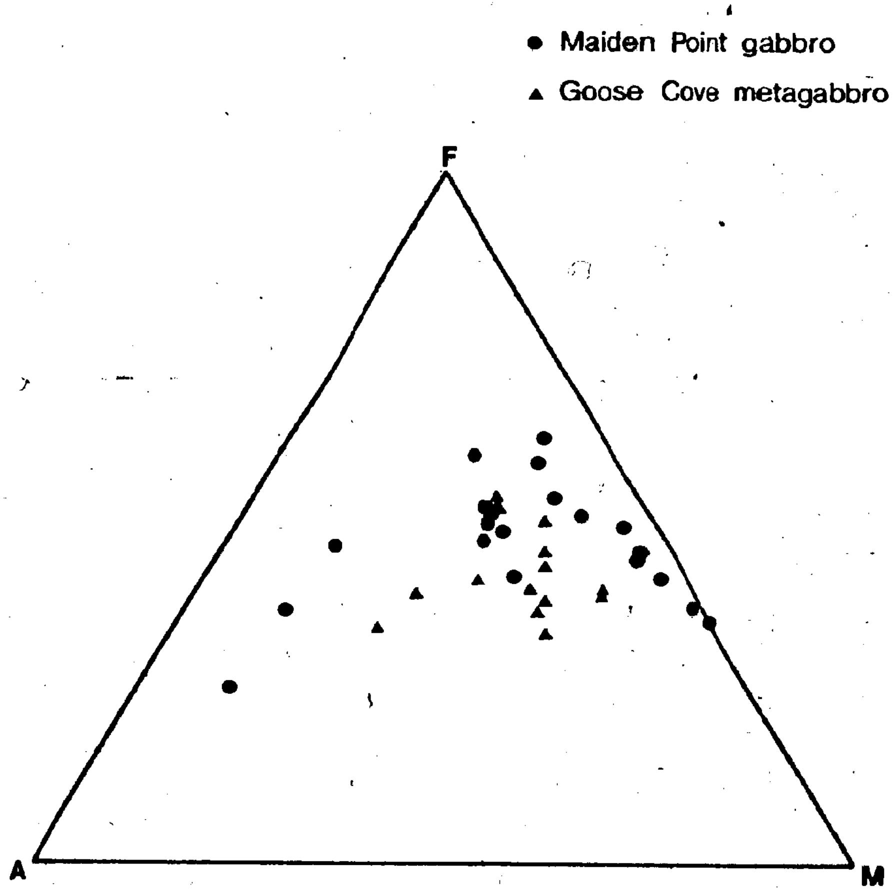
Ti/100-Yx3-Zr triangular diagram



fields after Pearce & Cann (1973)

Figure 27

A-F-M diagram



AFM diagram

CHAPTER 8

STRUCTURAL INTERPRETATION

Introduction

This section deals with the problems of structural correlation within and between the autochthonous and allochthonous units in the Quirpon area. The structure of each unit is treated separately and finally the correlated structures are related to the possible tectonic events that generated them.

The problems of structural correlation have been addressed in detail by Park (1979) and Williams (1970) who warn of the dangers in using fold style as well as orientation patterns as criteria for distinguishing separate generations of structures, and hence deformation events. Overprinting criteria are of fundamental importance when distinguishing relative age sequences of deformation, but even so caution must be exercised when defining deformation periods because structural overprinting can occur during a single distinct period of progressive deformation. Where overprinting criteria are lacking then folds have been grouped together based on style and are referred to as style groups rather than as generations (Williams, 1970). Therefore any correlation between deformational events which are recorded within each of the structural slices in the Quirpon area and which occurred prior to juxtaposition of the slices can be made on the grounds of similarity in structural style and orientation data. Post-emplacement structures should, however, be developed in all structural slices so that overprinting criteria can be used. This may be viewed together with evidence that may indicate a similar contemporaneous metamorphic history.

Deformational histories of individual units

White Islands Formation

Correlation of the structures developed in the White Islands Formation with those developed in the various units on Quirpon Island can only be made on the basis of orientation and structural style since there is no exposed contact with these units. The geometry and orientation of the inferred large scale F1 fold of the White Islands Formation correspond closely to the large scale F2 structures observed in the Goose Tickle and Maiden Point Formations. Since no mesoscopic F1 folds are seen in the White Islands Formation similarities in style cannot be compared. However the axial planar cleavages of both fold sets are similarly orientated, dipping steeply east-southeast though it is more intensely developed in the

White Islands formation. Thus it is possible that deformation in the White Islands Formation is correlative with the same deformation that generated F2 structures on Quirpon Island.

Goose Tickle Formation

F1 folds

The Goose Tickle Formation in the Quirpon area displays internal structural complexities. It has been shown that early tight to isoclinal F1 folds can be inferred on the basis of reversals in younging directions of the rocks with respect to S2 in the Grandmothers Cove inlier (Fig. 11, facing p.113). A refolded F1 fold hinge is almost completely exposed on rock D) of the Islets (Fig. 10, facing p.) and a minor hinge was observed on The Whale (Plate 30, facing p.90) (see Chapter 6). The deformation associated with F1 did not produce a tectonic fabric in the form of an axial plane foliation. Evidence for F1 structures elsewhere on Quirpon Island is ambiguous because all the remaining exposures are adjacent to the Maiden Point Formation where beds have been severely reworked by the effects of thrusting. It is not possible in these localities to distinguish between modified F1 structures or new F2 folds.

F2 folds

There is no evidence of early isoclinal folds within the Goose Tickle Formation exposed on the mainland between Point Vert and Chain Rock and elsewhere in Quirpon harbour which could be correlated with F1 folds on Quirpon Island (Fig. 13, facing p.119). The rocks here are considered to have suffered one phase of deformation producing one set of folds, F2, and an associated axial planar cleavage, S2. The possible reasons for the absence of F1 folds is dealt with later on in this section in the proposed structural model for the Goose Tickle and Maiden Point Formations.

F2 folds in Quirpon harbour and on Quirpon Island show similar fold style and fold geometry. Both fold sets are tight, asymmetric and northwesterly-inclined with variable axial plunges (Fig. 12, facing p.116). Since there is no cross-cutting evidence to suggest that either the mainland F2 set and the Quirpon Island F2 set are of different ages and since both fall into the same style group it is concluded that these folds were generated during the same phase of deformation and are hence time equivalent (see Fig. 7, back pocket).

Maiden Point Formation

Evidence from elsewhere in the Hare Bay allochthon shows that the Maiden Point Formation always lies structurally above the Goose Tickle Formation and below the Goose Cove Schist though not necessarily in contact with either (e.g. Tuke, 1968; Stevens, 1967; Williams and Smyth, 1973). During field mapping the same relationship was assumed to be true on Quirpon Island, where the Maiden Point formation rests above the Goose Tickle Formation from which it is separated by melange zones and below the Goose Cove Schist where the boundary is a mylonite zone.

F1 folds

Earliest deformation in the Maiden Point Formation is suggested by the presence of a single overturned F1 fold structure in Lighthouse Cove. Williams and Smyth (1974) also inferred the presence of early pre-cleavage recumbent folds in the Maiden Point Formation in St. Anthony harbour, and south of Hare Bay, by beds that face downwards along the post-emplacement cleavage. These folds either pre-date or relate to the emplacement of the Maiden Point Slice (Williams and Smyth, 1974). It is possible that the Lighthouse Cove fold is correlative with these.

F2 folds

F2 folds vary in style from a) tight to isoclinal (e.g. Pigeon Cove and Grapnel Cove) to b) large scale similar folds with interlimb angles up to 90° (e.g. Colombier Cove, Cape Bauld and south Pigeon Cove, Figs. 15c, d & e, facing p.127). The two style groups are clearly defined on the basis of fold morphology but both carry the same axial planar cleavage, S2. Both maintain consistent asymmetries and overprinting between them is not observed. They are thus considered to belong to the same fold generation.

All the structures observed between south Pigeon Cove and Cape Bauld, and along the west coast as far south as the Islets, belong to the F2 generation of folds. Fold asymmetries are consistent with the interpretation that they lie on the northwestern limb of a major steeply east to southeasterly-plunging and south facing fold structure (Fig. 16, facing p.131). If this is the case then the Maiden Point Formation on Quirpon Island represents one limb of a large F2 structure. The eastern limb of this structure is located somewhere to the east of Quirpon Island (Fig. 20, facing p.150). It is important to note that the Maiden Point sandstones in the western and northern part of Quirpon Island young consistently to the east and that the formation is structurally overturned against the western edge of the Goose Tickle Formation in the Grandmother's Cove inlier. This relationship is reversed on Jacques Cartier Island where the sandstones young to the west and are overturned against the Goose Tickle Formation.

This raises questions about the structural relationship between the other inliers of the Goose Tickle Formation and the Maiden Point Formation. The Maiden Point sandstones at The Whale and at Whale Point young away from the thrust contacts with the Goose Tickle inliers. However, at Lighthouse Cove the Maiden Point sandstones young towards the southeast on both sides of the Goose Tickle inlier. The inliers cannot therefore be explained as simple anticlinal structures within the Maiden Point Formation and appear to be related to Maiden Point structure.

Maiden Point/Goose Tickle Formations F1 fold correlations

Pre-cleavage deformation causing F1 folding can be demonstrated in the Maiden Point Formation on Quirpon Island and elsewhere in the Hare Bay allochthon (Williams and Smyth, 1974). Pre-cleavage deformation causing the development of isoclinal F1 folds has also been demonstrated for the Goose Tickle Formation in the Grandmothers Cove inlier and on rock D. of the Islets.

Smyth (1973) and Williams and Smyth (1974) correlate westward-facing recumbent folds in the Maiden Point

Formation south of Hare Bay with pre- to syn-emplacement deformation of the allochthon. It is believed that the Goose Tickle and Maiden Point Formation F1 folds, and the refolded folds in the Goose Tickle/Maiden Point Formation interformational melange zones are structurally equivalent to these, though fold style and geometry cannot be compared.

Maiden Point/Goose Tickle Formation F2 fold correlations

Between the south tip of Quirpon Island and Herring Cove Head the Maiden Point sandstones are overturned and young to the southwest towards the contact with the Goose Tickle Formation in the Grandmother's Cove inlier. S2 cleavage in this region strikes north-northwest whilst bedding strikes to the northwest. The younging and bedding and cleavage relationships in the Maiden Point Formation F2 folds together with F2 fold asymmetries in the Goose Tickle Formation inlier in Grandmother's Cove, suggest that the Goose Tickle Formation and the Maiden Point Formation in this area form a large scale F2 antiformal structure related to folding of the tectonic contacts between the two formations. However when the axial trace of this inferred structure is constructed along strike through the Maiden Point Formation the expected reversals in younging direction and changes in fold symmetry to the southeast of the axis south of Pigeon Cove are not observed. Instead, the consistency of Maiden Point F2 fold asymmetries and younging directions in the northern part of Quirpon Island suggests that the Goose Tickle and Maiden Point rocks form the northwest limb of a large scale F2 synclinal fold which closes to the northeast and which has an axial trace considerably to the east of Quirpon Island (Fig. 16, facing p.131).

The discrepant F2 fold symmetries in the Maiden Point and Goose Tickle Formations in the southern part of Quirpon Island can be explained if the Grandmother's Cove inlier is interpreted as a detached sliver of Goose Tickle Formation now resting in the limb of a major Maiden Point F2 structure. Further, the distribution of all remaining Goose Tickle Formation exposures within the Maiden Point Formation can also be explained as detached slivers.

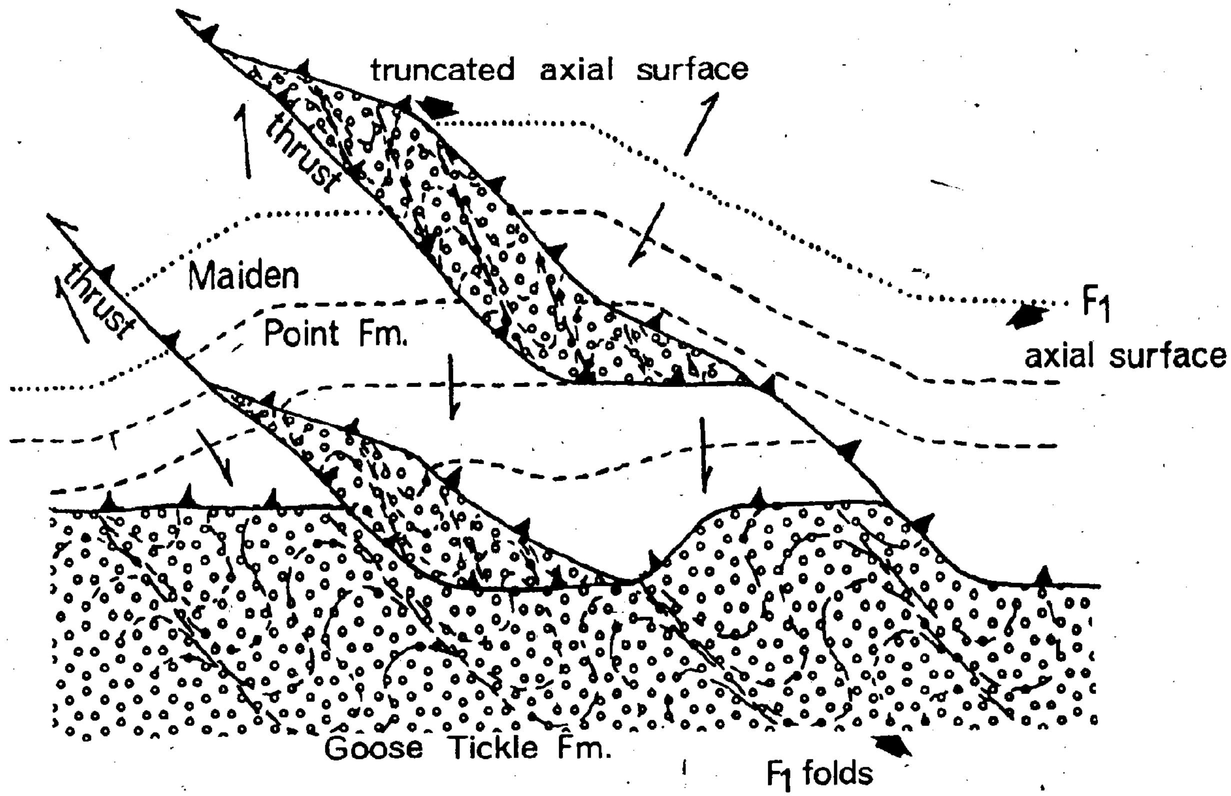
A structural model for the Goose Tickle and Maiden Point Formations

If the exposures of the Goose Tickle Formation on Quirpon Island and Jacques Cartier Island are interpreted as allochthonous slivers resting in the Maiden Point Formation then structural discrepancies between the two Formations can be explained. The Goose Tickle Formation is thus interpreted to have been incorporated into the Maiden Point Formation, following or in relation to the development of F1 folds during emplacement of the Allochthon, along a series of rising thrust faults that root in, or below, the allochthonous domain of the Goose Tickle Formation (Fig. 28). Large scale F1 recumbent nappe structures were probably being developed during thrusting of the Maiden Point Formation resulting in an inverted stratigraphy above the Goose Tickle Formation on Quirpon Island. The nature of thrusting retains a consistently overturned Maiden Point Formation stratigraphy (Fig. 28). It is likely that the Degrat Harbour melange and the similar melange found along strike around the south tip of Quirpon Island were generated during thrusting because they contain blocks of exotic rocks tectonically derived from lithologies (possibly the Northwest Arm Formation) not exposed in the Quirpon area (see Chapter 5).

The slivers of rocks of Goose Tickle Formation were transported upwards into the thrust slice of rocks of the

Figure 28

Diagrammatic cross-section to show how the Goose Tickle Formation has been structurally incorporated in to the Maiden Point Formation as discrete slivers along rising thrusts. Note the truncation of a major Maiden Point recumbent F1 fold by the thrusts. F1 folds shown for the Goose Tickle and Maiden Point Formations are digrammatic and do not intend to imply differing fold style or orientation



truncated axial surface
thrust
thrust
Maiden
Point Fm.
F_1
axial surface
Goose Tickle Fm.
F_1 folds

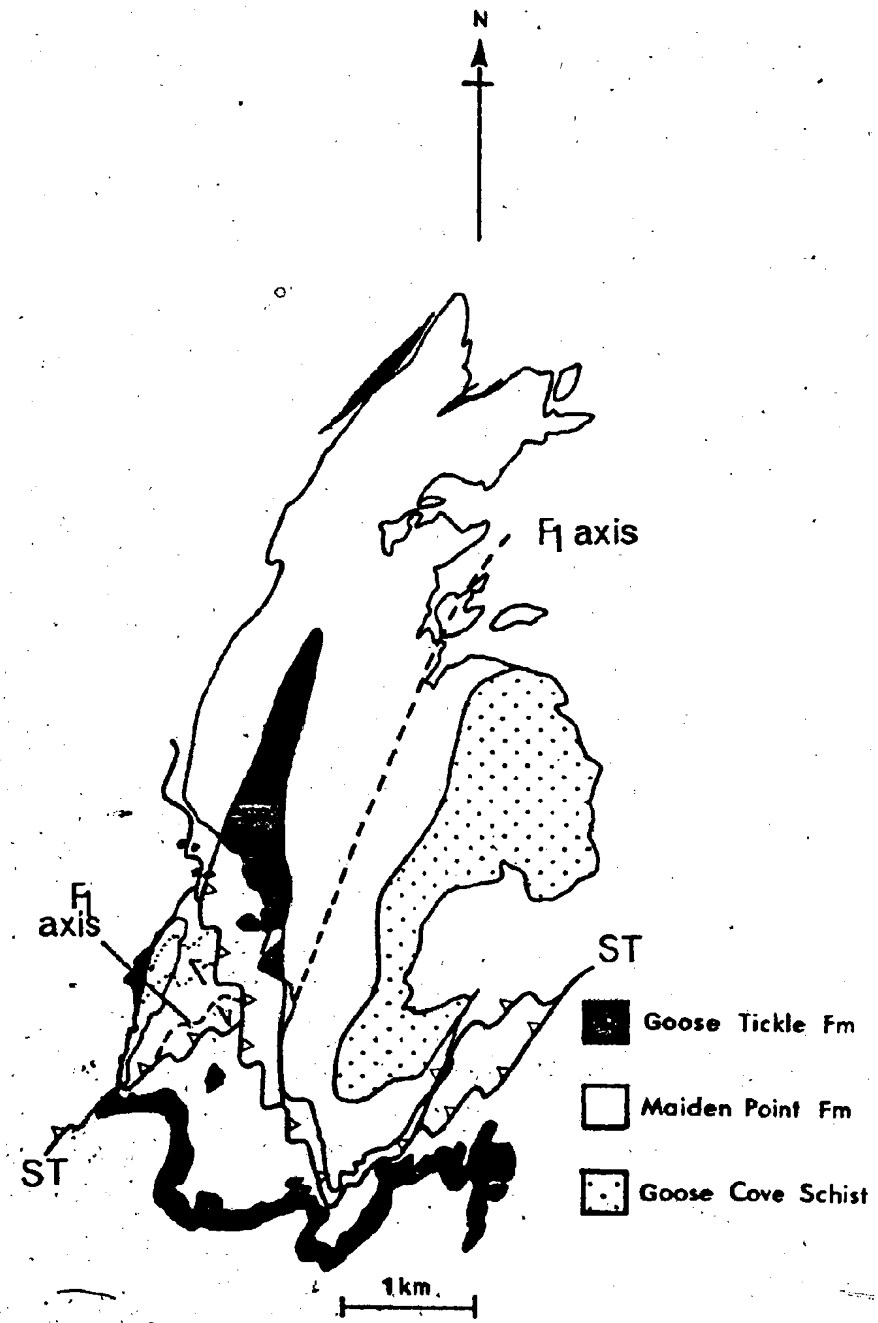
Maiden Point Formation along imbricate thrusts. The two slivers of Goose Tickle Formation which are now exposed in the Grandmother's Cove inlier and on the west side of Jacques Cartier Island together "sandwiched" a dismembered sliver of Maiden Point Formation lithology now exposed on Jacques Cartier Island (Fig. 29). The thrusts also cut obliquely through and offset a major Maiden Point Formation F1 fold axis (Figs. 28 & 29). The offsetting of a major Maiden Point Formation F1 fold axis by imbricate thrusts explains otherwise ambiguous reversals in younging directions within the Formation (Fig. 29). Together the imbricated Maiden Point and Goose Tickle Formations were thrusted above structurally lower autochthonous rocks of the Goose Tickle Formation that were not affected by F1 folds (now exposed along the shore of Quirpon harbour) (Figs. 28 & 29). Subsequent deformation folded the thrust contacts generating the F2 folds in the Maiden Point Formation and in the allochthonous and autochthonous rocks of the Goose Tickle Formation.

Geometry of folded thrusts

It will be noted that F2 folds do not appear to affect the two large bodies of Maiden Point pillow lava located between west Pigeon Cove and Dumenil Point and south Pigeon Cove and Merchant island, respectively. This can be explained if these two bodies were orientated coaxially

Figure 29

The geometry of folded thrusts on Quirpon Island. Note the large scale Maiden Point F1 fold axis is truncated against the Grandmother's Cove inlier of Goose Tickle Formation rocks. This explains facing reversals in the Maiden Point Formation with respect to S2.
ST= sole thrust (interpreted)

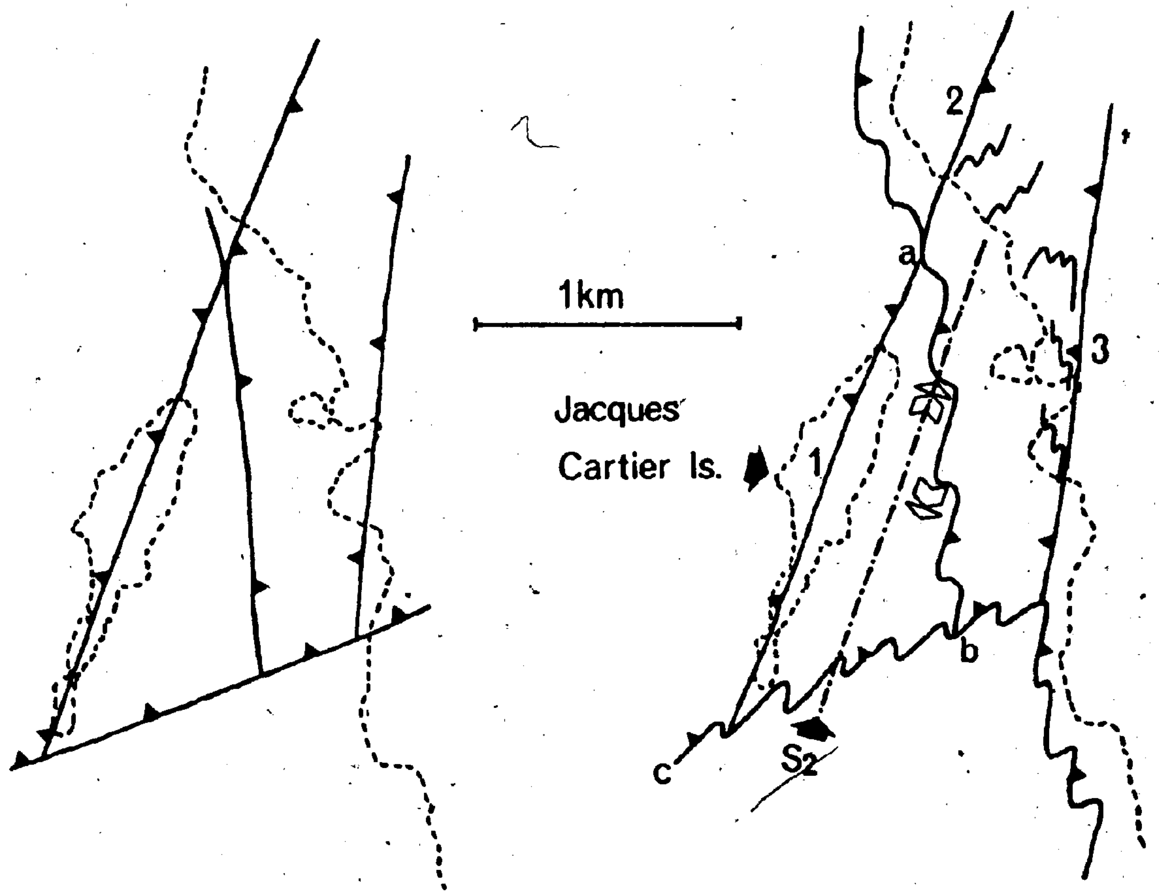

N
F1 axis
F1 axis
ST
ST
Goose Tickle Fm
Maiden Point Fm
Goose Cove Schist
1 km.

with respect to F2 fold axes prior to F2 folding. In other areas, pillow lava outcrops that were originally oblique to F2 axes on the south tip of Quirpon Island have been rotated and incorporated into the large scale F2 structure in this region. Similar reasoning explains the apparently unaffected contacts between the Goose Tickle Formation inliers and the Maiden Point Formation because these inliers may also have been orientated coaxially to F2 fold axes (Fig. 30 explains the geometry of this situation diagrammatically). Goose Tickle/Maiden Point Formation contacts that were originally oblique to F2 fold axes are not exposed, but are interpreted in this model to occur within Quirpon harbour. The anomalous fold asymmetries along the Goose Tickle/Maiden Point Formation contact on the southwest side of the Grandmother's Cove inlier can be explained by the initial orientation of this thrust oblique to subsequent F2 fold axes and is shown in Figure 30.
From this interpretation arise two important structural implications;

i) the Maiden Point and Goose Tickle Formations were brought together along a major basal thrust, probably during F1 folding related to emplacement. This thrust is not exposed, but is inferred to lie within Quirpon harbour separating the autochthonous domain of the Goose Tickle Formation from the allochthonous Goose Tickle and Maiden Point Formations (Figs. 28 & 29, facing pages 185 & 187).

Figure 30

Diagram to illustrate how the geometry of folded thrust contacts between the Goose Tickle and Maiden Point Formations can be explained by assuming obliquity of some thrusts to F2 fold axes prior to F2 folding. thrusts 1, 2 and 3 are unaffected by F2 folds because they were oriented coaxially to F2 fold axes. Thrust section A-B though located on the western limb of an antiformal structure shows S-shaped F2 fold asymmetries. Thrust section B-C, located on the same limb of this structure, shows Z-shaped F2 fold asymmetries. Arrows show the relative direction of displacement during F2 folding



1km
Jacques Cartier Is.
1
2
3
a
b
c
S_2

ii) the Maiden Point Formation F1 folds are developed on a very large scale because reversals in younging directions in the F2 folds are not commonly observed, except in Lighthouse Cove and on the south tip of Quirpon Island. Conversely, Goose Tickle Formation F1 folds are developed on a relatively small scale, because reversals in younging directions are observed within mesoscopic F2 folds in the Grandmother's Cove inlier, and on rock D. of the Islets (Fig. 10, facing p.108).

Maiden Point and Goose Tickle Formation F2 folds are very tight on the west side of Quirpon Island and along the central shore of Quirpon harbour. Folding becomes more open to the east where, on the eastern limb of the large scale F2 fold that affects the Maiden Point Formation intraformational melange zone on the south tip of Quirpon Island, lithologies dip steeply northwest. Brief visual reconnaissance of the autochthonous domain of the Goose Tickle Formation east of Quirpon harbour reveals that F2 folds become progressively more and more open to the east and at Cobbler island beds have a gentle eastward dip.

Humber Arm correlations

Because the Goose Tickle Formation on Quirpon Island has been shown to be allochthonous then a correlation, based on structural position and tectonic lithofacies, can be made between the transported Goose Tickle Formation and the tectono-stratigraphically equivalent Blow-Me-Down Brook Formation of the upper Curling Group of the Humber Arm Supergroup of the Bay of Islands (see Stevens, 1970) (Fig. 31, located in back pocket). The Humber Arm Supergroup includes the transported rocks of the Curling and Cow Head Groups. Stevens (1970) states that the type section for the Curling Group is in the Humber Arm Allochthon, and divides it into three units;

i) a lower quartzo-feldspathic flysch, which includes the Summerside, Meadows and Irishtown Formations of the Humber Arm Allochthon, and the Maiden Point and Canada Head Formations of the Hare Bay Allochthon,

ii) a carbonate flysch, which includes the Cooks Brook, Middle Arm Point and Green Point Formations and the Cooks limestone of the Humber Arm Allochthon and the Northwest Arm Formation of the Hare Bay Allochthon, and

iii) an easterly-derived upper quartzo-feldspathic flysch, which includes the Blow-Me-Down Brook Formation (which is correlated with the allochthonous Goose Tickle Formation on Quirpon Island)

The correlation is made because,

a) the upper quartzo-feldspathic flysch and the Goose Tickle Formation are easterly-derived.

b) the upper quartzo-feldspathic flysch and the Goose Tickle Formation are transported.

However the transported Goose Tickle Formation (upper quartzo-feldspathic flysch) on Quirpon Island lies structurally below the Maiden Point Formation, which is part of the lower quartzo-feldspathic flysch (Stevens, 1970) (Fig. 31, back pocket).

Goose Cove Schist

The Goose Cove Schist has been shown to have suffered at least three phases of deformation on Quirpon Island. These are briefly;

i) development of an early coarse-grained (Act1) amphibolite foliation (S1),

ii) folding of S1 by F1 folds which are associated with an axial planar foliation, S2. S2 was generated from the dynamic recrystallization of Act1 to Act2, and

iii) deformation of F1/S2 by F2 folds and associated conjugate crenulations S3 and S4, and the development of a mineral lineation (L3) in the metagabbros.

Goose Cove Schist/Maiden Point/ Goose Tickle Formations structural correlations

It is not possible to make correlations between early structures in the Goose Cove Schist and structures observed in lower slices and in the autochthonous domain in the Quirpon area because of the absence of overprinting criteria and because the rocks are in different slices. Importantly, the Goose Cove Schist preserves no large scale structures prior to F2. This is probably due to intense reworking of earlier structures during the prolonged period of greenschist facies metamorphism during which the S2 foliation was generated, and also to the lack of continuous marker horizons which might enable fold surfaces to be traced.

However, the final phase of folding (F2) affects the Goose Cove Schist/Maiden Point Formation contact. This is well demonstrated in the region between Whale Point and Alun Point on the south tip of Quirpon Island where folding of the contact can be related to the gently northeast-plunging large scale F2 synform (Fig. 20e, facing p.150). The outcrop pattern of the fold surface parallels the F2 fold which affects the intraformational melange zone in the Maiden Point Formation in this area, clearly indicating that both Maiden Point Formation F2 and Goose Cove Schist F2 folds belong to the same generation and are of post-emplacement age.

It is not possible to correlate earlier structures in the Goose Cove Schist with others in the lower allochthonous slices using fold style criteria because mesoscopic and large scale structures in the Goose Cove Schist are absent. However, the Maiden Point gabbros and pillow lavas suffered pervasive post-emplacement lower greenschist facies metamorphism subsequent to Maiden Point F2 folding whilst the Goose Cove Schist was undergoing waning greenschist facies metamorphism during generation of F2 folds. The implication is, therefore, that lower greenschist facies metamorphism in the Maiden Point Formation can be related to waning greenschist facies metamorphism in the juxtaposed Goose Cove Schist which would provide a logical heat source for metamorphism.

Fold preservation in the allochthonous rocks

It is important to emphasize that although large scale isoclinal emplacement folds can be inferred in the Goose Tickle and Maiden Point Formations (F1), no large scale folds are observed in the Goose Cove Schist that can be related to emplacement of the allochthon. This may reflect, as already mentioned, the effect of severe reworking of such possible folds or the effects of a different deformation mechanism. It could also reflect a temporal migration of strain towards lower structural levels, the higher nappes and duplexes starting to ride passively on the lower units which were undergoing large scale recumbent folding directly above the sole thrust.

CHAPTER 9

GEOPHYSICAL ANOMALIES

Introduction

The conflict between interpretations of crustal structures based solely on surface geology can be resolved by using geophysical information which is able to add a third dimension, depth of section, to these interpretations. Gravity data for the Quirpon area are taken from the 1:1,000,000 scale Bouguer Anomaly Map of the Appalachian Orogen (Haworth, _et al_., 1980) since regional gravity data are unavailable. Regional magnetic maps for the Quirpon area are available at one inch to four miles (GSC map 7366G) and one inch to one mile (GSC maps 4415G & 4418G).

Magnetic anomalies

A magnetic anomaly is defined as the deviation from the normal value of the earth's magnetic field. Measurements of the magnetic properties of Newfoundland ophiolites and pillow lavas yield arithmetic means of $3.5-50.10^{-3}$ Am^{-1} (Haworth & Miller, 1982). Haworth & Miller (1982) found the scatter in measured values so large that they adopted a constant value of 25.10 Am^{-1} for ultramafic rocks to determine the general shapes and attitudes of the bodies.

Previous work in the Hare Bay area

Chlorite schists have been interpreted offshore east of the White Islands by Haworth _et al_. (1976a), and their presence has been confirmed from a drill core sample from east of Hare Bay (Haworth _et al_., 1976b) (Fig. 32). Haworth _et al_. (1976b) correlated these rocks with the chlorite schists of the Fleur dė Lys equivalents exposed on Groais Island (Kennedy _et al_., 1973). They tentatively asserted that the linear north-south trending magnetic "ridges" east of Hare Bay might be interpreted as indicating antiforms with cores of chlorite schist either exposed or in subsurface close to the seafloor similar to the structures observed on Groais Island by Kennedy _et al_. (1973). Haworth _et al_. (1976a&b) also considered this linear anomaly, which extends from east of Belle Isle to Hare Bay, to be part of the northern extension of the Fleur de Lys equivalent and not part of the Goose Cove Schist.

Core 17 (Fig. 32) recovered foliated sandstone and quartz conglomerate of the Fleur de Lys type (Haworth _et al_., 1976b). Noting that Precambrian clastics crop out on Belle Isle and on the White Islands (the White Islands Formation, this work) they interpreted a western

Figure 32

Geology of the continental shelf off southeastern Labrador (after Haworth et al., 1976a).

HARE BAY ALLOCHTHON

HO - Hadrynian to middle Ordovician greywackes, volcanics, greenschists, amphibolites and peridotite

WESTERN AUTOCHTHONOUS ROCKS

CO - upper Cambrian to middle Ordovician limestone, dolomite and, in upper part, slate of the Goose Tickle Formation

HC - Upper Hadrynian and Cambrian quartzite, slate, limestone, dolomite, minor basalt (Bateau, Lighthouse Cove, Bradore, Forteau and Hawke Bay Formations)

H - Grenville gneiss, schist, granite and gabbro

EASTERN AUTOCHTHONOUS ROCKS

OS - Ordovician/Silurian volcanics and minor sediments

HCF - psammitic and pelitic schists, basic schists, and amphibolites

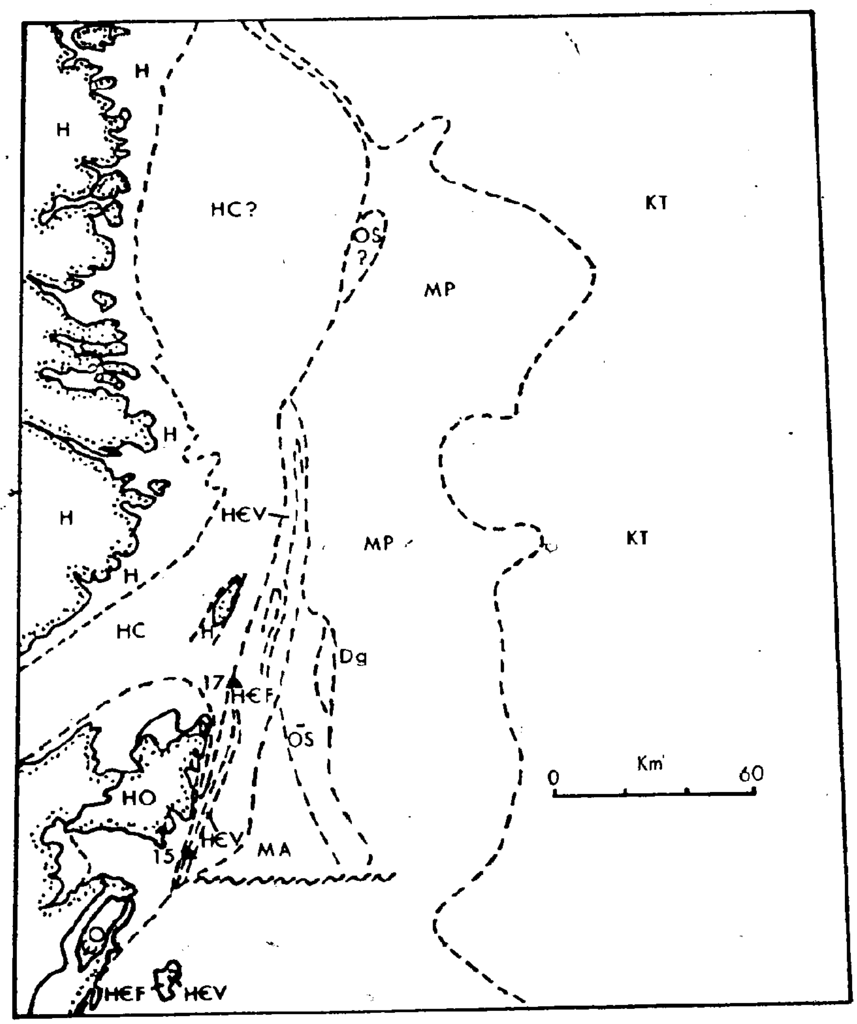
HCV - chlorite schist, metagabbro and peridotite

MA and MP - Mississippian conglomerates, sandstones and shales

KT - Cretaceous/Tertiary sandstone, siltstone and mudstone

OTHER SYMBOLS

Black triangles and numbers refer to core locations referred to in text


H
H
HC?
OS
?
MP
KT
H
H
HЄV
MP
KT
H
HC
H
Dg
17
HЄF
OS
0
Km
60
HO
15
HЄV
MA
HЄF
HЄV

(structural?) boundary of the Fleur de Lys to lie east of the exposures of the Bateau Formation on Belle Isle and west of core 17 and the chlorite schists (Fig. 32). To the east the Fleur de Lys is in contact with Mississippian and Pennsylvanian units. Igneous rocks retrieved further east have been correlated with the Cape St. John Group which lies at the eastern edge of the Fleur de Lys Supergroup on the Burlington Peninsula (Haworth _et al._, 1976a&b).

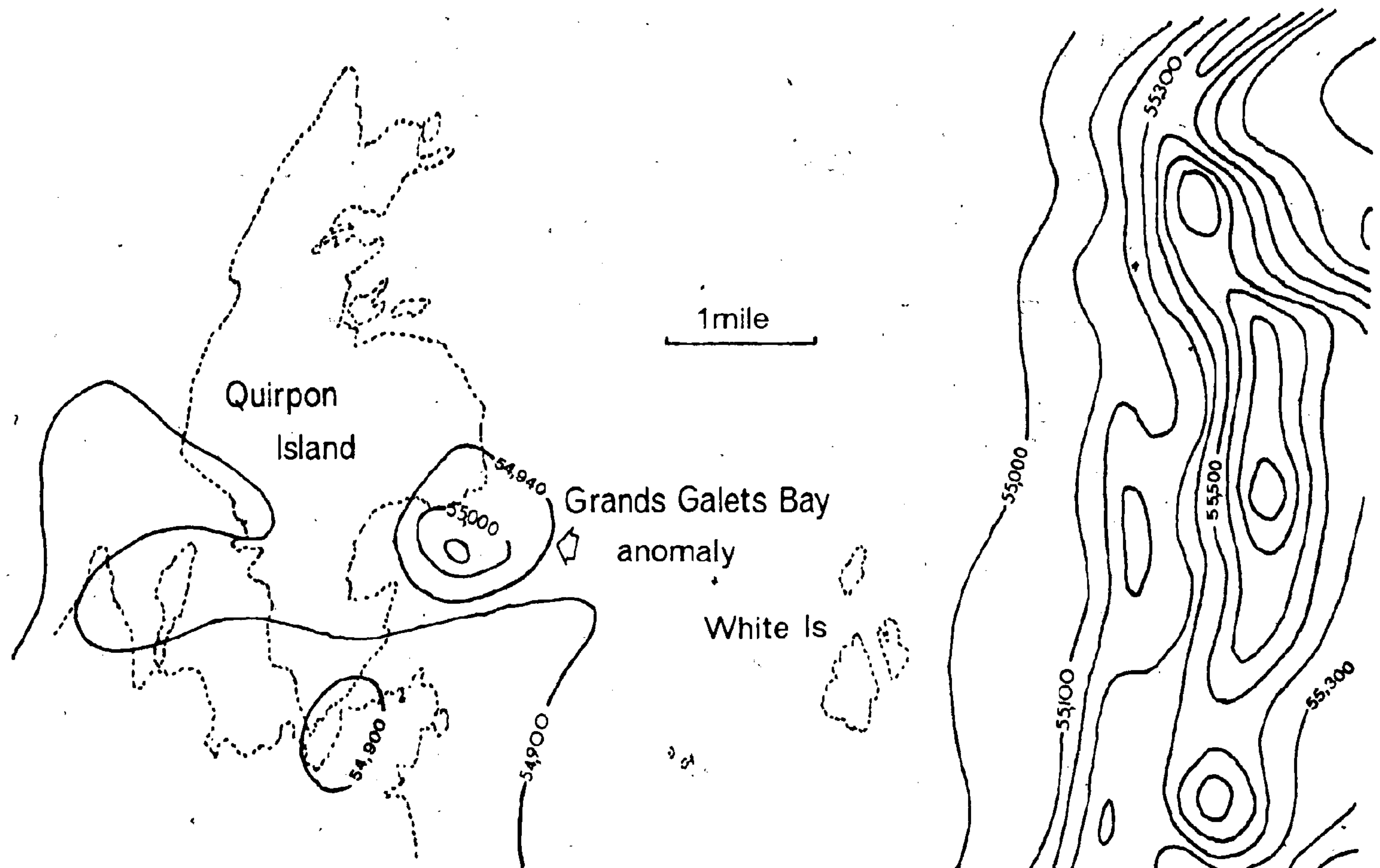
Williams _et al._ (1973) and Williams & Smyth (1974) interpreted the sharp anomaly east of the Fishot Islands as part of the White Hills Peridotite sheet exposed on land northwest of Goose Cove, though Haworth _et al._ (1976a&b) made no mention of this anomaly.

The Quirpon area magnetic anomalies

Approximately one kilometre east of the White Islands the 55,000 gammma isomagnetic line approximates the sharp western edge of the magnetic "ridges". Haworth _et al._ (1976b) interpreted the Fleur de Lys/White Islands Formation (Bateau Formation) contact at this location. The eastern boundary of this anomaly is ragged and diffuse suggesting a shallowly east-dipping body (Fig. 33). West of the White Islands (and presumably White Rocks) Haworth _et al._ (1976a) interpreted the boundary between the White Islands Formation (Bateau Formation) in the east and the Cambro-Ordovician limestone shelf sequence, including the

Figure 33

Magnetic anomaly map of the Quirpon area



Quirpon
Island
54,940
55,000
Grands Galets Bay
anomaly
White Is
54,900
54,900
1mile
55,000
55,100
55300
55,500
55,300

Goose Tickle Formation, in the west.

In the centre of Grands Galets Bay there is a roughly circular anomaly, defined by the 55,000 gamma isomagnetic line. The peak of the anomaly reaches 55,100 gammas (Fig. 34) which is well within the range of the offshore magnetic "ridges". It is interesting to note that the Goose Cove Schist on Quirpon Island has no magnetic signature which suggests that this unit is rather thin. This agrees with the observed thickness of the Goose Cove Schist of 170m (Chapter 3). It is relevant to note that throughout the Hare Bay Allochthon the Goose Cove Schist does not have a magnetic signature (see GSC map 4418G).

The shape of the Grands Galets Bay anomaly suggests the presence of a small outlier of magnetic material. The strength of the anomaly is above the range for Newfoundland ultramafics as defined by Haworth & Miller (1982). It is possible that this body is a remnant of peridotite since its position suggests that it rests above the Goose Cove Schist in the core of the large scale F3 fold exposed between Whale Point and Quirpon harbour.

Bouguer anomalies

Because gravity anomalies show the variations in density of rocks in the earth's lithosphere, information about near surface rocks is masked by the background strength of the anomaly. This contrasts with magnetic anomalies which reveal information mainly from near surface rocks. Consequently gravity anomalies tend to be much larger and do not reveal changes in geological structure on a local scale as well.

The Quirpon area anomalies

Haworth _et al_. (1980) show Quirpon Island lying on the 15 milligal contour. This value separates a major, rather featureless positive anomaly about 100km east of Hare Bay which peaks at slightly more than 60 milligals, from a major negative anomaly located slightly southwest of Hare Bay on the Northern Peninsula which peaks at slightly less than -60 milligals. The negative anomaly is related to the Cambro-Ordovician platformal carbonates of the Table Head and St. George Groups.

The zone between the two anomalies drops steeply from 40 to -40 milligals over about 50km, and has a strong north-south linearity, the trend of which correlates well with the similarly trending magnetic "ridges" described by Haworth _et al_. (1976). The zone represents the boundary between rocks of higher density to the east and lower density sediments to the west. There are no local anomalies that can be correlated with the known geology of the Hare Bay Allochthon.

CONCLUSIONS

Geological evolution

Adequate discussions on the geological evolution of western Newfoundland with respect to the birth and destruction of the Iapetus Ocean have been given by several authors (e.g. Stevens, 1970; Smyth, 1973; Williams and Stevens, 1974; Williams 1975; Malpas, 1976; Williams and Smyth (in press) and Jamieson, 1979). A brief synopsis of the geological history has been given in the Introduction. A detailed discussion is not presented here because this would be largely repetative, and is beyond the scope of this thesis.

Summary

The purpose and scope of the thesis has been to analyze one part of the Hare Bay Allochthon in order to clarify and understand the detailed tectonic and metamorphic processes during emplacement with particular emphasis on structures and structural correlation. The conclusions of this analysis are summarized below in point form.

1. The rocks in the Quirpon area show a reversed metamorphic gradient. The structurally highest unit, the

Goose Cove Schist, is a retrogressed actinolite greenschist which forms part of the dynamothermal aureole of the ophiolite of the St. Anthony Complex. Below this occur rocks of the Maiden Point Formation which have undergone lower greenschist metamorphism probably as a result of juxtaposition against the cooling Goose Cove Schist. The lowest units, which consist of the White Islands and Goose Tickle Formations show evidence of sub-greenschist facies metamorphism.

2. It has been shown that the Goose Tickle Formation is in part allochthonous because parts of the Formation occur as discrete slivers in duplexes with the allochthonous Maiden Point Formation. The presence of inferred emplacement-related pre-cleavage isoclinal folds (F1) are tectonically equivalent to pre-cleavage isoclinal folds within the Maiden Point Formation. The absence of a tectonic foliation with these folds is unusual but has been observed south of Hare Bay by Smyth (1973) and may be the result of soft sediment deformation.

3. A tectonostratigraphic correlation has been made between the allochthonous Goose Tickle Formation and the Blow-Me-Down Brook Formation of the Upper Curling Group of the Humber Arm Supergroup of the Bay of Islands ophiolite complex.

4. The Maiden Point Formation is structurally overturned against the underlying autochthonous Goose Tickle Formation.

5. A large scale discontinuous intraformational melange zone in the Maiden Point Formation (the Degrat Harbour melange) contains blocks of exotic lithologies which may have been incorporated from the Northwest Arm Formation which, though not present in the Quirpon Island section, is elsewhere structurally lower than the Maiden Point Formation.

6. An emplacement-related ductile mylonite zone marks the contact between the Maiden Point Formation and the Goose Cove Schist and is developed primarily in Maiden Point sediments. Late stage movement is indicated by several ultramylonite zones which truncate the mylonite foliation.

7. The Goose Cove Schist preserves only two recognizable fold generations (F1 and F2) which are developed on a microscopic and small scale. A large scale post-emplacement (F2) fold affects the contact with the Maiden Point Formation allowing correlation of post-emplacement structures in both units and in the Goose Tickle Formation. The lack of mesoscopic and large scale pre-emplacement structures in the Goose Cove Schist is

probably due to the absence of continuous marker horizons.

8. A well defined magnetic anomaly suggests the presence of an outlier of peridotite on the seafloor of Grands Galets Bay.

9. F2 fold amplitudes in the Goose Tickle Formation become shallower towards the east. This is in contrast to the observation elsewhere in the Hare Bay Allochthon that post-emplacement folds die out westwards. This may be because stratigraphically lower rocks are encountered to the east which, because they were deeply buried, escaped deformation during emplacement.

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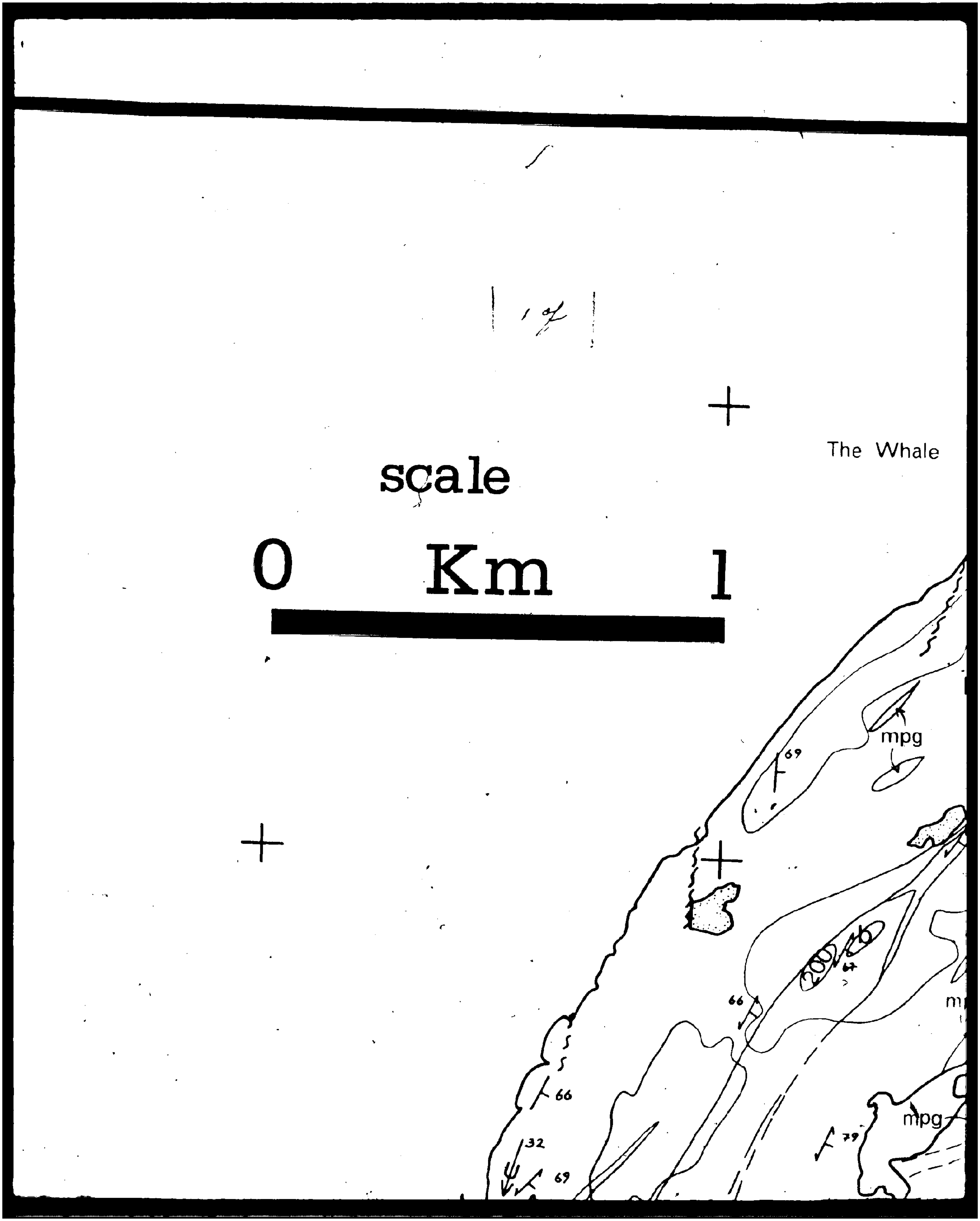
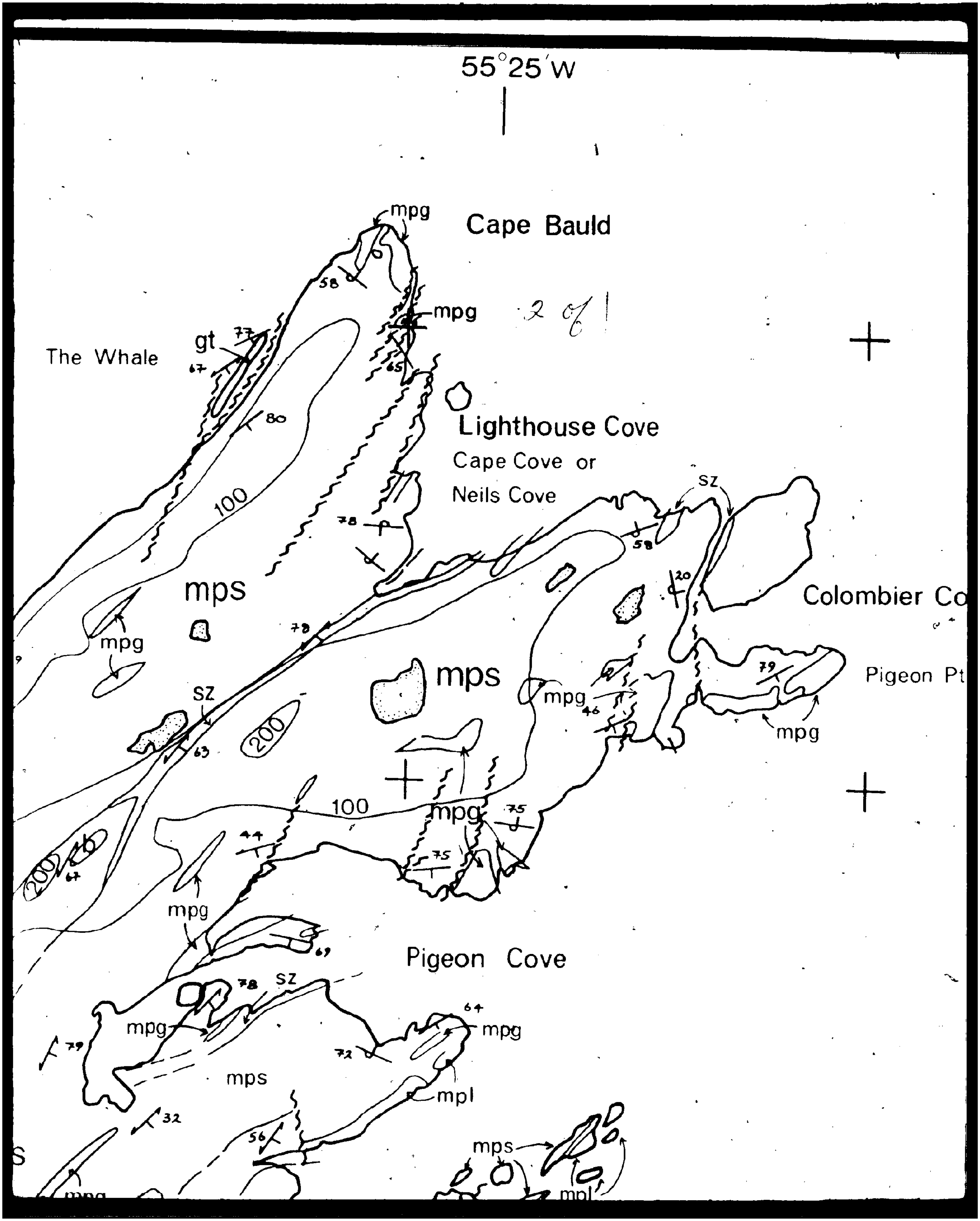
Figure 1

Geology of Quirpon Island and location map



The Whale
scale
0 Km 1
mpg
69
66
66
32
69
79
mpg



55°25'W
Cape Bauld
mpg
2 of 1
The Whale
gt
Lighthouse Cove
Cape Cove or
Neils Cove
SZ
mps
100
Colombier Co
mpg
mps
mpg
Pigeon Pt
SZ
200
mpg
100
mpg
200
mpg
Pigeon Cove
SZ
mpg
mpg
mps
mpl
mps
mpl

The Geology of Quirpon and the White Islands.

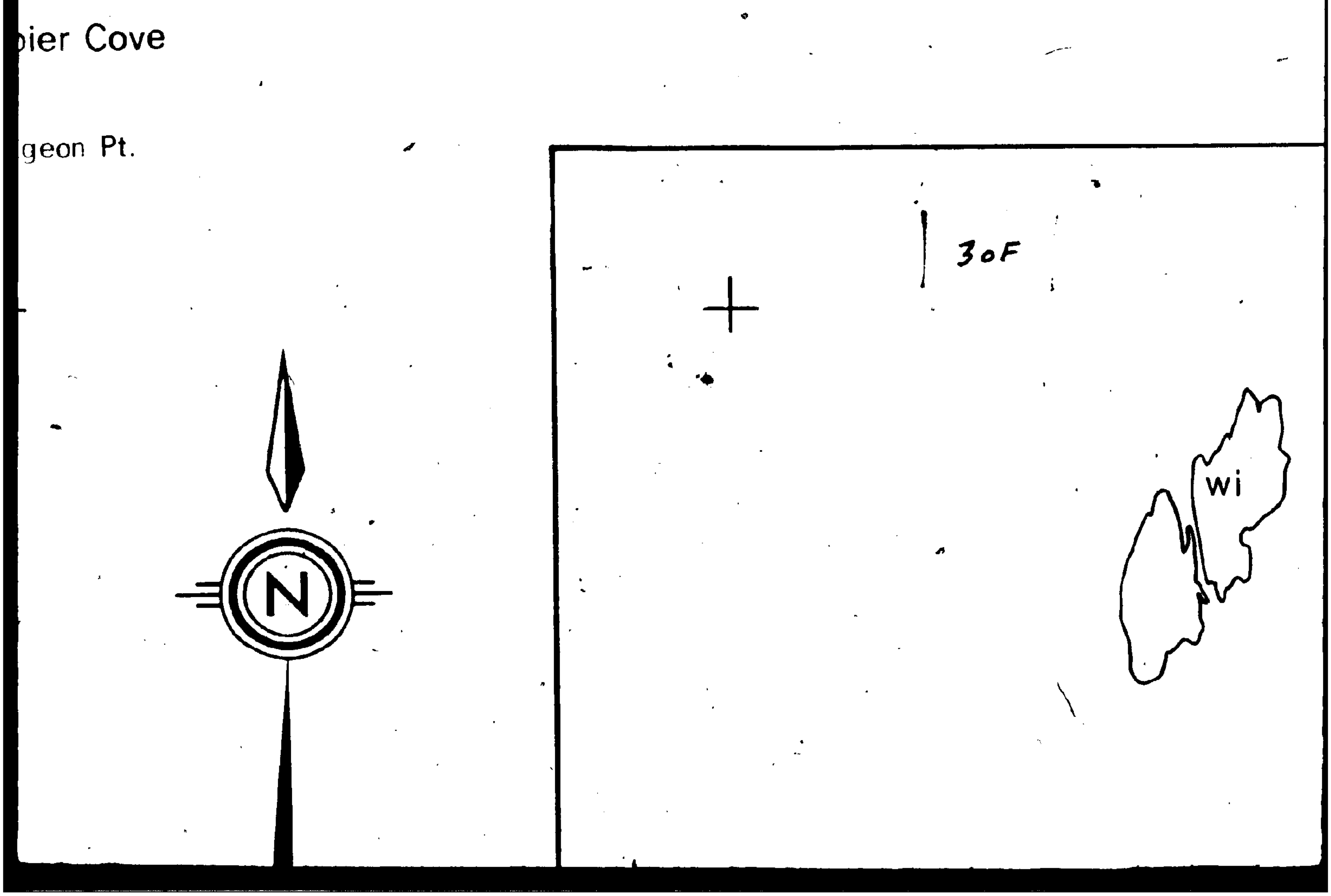
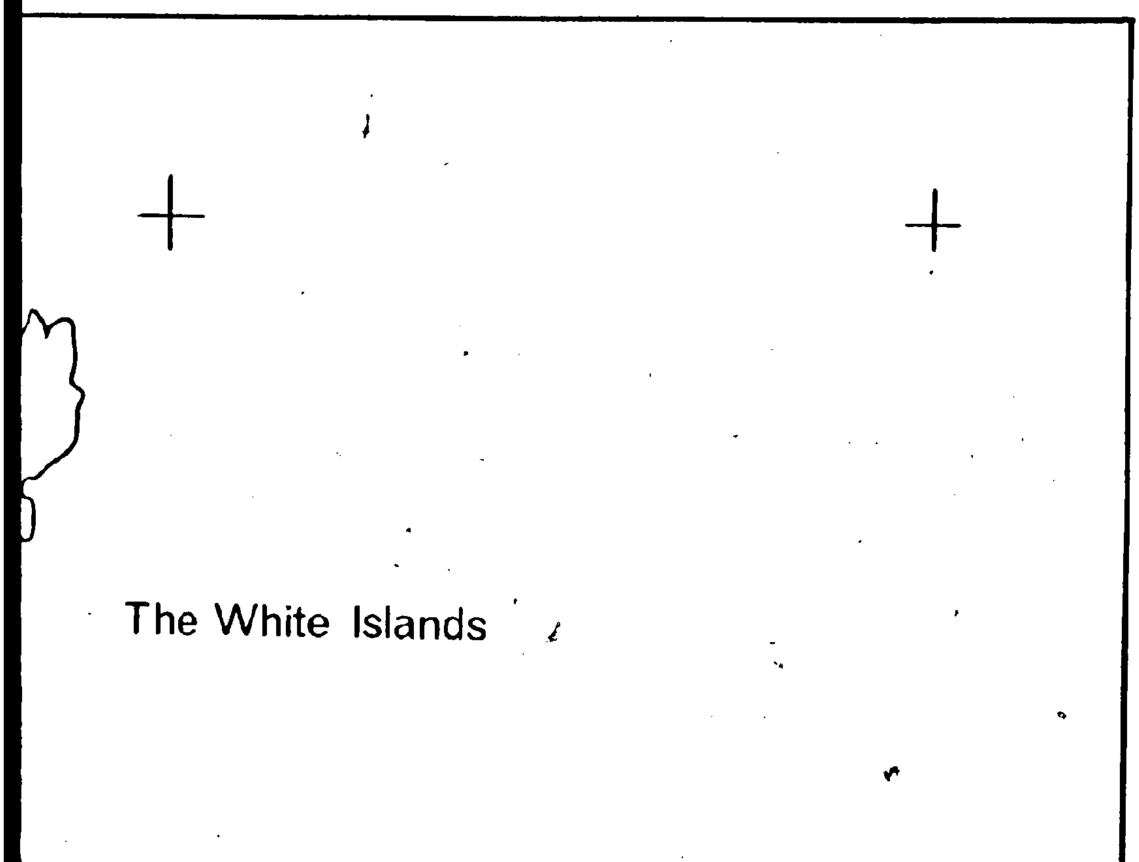


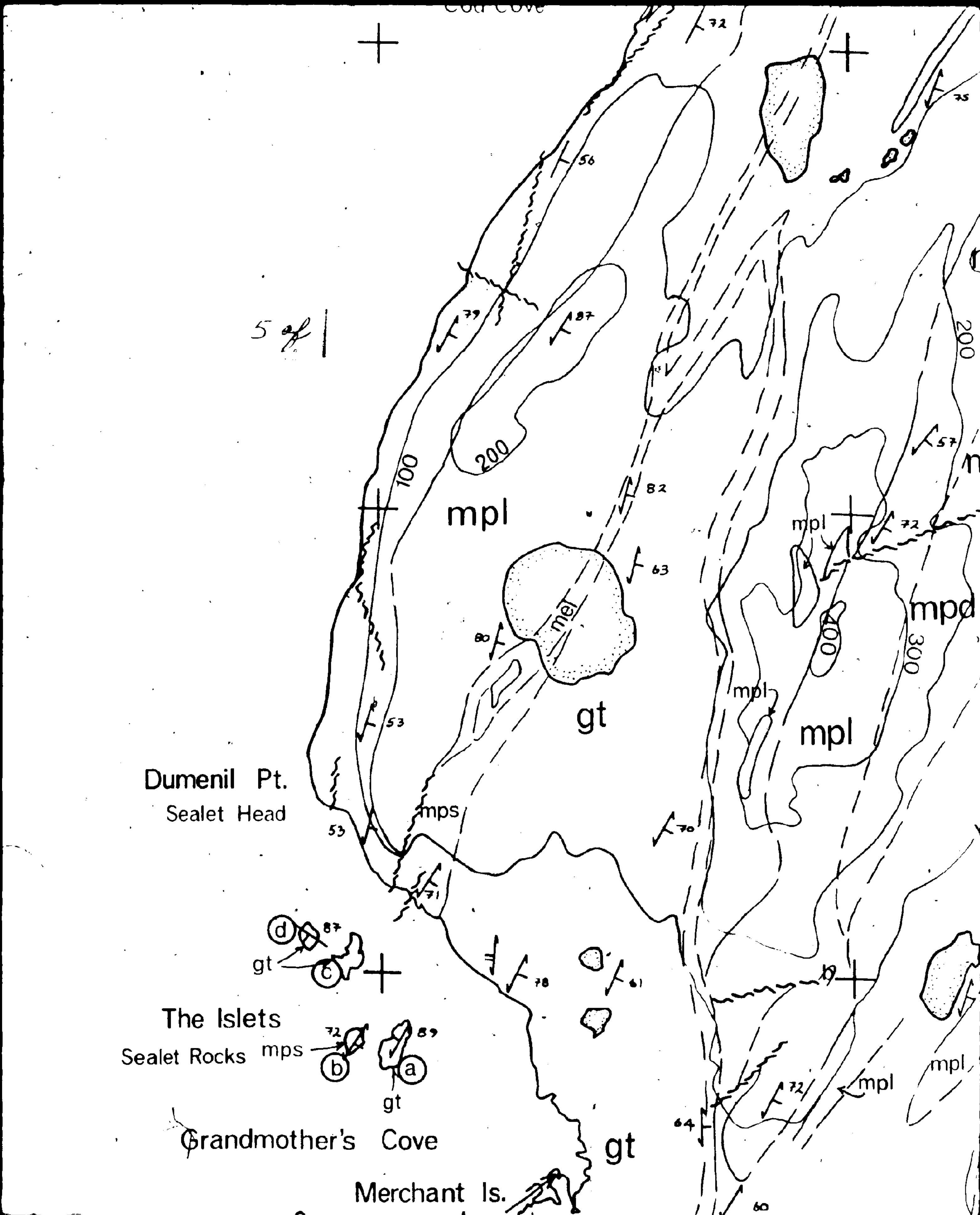
FIG. 1

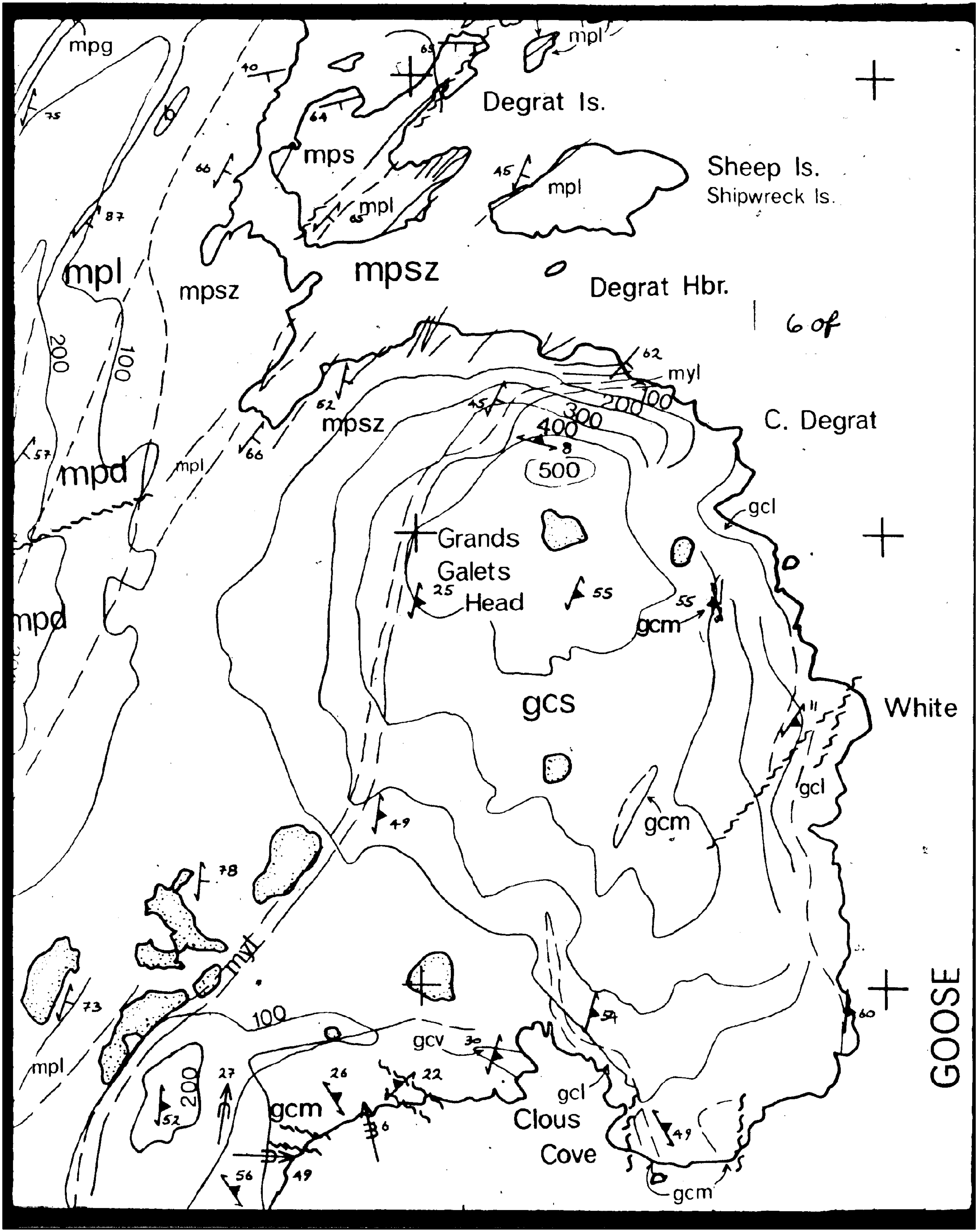
on Island

s.

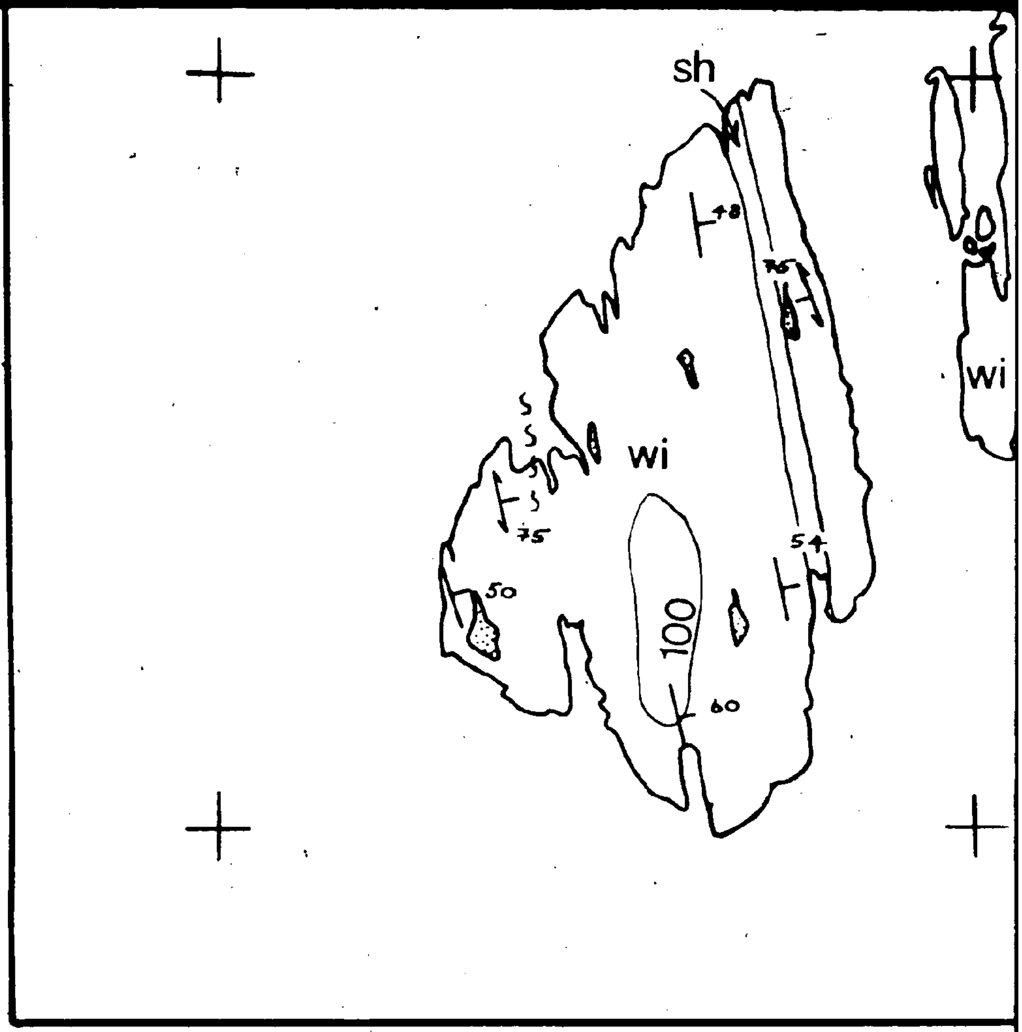
4 OF 1




Cod Cove
5 of
mpl
gt
mel
mpd
mps
200
100
300
400
Dumenil Pt.
Sealet Head
The Islets
Sealet Rocks
Grandmother's Cove
Merchant Is.
d
c
b
a



mpg
Degrat Is.
mps
mpl
Sheep Is.
Shipwreck Is.
mpsz
Degrat Hbr.
6 of
mpl
mpsz
myl
C. Degrat
mpsz
mpd
500
Grands
Galets
Head
gcl
gcm
gcs
White
gcl
gcm
mpd
myl
100
gcv
mpl
200
gcm
gcl
Clous
Cove
gcm
GOOSE



ite Pt.

LEGEND

(structural sequence only, stratigraphic order unknown)

70F

GOOSE COVE SCHIST

gcs	strongly foliated, fine grained actinolite schist
gcm'	fine to medium grained foliated metagabbro
gcv	fine grained crudely foliated metavolcanics
gcl	fine grained crudely foliated calcareous metasediments

SYMBOLS

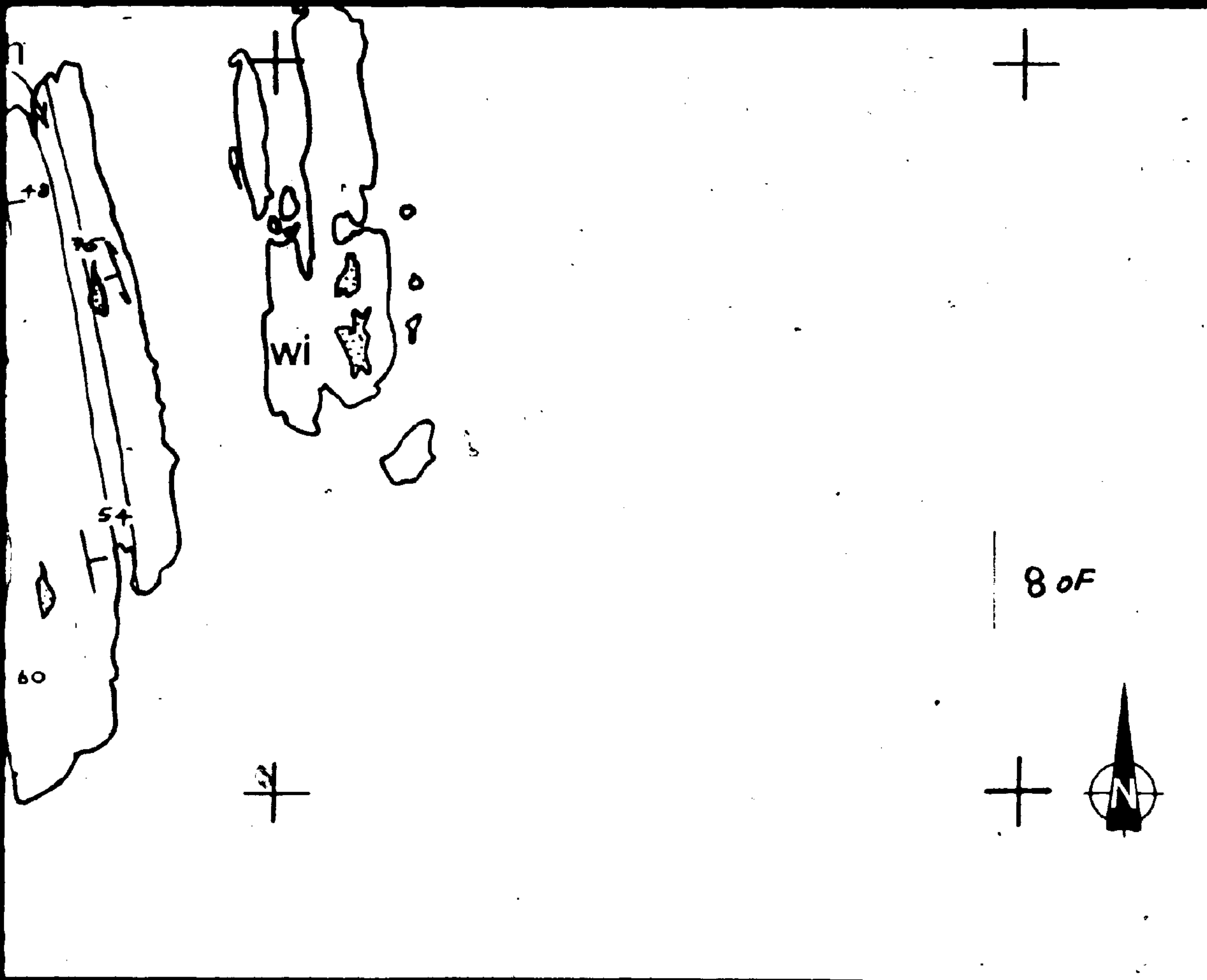
bedding to

" ov

S_1 cleavage

S_2 "

S_2 "



SYMBOLS

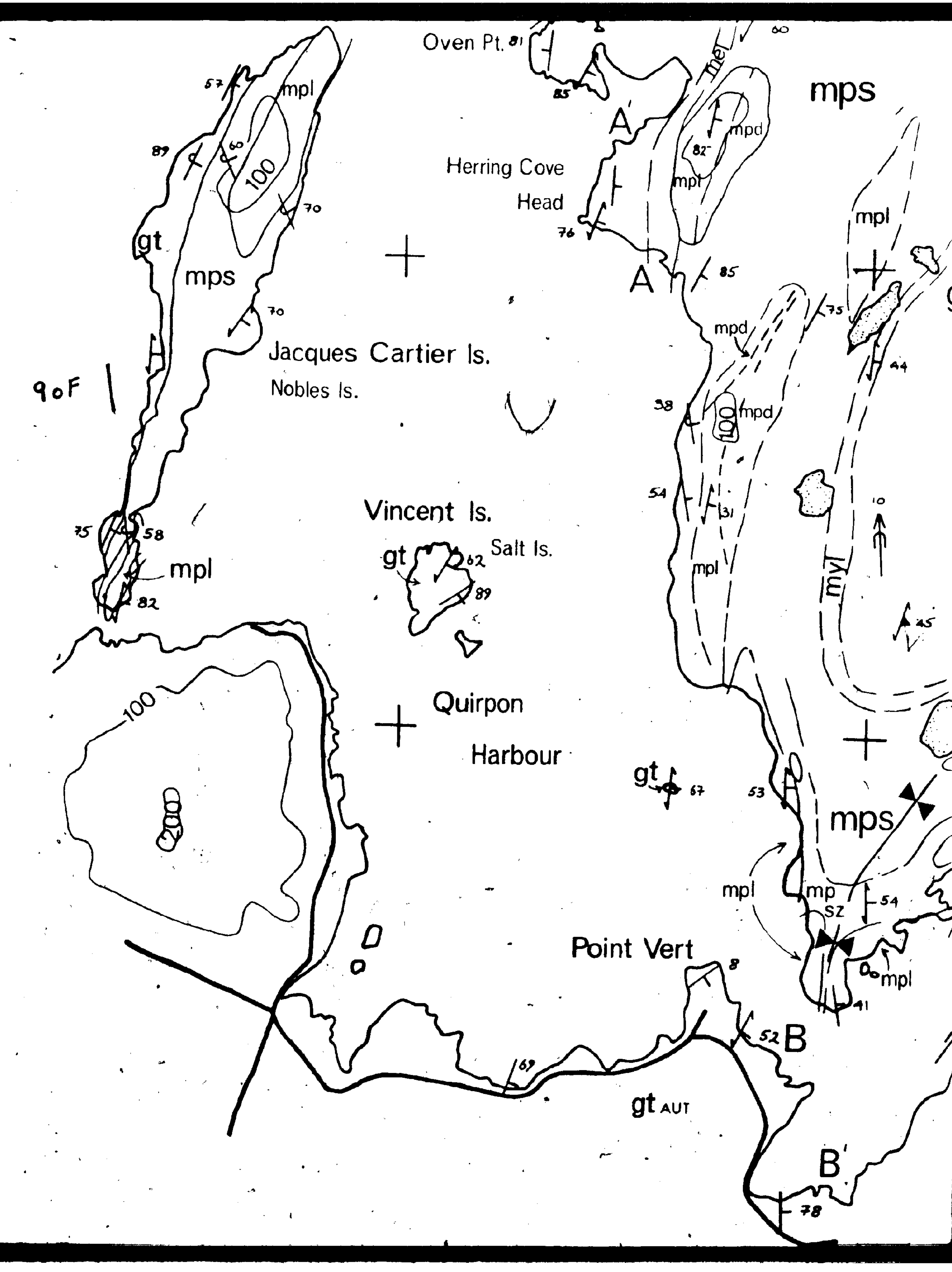
bedding tops known

" overturned

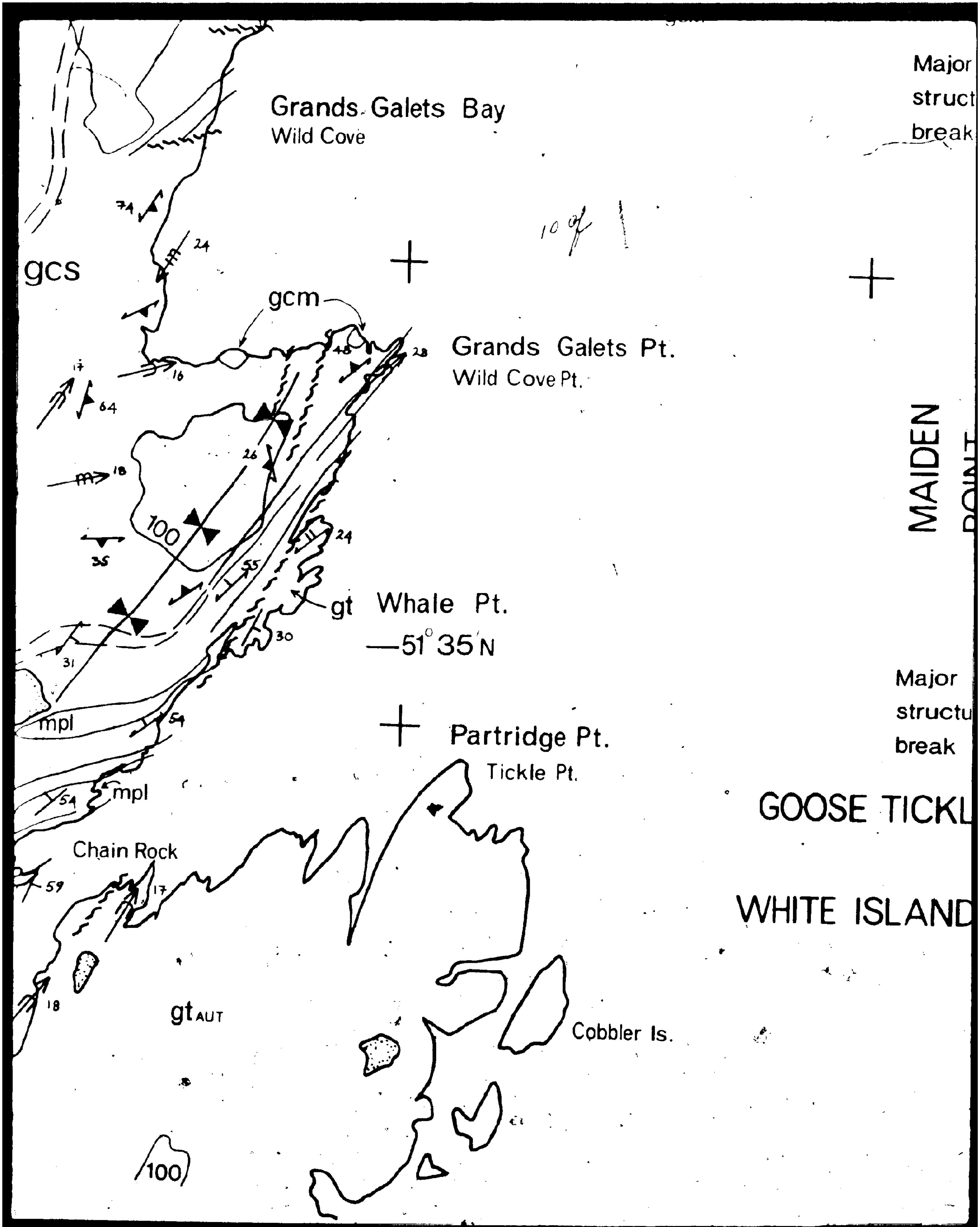
S_1 cleavage (Goose Tickle & Maiden Point Fms.)

S_2 " " " "

S_2 " (Goose Cove Schist)



Oven Pt.
mps
mpl
mpd
Herring Cove
Head
A'
A
100
gt
Jacques Cartier Is.
Nobles Is.
90F
Vincent Is.
Salt Is.
myl
Quirpon
Harbour
200
mps
mp
sz
Point Vert
B
B'
gt AUT


Grands Galets Bay
Wild Cove
Major
struct
break
10 of
gcs
gcm
Grands Galets Pt.
Wild Cove Pt.
MAIDEN
100
gt
Whale Pt.
—51° 35′N
Major
structu
break
mpl
Partridge Pt.
Tickle Pt.
mpl
GOOSE TICKL
Chain Rock
WHITE ISLAND
gtAUT
Cobbler Is.
100

11 of 11

...ral	myl	mylonite zone
POINT Fm.	mps	fine to coarse grained. sandstone with minor shale & siltstone
	b mpl	variolitic pillow lava with minor pillow breccia
	mpd	fine grained massive diorite
	mpg	medium to coarse grained gabbro
	mpsz & sz	mélange, with large blocks of pillow lava, limestone & sandstone in cleaved black shale matrix
...ral	mel	mélange zone with blocks of Goose Tickle & Maiden Point Fm. lithologies & peridotite (?)
...LE Fm.	gt gtAUT	alternating graded sandstone shale & siltstone, allochthonous & autochonous
...DS Fm.	wi sh wi	coarse white sandstone with single shale band

	fold axis
	mineral lineation
	thrust, defined & ap...
	geological contact
100	contour in feet
	synformal axis
	fault
Vincent Is.	place nam...
Salt Is.	local name

geology by C. Woodwo...

fold axis

mineral lineation

thrust, defined & approx.

geological contact " "

contour in feet

synformal axis

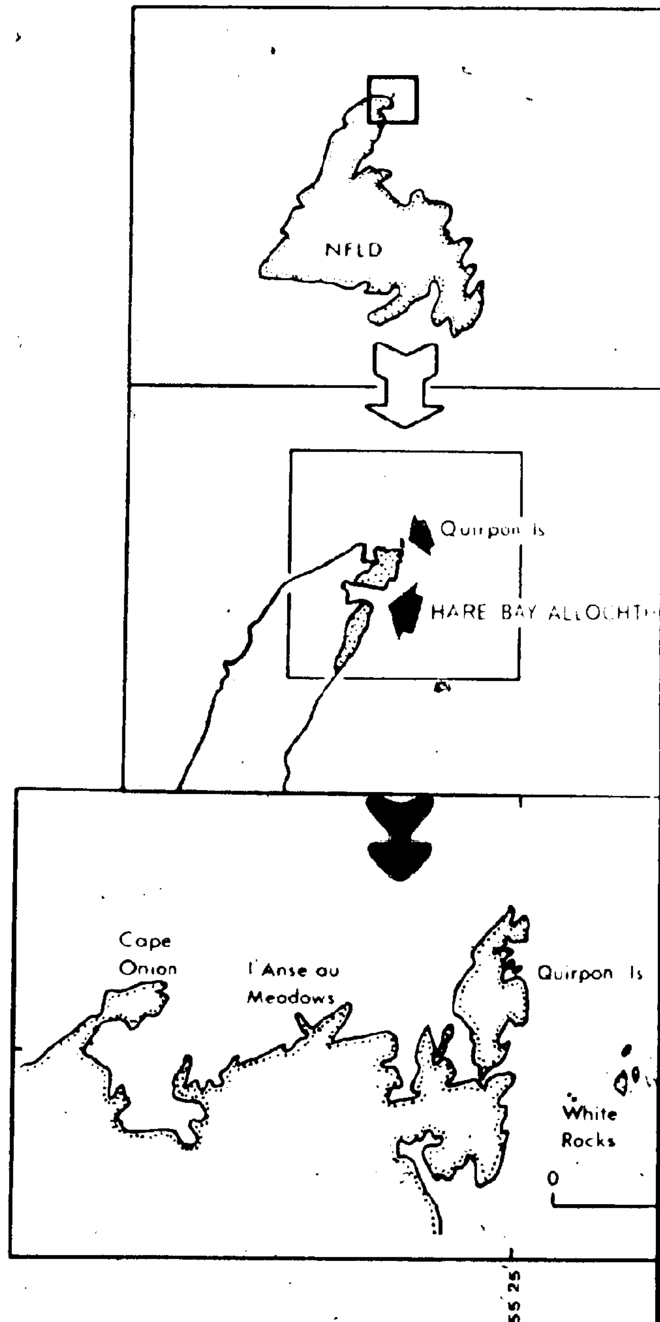
fault

Vincent Is. place name on survey map and

Salt Is. local name

12 of 12

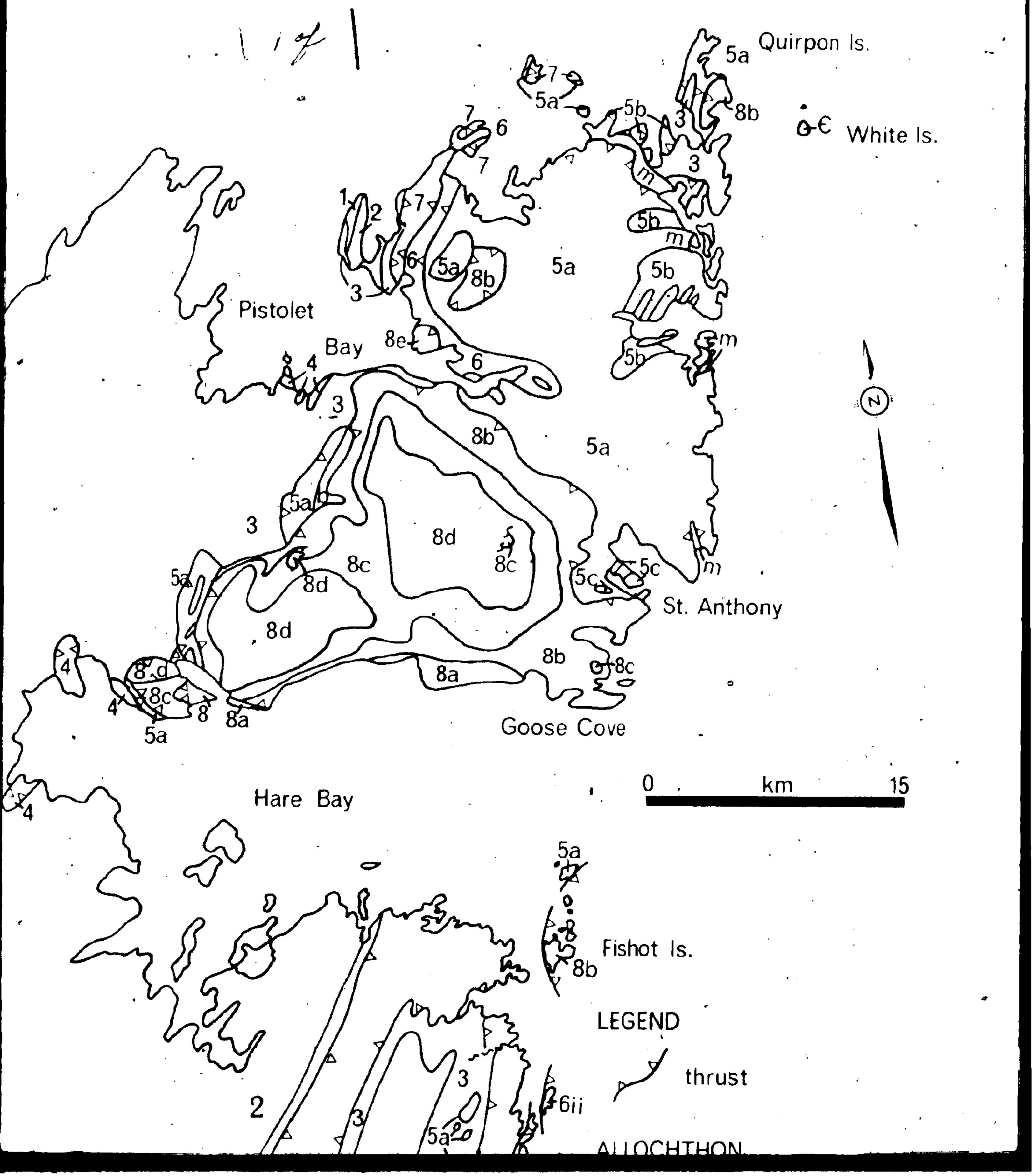
Location map



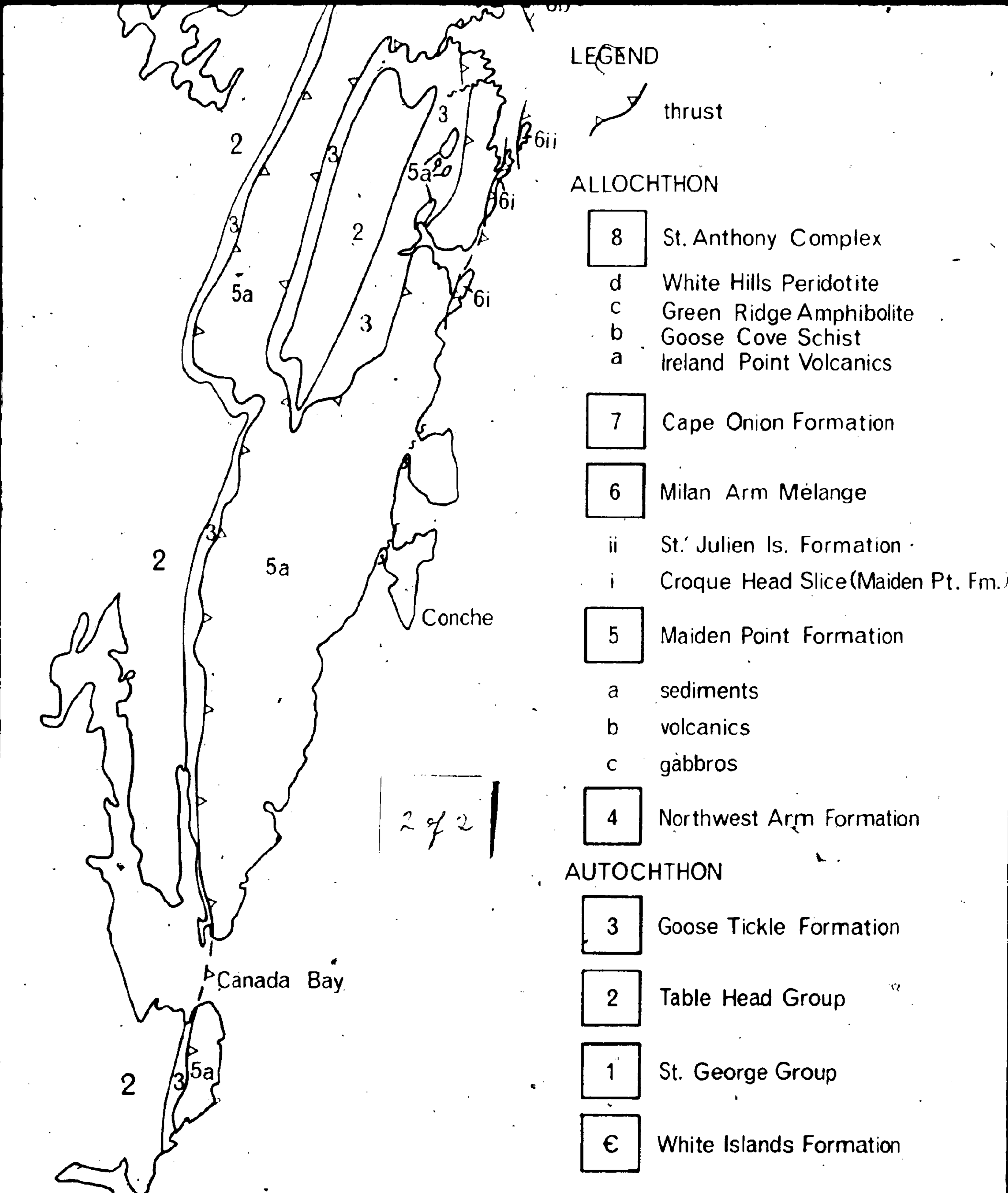
geology by C. Woodworth-Lynas 1982

Figure 2

Geology of the Hare Bay Allochthon, after Williams, Smyth and Stevens (1973); Smyth (1973); Williams and Smyth (in press); DeLong (unpublished); Talkington (1981); Jamieson (1979) and Woodworth-Lynas (this work)



Quirpon Is.
White Is.
Pistolet
Bay
St. Anthony
Goose Cove
Hare Bay
Fishot Is.
0 km 15
LEGEND
thrust
ALLOCHTHON


LEGEND
thrust
ALLOCHTHON
8 St. Anthony Complex
d White Hills Peridotite
c Green Ridge Amphibolite
b Goose Cove Schist
a Ireland Point Volcanics
7 Cape Onion Formation
6 Milan Arm Mélange
ii St. Julien Is. Formation
i Croque Head Slice (Maiden Pt. Fm.)
5 Maiden Point Formation
a sediments
b volcanics
c gabbros
4 Northwest Arm Formation
AUTOCHTHON
3 Goose Tickle Formation
2 Table Head Group
1 St. George Group
€ White Islands Formation
Conche
Canada Bay
2
3
5a
6i
6ii
2 of 2

RELATIVE AGE OF DEFORMATION AND TYPES OF STRUCTURE

AUTOCHTHON		ALLOCHTHON		
WHITE ISLANDS Fm.	**GOOSE TICKLE Fm.**	**GOOSE TICKLE Fm.**	**MAIDEN POINT Fm.**	
				L A C M
		Inferred large scale isoclinal F1 folds no axial planar foliation.	Inferred large scale tight/isoclinal F1 folds. No axial planar foliation Lower greenschist facies	J t c G Il
Inferred tight, N.W. inclined, large scale F1 folds. Axial planar cleavage, S1	Tight, N.W. inclined mesoscopic and large scale F2 folds. Axial planar cleavage, S2	Tight, N.W. inclined mesoscopic/large scale F2 folds. Axial planar cleavage, S2, folding affects contacts with Maiden Point Fm.	Tight N.W. inclined mesoscopic/large scale F2 folds. Axial planar cleavage, S_2. Folding affects contacts wi h Goose Tickle Fm.	Co S 1 L W Wa
Minor sparse kinking	Sparse small scale, open F2 folds affecting S2, minor fracture cleavage, S3	Sparse minor fracture cleavage, S_3. No folds	Sparse mesoscopic F3 folds. Minor fracture cleavage, S3 not associated with F3.	

1 of

CTURE ON QUIRPON (CORRELATION CHART)

Fm.	GOOSE COVE SCHIST: ACTINOLITE SCHIST	GOOSE COVE SCHIST: METAGABBRO	INTERPRETAT
	Development of S1 foliation and of Act1 porphyroblasts. No folds observed. Middle greenschist facies	Development of S1 foliation and of Act 1 Porphyroblasts. No folds observed. Middle Greenschist facies	Pre-emplacement deformation p allochthonous slices, possibl Goose Cove Schist along an Ea
cale F1 planar facies	S1 folded (F1 folds) and transposed into S2 during re'x of Act1 to Act2 porphyroblasts. Garnet growth at this stage Middle greenschist facies	S1 transposed into S2. Recrystallization phase and generation of Act 2 prophyroblasts Middle Greenschist facies	Late stage emplacement deform Maiden Point Fm and incorpora terrane. Melanges developed Gabbros/Pillow Lavas from con Ultramylonites developed in G
ned scale planar lding wi h	Conjugate crenulation S3 and S4 and crenulation lineationL3a. No associated folds. Large scale F2 folding of contact with Maiden Point Fm. Waning Greenschist facies	Development of sparse crenulation (equivalent to S3/S4). No observed folds. Waning Greenschist facies	Post emplacement deformation.
F3 cture F3.			Late Post-Emplacement Deforma

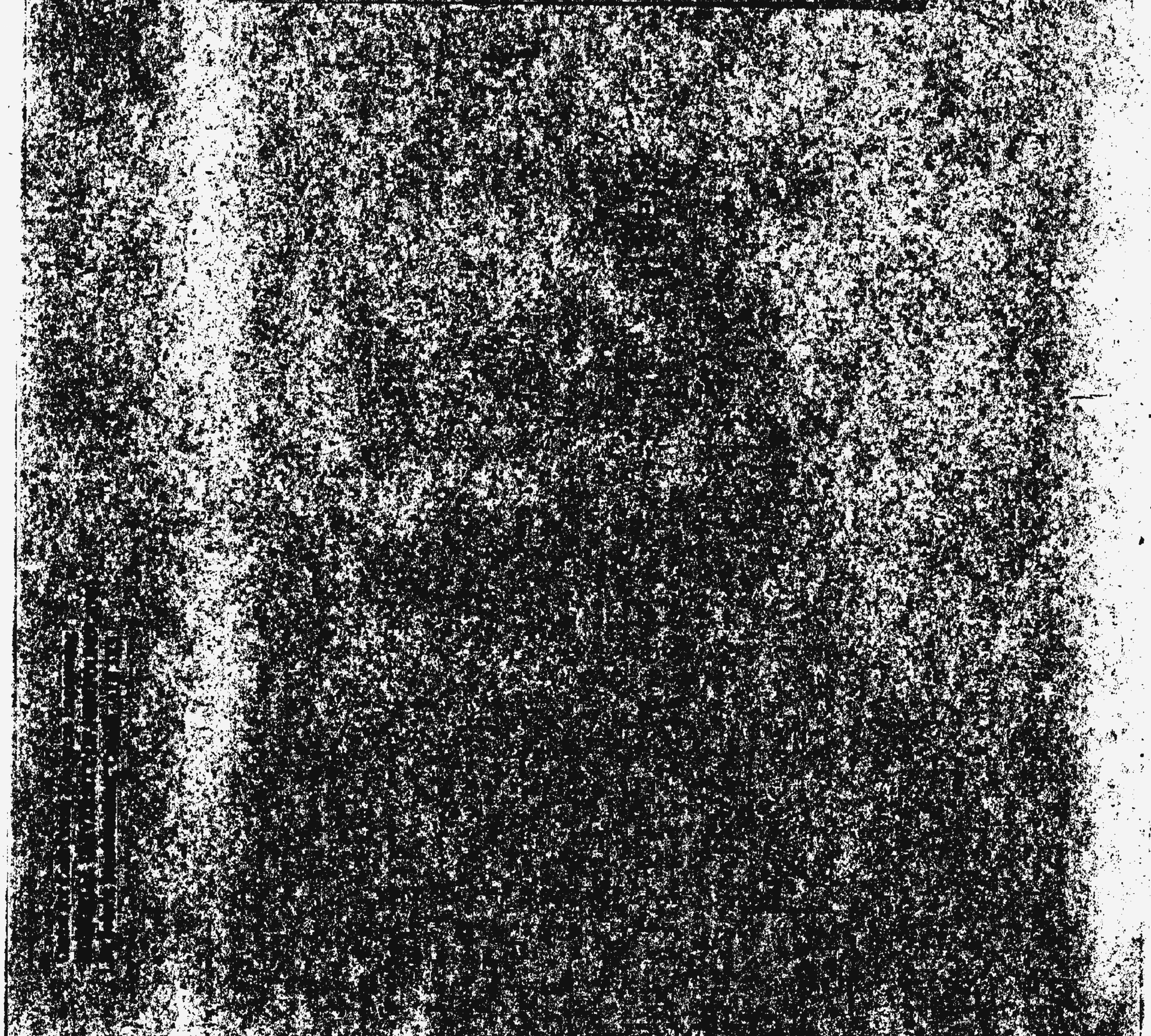
2 of

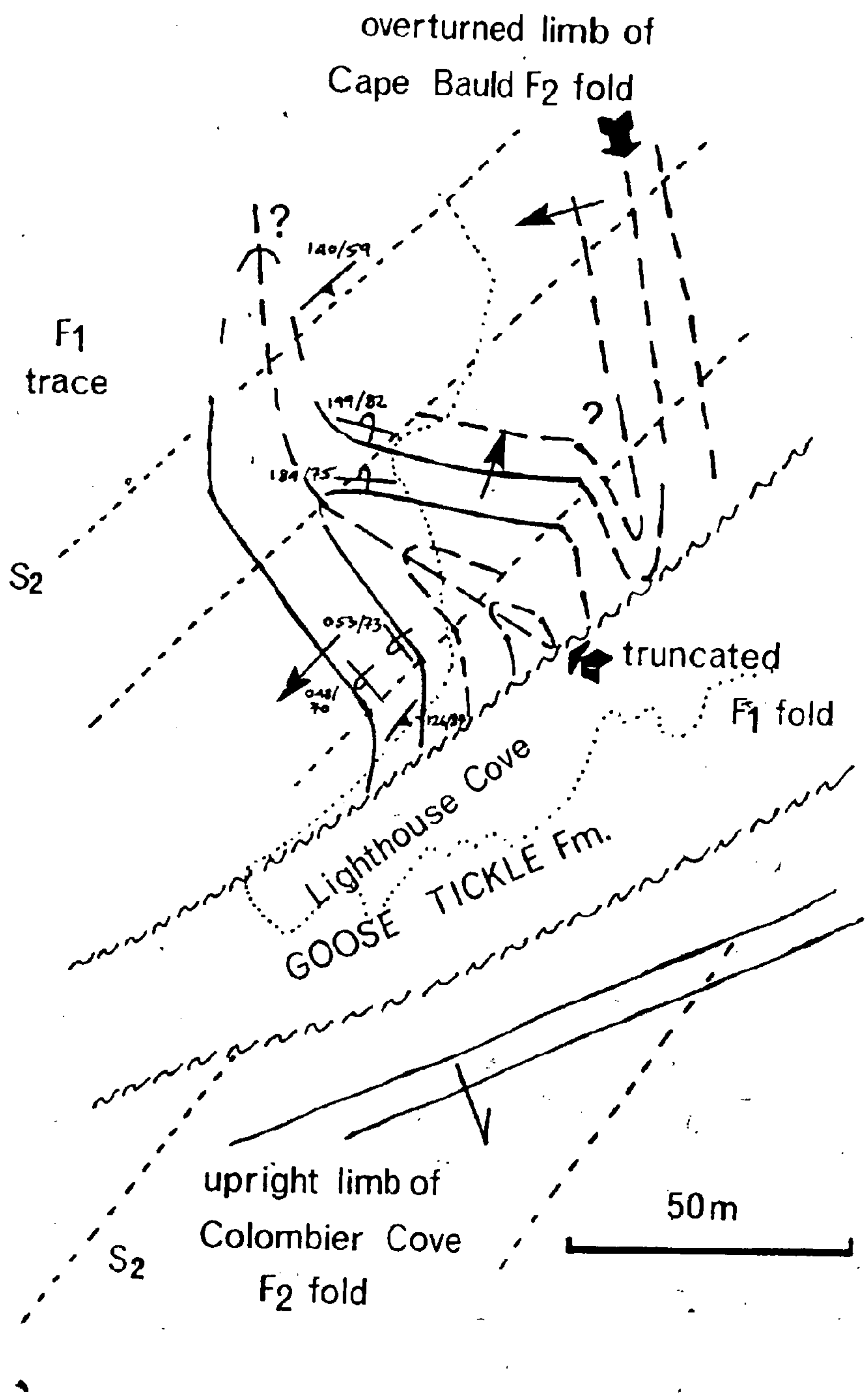
INTERPRETATION

on and of folds	Pre-emplacement deformation probably related to initial stacking of allochthonous slices, possibly by partial incorporation of the Goose Cove Schist along an Eastward dipping Benioff zone.	?
crystall- ion of	Late stage emplacement deformation."soft" deformation in Goose Tickle and Maiden Point Fm and incorporation of Goose Tickle slivers into Allochthonous terrane. Melanges developed at this stage. Metamorphism of Maiden Point Gabbros/Pillow Lavas from convected heat of overlying Goose Cove Schist. Ultramylonites developed in Goose Cove Schist/Maiden Point fm Mylonite Zone.	? TACONIC
nulation No	Post emplacement deformation. All units and tectonic contacts affected.	
	Late Post-Emplacement Deformation	?
		? ACADIAN ?

Figure 14a

The geometry of an F1 fold in Lighthouse Cove

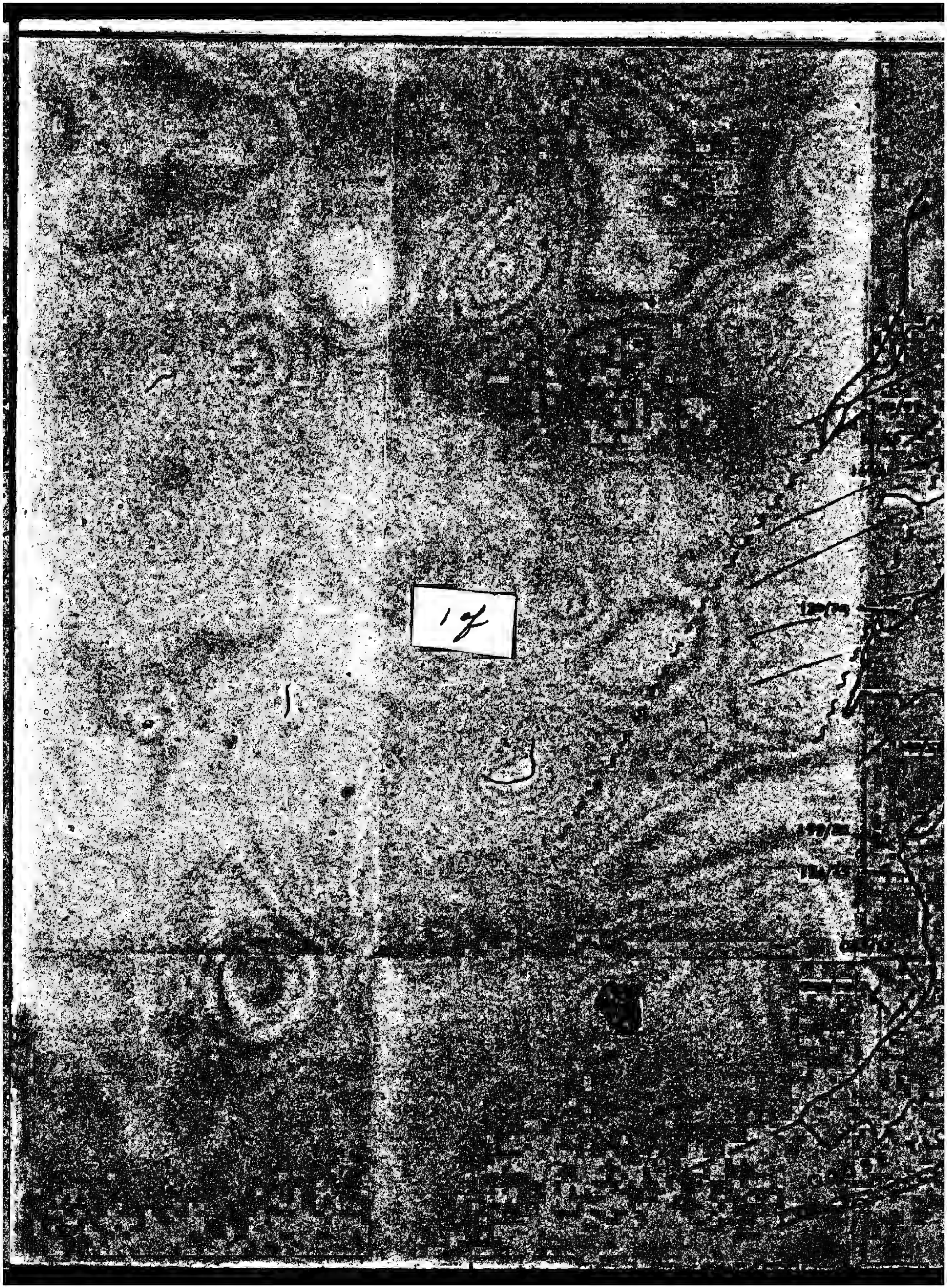




overturned limb of
Cape Bauld F2 fold
1?
140/59
F1
trace
199/82
?
184/75
S2
053/73
048/70
124/39
truncated
F1 fold
Lighthouse Cove
GOOSE TICKLE Fm.
upright limb of
Colombier Cove
F2 fold
S2
50 m

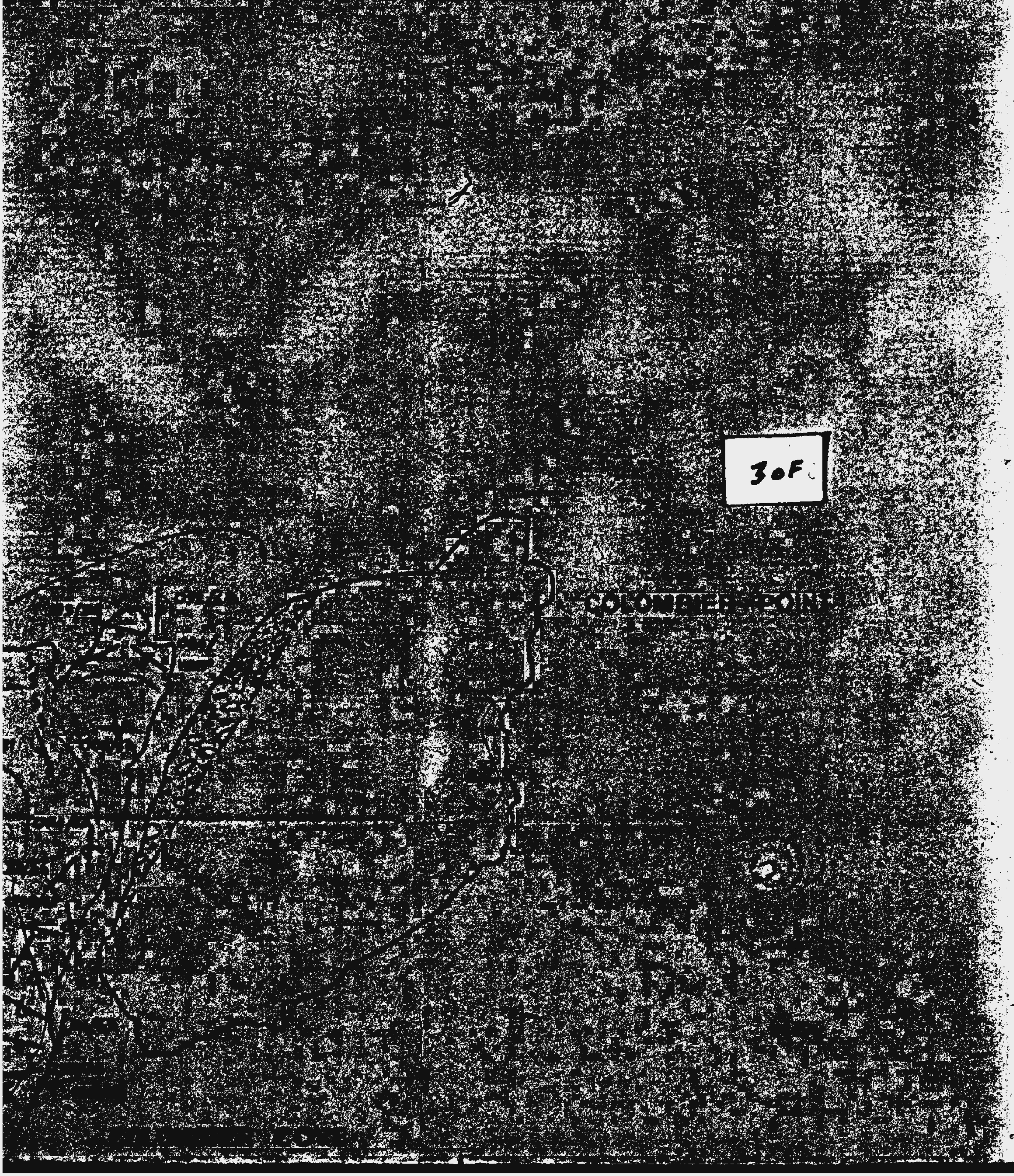
Figure 14b

Geology of Colombier Cove.


17

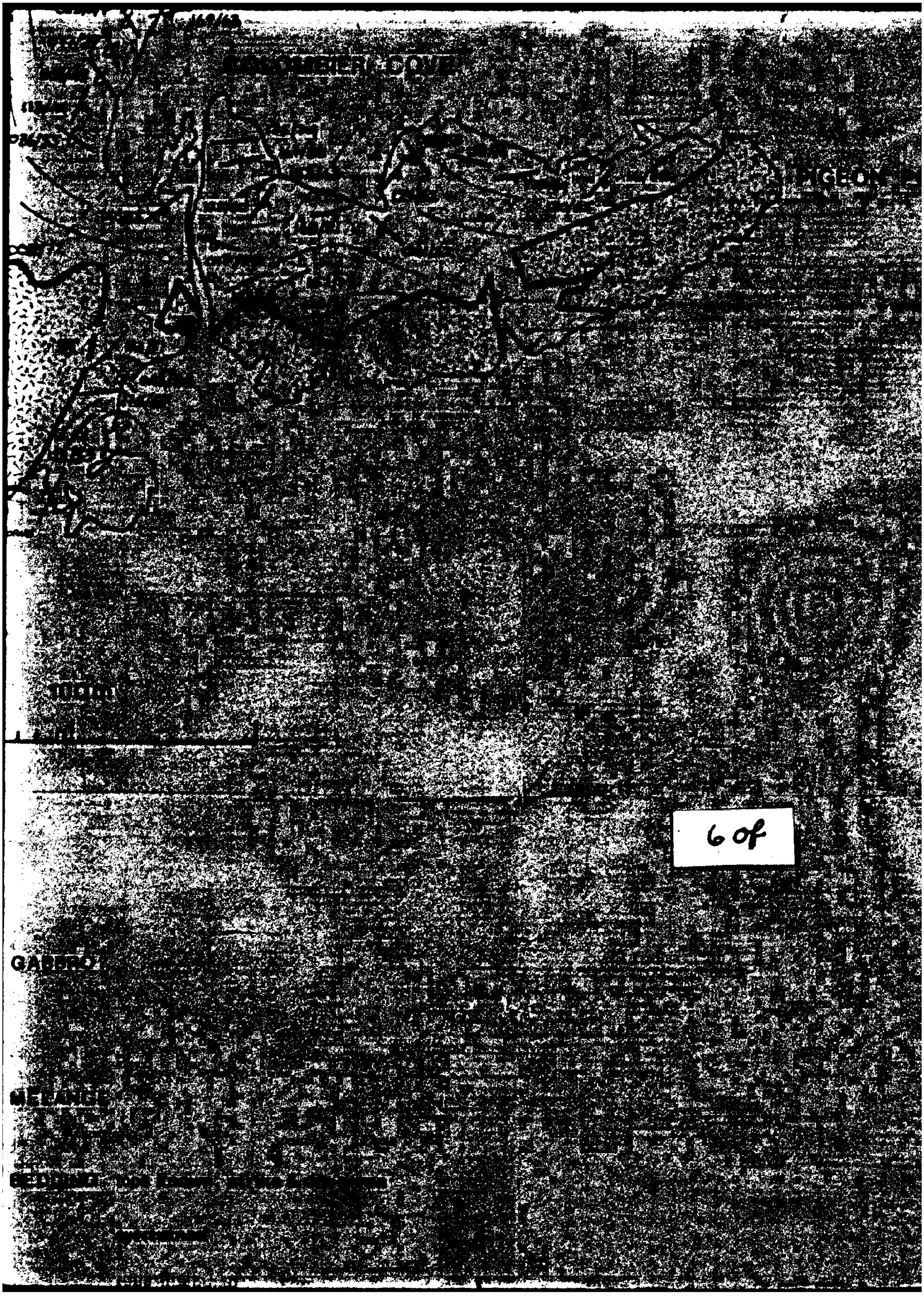

OF THE MAIDEN POINT
CAGE COVE
2 of

III. AROUND COLOMBIER COVE




4 OF
PIGEON COVE


5 of
KEY
GABBRO
N



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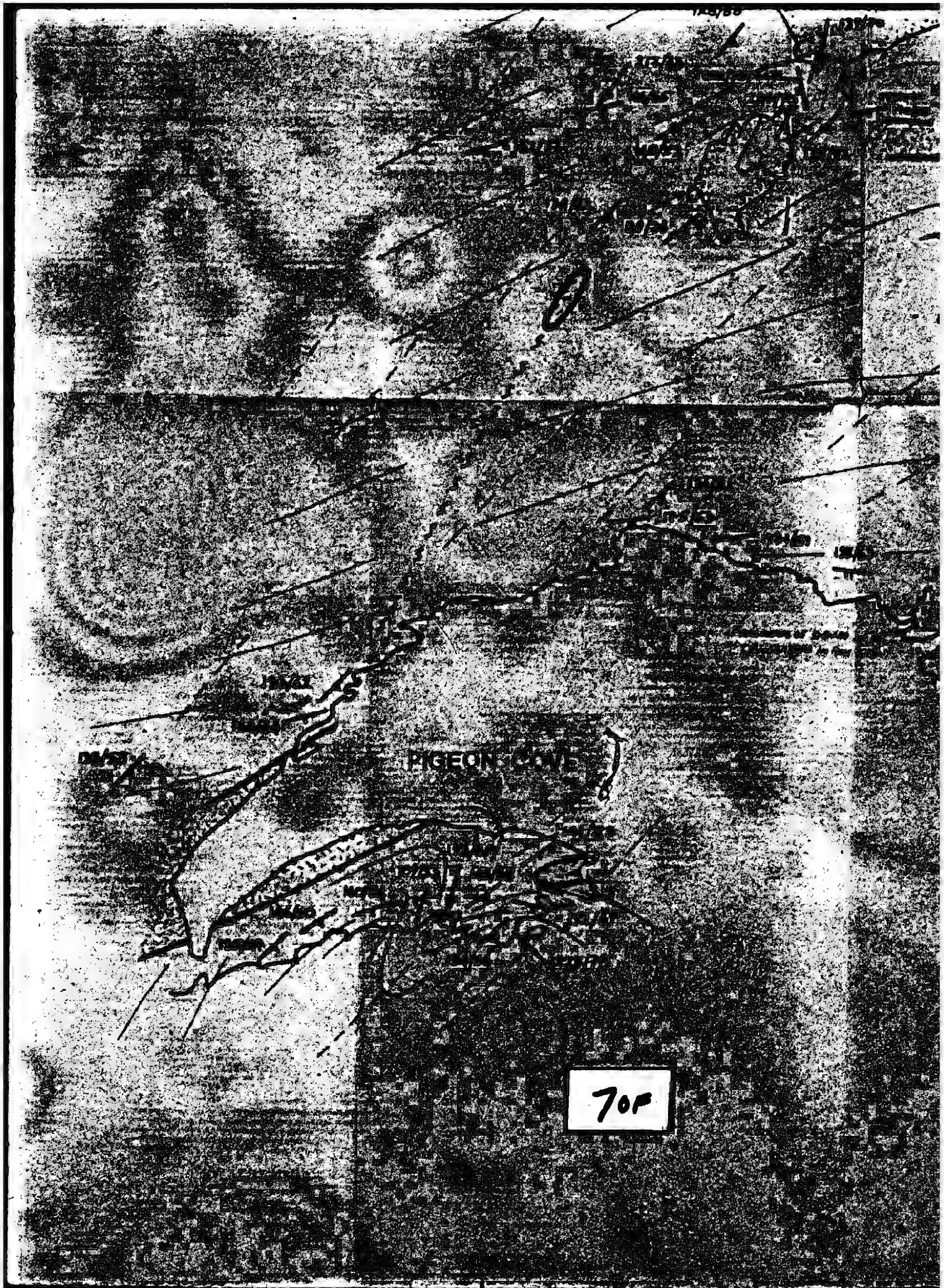
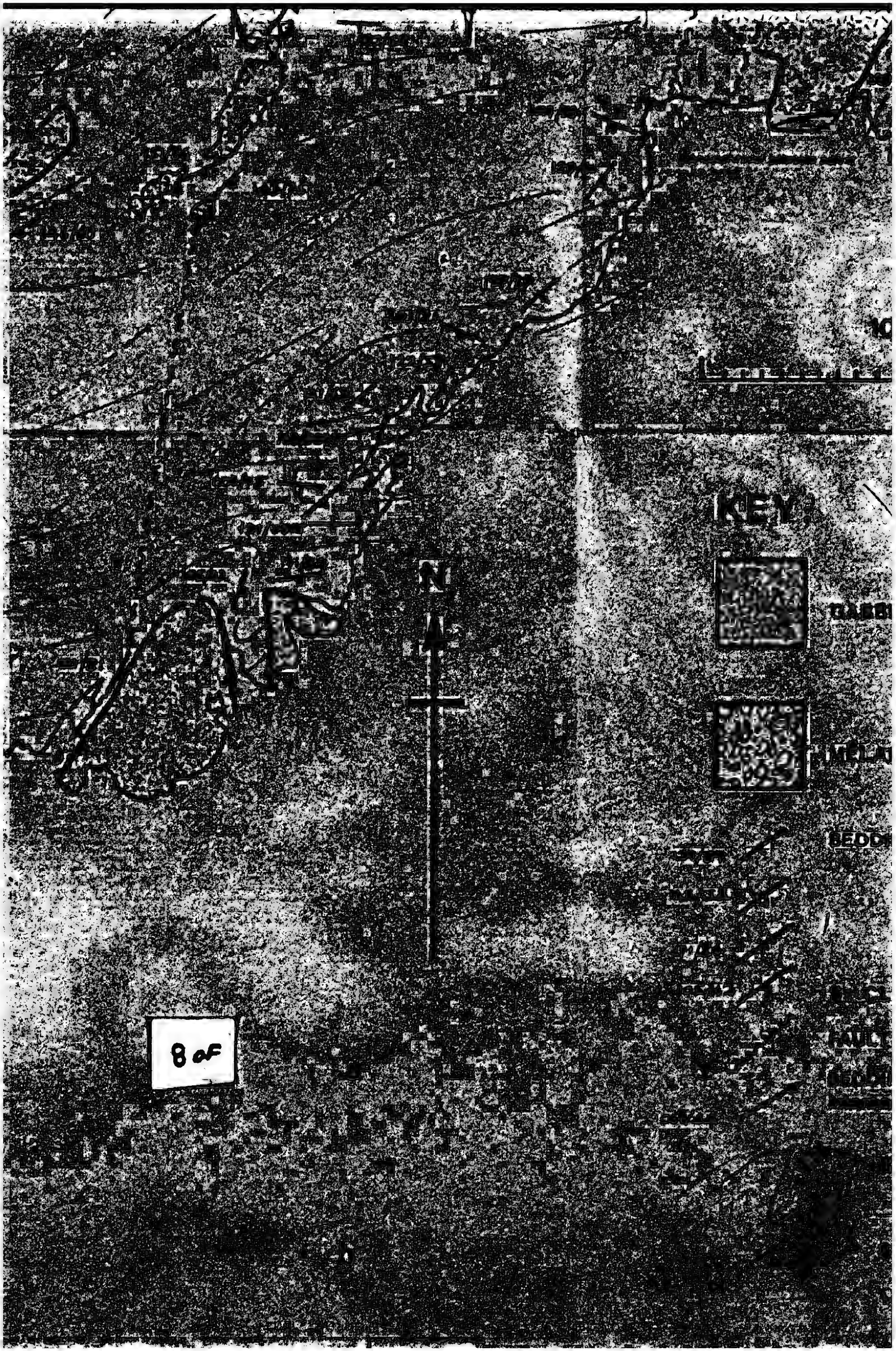

PIGEON COVE
7OF



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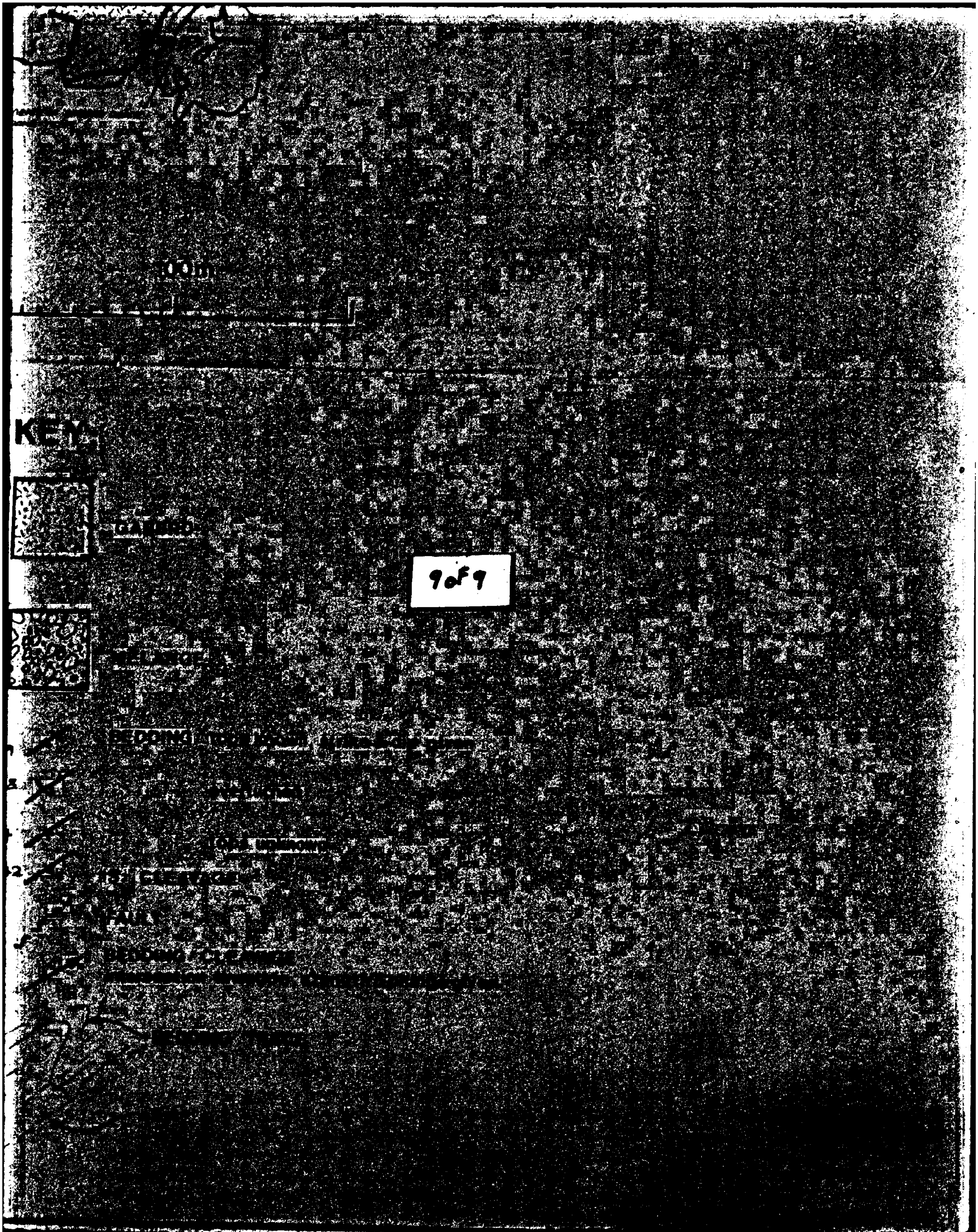
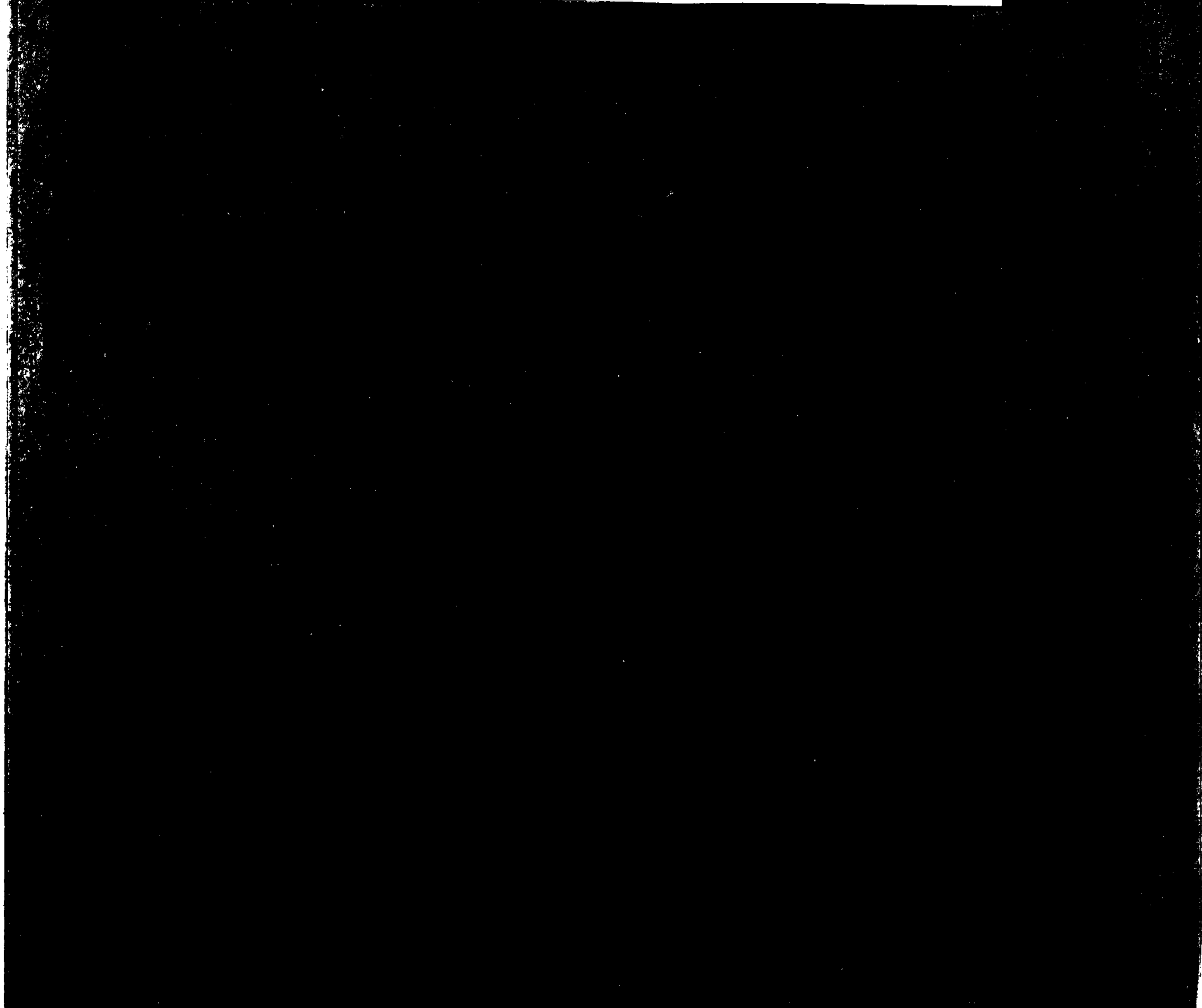

100m
KEY
GABBRO
9 of 9
MELANGE
BEDDING
CLEAVAGE
FAULT

Figure 31

Comparison between structural stacking order and original position of slices at Quirpon (Hare Bay) and In the Humber Arm Allochthon. This figure shows the correlation between the transported Goose Tickle Formation and the tectonostratigraphically equivalent Blow-Me-Down Brook Formation



COMPARISON BETWEEN STRUCTURAL STACKING ORDER & ORIGINAL POSITION OF SLICES AT QUIRPON (HARE BAY) AND IN THE HUMBER ARM ALLOCHTHON.