# STRUCTURAL STUDIES OF THE GANDER AND DAVIDSVILLE GROUPS IN THE CARMANVILLE - LADLE COVE AREAS, NEWFOUNDLAND



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by

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ABSTRACT

The study area lies in the northeastern margin of the Central Mobile Belt of Newfoundland Appalachians. It is underlain by the lower Palaeozoic rocks of the Gander and Davidsville Groups, and an older gneissic complex considered a basement to the Gander Group.

The gneissic basement consists mostly of psammitic banded gneisses and interbedded micaceous quartzites which were unconformably overlain by the Gander Group. The latter includes psammitic and semi-pelitic schists, minor conglomerates, greywackes and basic lava flows that acquired a pre-Middle Ordovician composite fabric and a greenschist to amphibolite facies grade of metamorphism. The Group is separated from the overlying less deformed and metamorphosed sequence of mafic agglomerates, grey slates, interlayered siltstones, minor conglomerates, greywackes and black slates of the Middle Ordovician Davidsville Group by either a mélange, ultramafic belt, or a fault.

Intrusion of the pre-Middle Ordovician garnetiferous muscovite-biotite granites post-dated the development of the composite gneissic banding in the gneissic basement, and predated the first deformation of the Gander Group. A post Middle Ordovician (pre-Devonian?) quartz diorite intruded the Gander Group, Davidsville Group and the mélange. Evidence suggests that the quartz diorite intruded the Davidsville Group before the latter was penetratively deformed.

The ultramafic rocks of the Gander Group are composed dominantly of pyroxenite, minor chromite bearing

serpentinites and talc-carbonate schists which were marginally metamorphosed, and have the same composite fabric as the enveloping metasedimentary rocks. They do not appear to be genetically related to the serpentinized dunite breccia, mafic pillow lavas and hornblende gabbros which were incorporated as blocks in the nearby mélange belt separating the Gander and Davidsville Groups. The mélange is considered tectonic, having been formed during the upthrusting of the Davidsville Group (onto the Gander Group) as a folded nappe.

Four main phases of deformation (each producing a fabric) are recognized in the Gander Group, and two other phases (one penetrative), which may or may not be related to those of the Gander Group, are recognized in the Davidsville Group. Evidence suggests that the third deformation of the Gander Group pre-dated the first deformation of the Davidsville Group. The main schistosity in the Gander Group is a second fabric, which has formed by transposition of an earlier one. Tight to isoclinal folds, boudins and interference patterns were produced during the second and third deformations of the Group. A major southwesterly plunging synform, and numerous minor folds were generated during the first deformation of the Davidsville Group. Kink bands and a series of faults offset the regional foliations and are believed to be developed after the main episodes of folding.

The climax of metamorphism in the Gander Group, occurred during the second phase of deformation, producing muscovite-biotite schists, actinolite schists, and amphibolites. A later thermal metamorphic event affected rocks of the Gander and Davidsville Groups.

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# CHAPTER ONE

# INTRODUCTION

## LOCATION

The study area is situated on the northeastern part of the Atlantic coast of Newfoundland between latitudes 49°17' and 49°29' North, and longitudes 54°5' and 54°00' East (Fig. 1). It covers approximately 256 $km^2$ (100 sq miles) and is accessible by road from Wesleyville (70.4km), and from Gander (65.6km).

Carmanville is the biggest of the three coastal (fishing) settlements located in the area. It is connected with Aspen Cove and Ladle Cove by an unpaved all-weather road. Carmanville is an important port of call for the Government Steamship Service. There is a regular ferry service between it and Fogo Island.

## PHYSIOGRAPHY

The main physiographic features of the area are that of a heavily glaciated region in which gentle rolling hills and ridges separate low-lying marshes with numerous ponds. Drainage is poor. The trend of these ridges and isolated hills conforms with the general NE-SW structural trend.

Post-Pleistocene erosion has not significantly altered the glacial topography. The rivers still flow as misfit streams in their flat-bottomed valleys, which are in places covered with glacial till and erratics. Numerous low-energy


Figure 1. Location Map.

streams connect several ponds through shallow and marshy gullies. The Ragged Harbour River which is fed by sluggish streams and ponds, drains the eastern half of the area. Its course is probably controlled by a NE-trending fault along most of its 21 km. length.

Evidence from glacial striations and roches moutonees (Plate 1) indicates that ice moved from SW to NE. The bush fire of 1961 destroyed the extensive spruce forest, and subsequent erosion has greatly increased the amount of exposure inland.

The percentage of rock outcrop is generally poor (less than 50%), but best exposures are seen along the coasts and at the crests of isolated hummocky hills and ridges. The high ground is formed by the mafic agglomerate, ultramafic and metasedimentary rocks, while the low ground is generally formed by the granitic rocks.

## GENERAL GEOLOGY

The study area lies in the northeastern margin of the Central Mobile Belt of the Newfoundland Appalachians (Figs.2a&b) It is underlain by the gneissic rocks of the gneissic terrane (Kennedy and McGonigal, 1972), polyphase-deformed metasedimentary rocks of the Gander group, less deformed and recrystallized mafic volcanic and sedimentary rocks of the younger Davidsville Group, and granitic to ultramafic rocks. The area represents the exposed northeastern end of the Gander Zone or Zone F (Williams et al, 1972) which extends

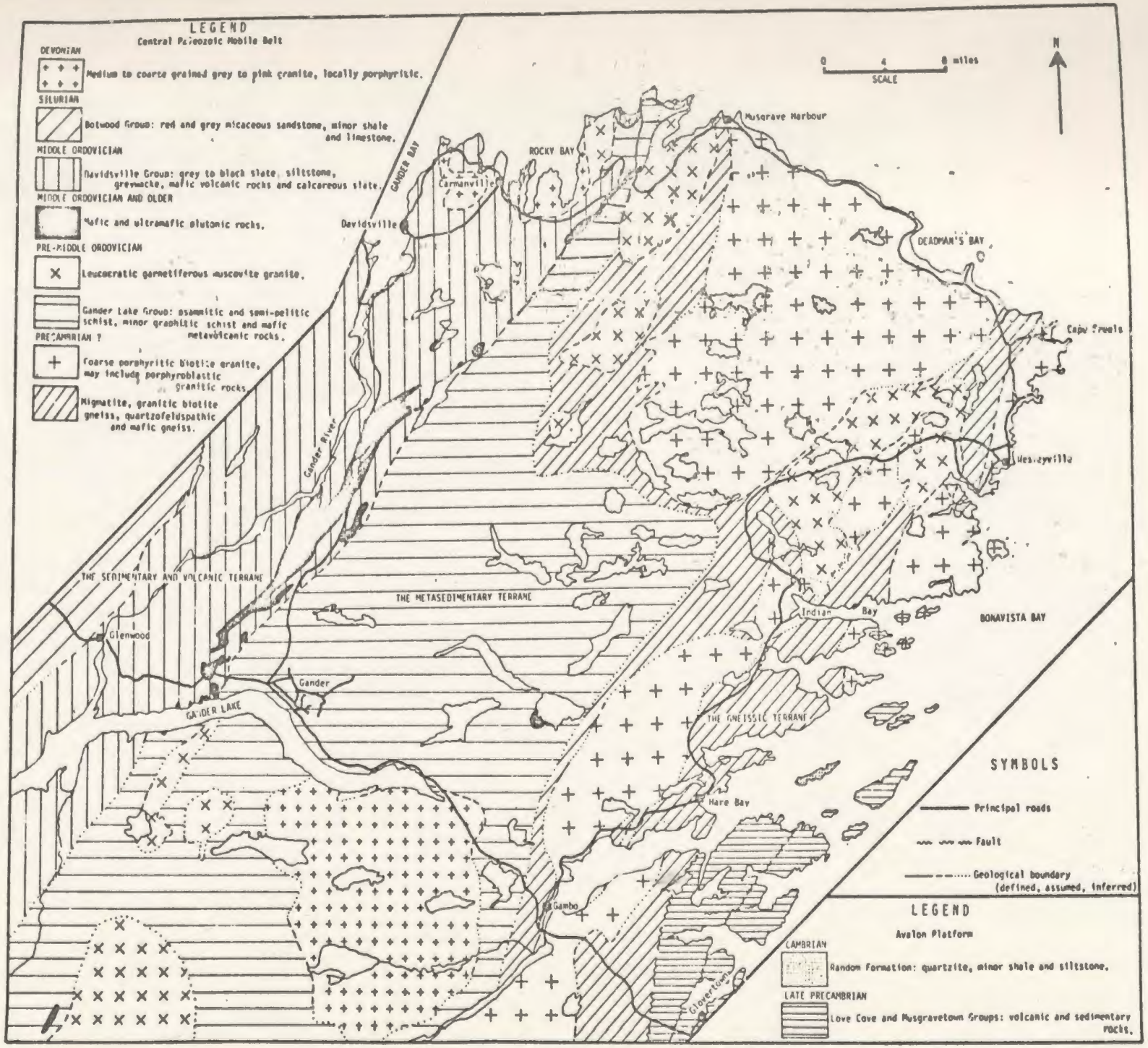



Figure 2b: Geologic summary map of the Gander region, slightly modified after Kennedy and McGonigal (1972).

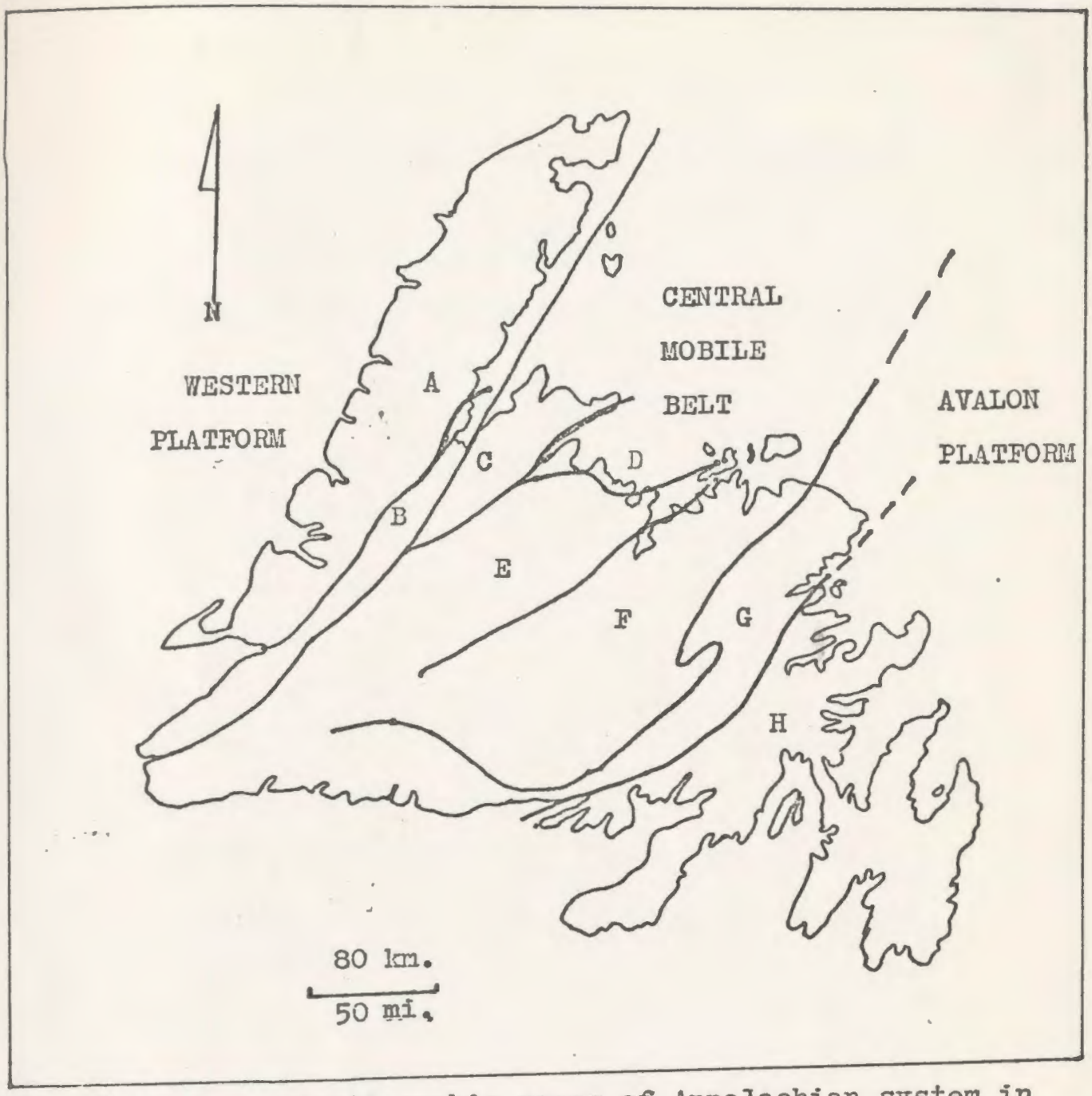



Figure 2b. Tectono-stratigraphic zones of Appalachian system in Newfoundland, after Williams et al, (1972).

southwards towards Baie d'Espoir on the south coast of Newfoundland. The Avalon Platform (Kay & Colbert,1965) consisting chiefly of Precambrian to Late Cambrian sediments and volcanic rocks, is situated east of the Gander Zone. The Gander Group is separated from the underlying gneissic basement by an inferred angular unconformity (Kennedy & McGonigal,1972a), and from the overlying Davidsville Group by either a melange, ultramafic rock or a fault.

The oldest rocks (in the area) are the para-gneisses and interlayered micaceous quartzite of the gneissic terrane exposed at the southeastern corner of the area. The composite gneissic banding of the rock pre-dates the intrusion of the pre-Middle Ordovician garnetiferous muscovite-biotite granite, and Kennedy and McGonigal (1972a) have suggested that the gneissic terrane is a basement to the Gander Group.

The Gander Group includes psammitic and semi-pelitic rocks, minor greywackes, conglomerates and basic volcanic flows. The Group acquired a pre-Middle Ordovician composite fabric and greenschist to amphibolite facies grade of metamorphism, and was intruded pre-tectonically by garnetiferous muscovite-biotite granites (cf.Kennedy & McGonigal,1972a). It has extensive inland and coastal outcrops in the Aspen Cove-Ladle Cove areas, but it is poorly exposed near its contact with the older para-gneissic rocks in the southeast (Fig. 3).

In this area, the phyllites and chlorite schists (of the Group) form discontinuous outcrops which are separated from the ultramafic rocks by a NE-trending fault.

The ultramafic rocks consist of actinolite pyroxenite (diallagite), and minor chromite bearing magnetic serpentinite which are marginally metamorphosed to talc-carbonate schists. These rocks have composite fabrics that are identical with those in the enveloping metasedimentary rocks of the Gander Group. They are therefore considered pre-Middle Ordovician in age.

The Davidsville Group is represented by mafic agglomerates, spotted grey slates and interlayered thin beds of siltstone, minor conglomerates, greywackes and black slates. The Group is best exposed between Carmanville and Bullrush Pond in the core of a major syncline where it overlies the metasediments of the Gander Group. Rocks of the Davidsville Group were thermally metamorphosed before they were penetratively deformed presumably during the Acadian (Middle Devonian) orogeny. The single axial planar cleavage is continuous throughout the metasedimentary rocks of this Group, and has a common NE regional trend which is subparallel to that of the composite regional schistosity in the Gander Group.

The melange belt separating the Gander and Davidsville Groups has dark slaty matrix and clasts of varying composition and sizes, including massive blocks of serpentinite, horn-

blende gabbro, metasediments (including metamorphic rocks probably derived from the Gander Group or older), mafic agglomerates and pillow lavas. The mélange also shows the effect of post emplacement thermal metamorphism, having been intruded by granitic rocks in the Aspen Cove and Carmanville areas.

PREVIOUS WORK

Pioneering work in the area started in the early days of Murray (1874), who was the first to organize a reconnaissance survey of the mineral resources in the Fogo District and Gander Lake areas. Howley (1876) described several outcrops of slates in the same area, and relying on local fossil evidence east of Gander Bay, he assigned a Silurian age to the slates. He also speculated on a possible occurrence of chromite deposits in the ultramafic rocks exposed northeast of Rocky Bay.

Several years later, Snelgrove (1939), described the general geology of Shoal Pond hill, and considered the chromite-bearing serpentinite as intrusive into sedimentary and volcanic rocks. Subsequent works were directed towards economic exploration of the ultramafic belt.

Regional reconnaissance work started in the south when Twenhofel (1947), described a sequence of phyllites, slates, argillites and quartzites exposed in the shore cliffs

of Gander Lake as 'Gander Lake Series.' He considered them to be Silurian in age because of their similarity in lithology with his Yellow Fox, Indian Island and Dog Bay Formations. Baird (1951) however found Middle Ordovician graptolites (Dicronograptus and Climacograptus) in the black slates of the same 'Series' exposed near Glenwood on the bank of the Gander River.

Jenness (1958) described the sedimentary and volcanic rocks enveloping the Gander River Ultramafic Belt as the Gander Lake Group. He subdivided the group into three conformable Lower, Middle and Upper units, and assigned a Middle Ordovician age to them on the basis of Middle Ordovician brachiopods and trilobites found in the Middle and Upper units. He considered a sequence of interbedded greywackes, sandstones, conglomerates, mafic tuffs and agglomerates exposed at the shore line of the Gander Lake as typical of the Gander Lake Group (Middle and Upper units). He defined the Lower unit to include the oldest and most recrystallized rocks (gneisses and schists) of the group, and argued that metamorphism was thermally induced, increasing from west towards the granitic plutons in the east where it reached a biotite grade. The intrusive granitic masses in the area were considered Devonian in age (Jenness 1958, 1963; Williams, 1964b) implying that the thermal metamorphic event in Jenness' Gander Lake Group was also Devonian in age.

Recent work by Kennedy and McGonigal (1972a), has shown that rocks previously described as the Gander Lake Group (Jenness, 1958; Williams, 1964b), have different tectonic,metamorphic and granitic intrusive histories. They argued that the rocks hitherto described as part of Jenness' Lower unit included metasedimentary rocks that had acquired a pre-Middle Ordovician composite fabric,and had been intruded by granites before the deposition of most of the rocks mapped as the Middle and Upper units by Jenness, and which were underlain by an even older gneissic basement. The result of their structural studies shows that Jenness' Gander Lake Group can be divided into three distinct terranes referred to as the "Gneissic, Metasedimentary and Sedimentary and Volcanic Terranes". They considered the gneissic terrane as the oldest, and probably a basement to the metasedimentary terrane from which it is separated by an inferred angular unconformity. Kennedy and McGonigal referred to the metasedimentary terrane as the Gander Lake Group which they said was intruded pre-tectonically by leucocratic garnetiferous granites, and had acquired composite fabric before the deposition of the Middle Ordovician and Silurian sedimentary and volcanic terrane (Middle and Upper units of Jenness' Gander Lake Group and the Silurian Botwood Group). For the Middle Ordovician rocks, they have proposed a new name, Davidsville Group, and observed that the Group is less re-

crystallized and deformed than the underlying Gander Lake Group with which it is separated by a mélange zone or angular unconformity.

PRESENT WORK

The important recognition by Kennedy and McGonigal (1972), that rocks hitherto described as the Gander Lake Group (Jenness, 1958; Williams, 1964b), have complex but distinct depositional, tectonic, metamorphic and granitic intrusive histories, makes further work in the eastern margin of the Central Mobile Belt of Newfoundland Appalachians increasingly necessary. The only effective way of attempting a tectono-stratigraphic subdivision of rocks that have passed through several phases of deformation and metamorphism (plus granitic intrusive episodes), is to study their internal structures and major events related to these.

Further structural work in this area was suggested by Dr. M.J. Kennedy, and the field work was done by the writer in summer 1972.

The present work accepts Kennedy and McGonigal's three-group subdivisions of Jenness' original Gander Lake Group, but prefers to use the name Gander Group for their meta-sedimentary terrane after McGonigal (1973) Abundant evidence now exists in carrying out complete delineation of geologic boundaries between the Gander and Davidsville Groups.

More outcrops of the mélange belt are mapped inland, and the belt can be seen to separate the two groups. The intrusive relationships of pegmatitic quartzo-feldspathic veins associated with post-Middle Ordovician granitic masses, and the age of common (contact) metamorphic minerals relative to deformational phases, have all helped in a complete delineation. The ultramafic rocks previously mapped as intrusive into the Davidsville Group have the same (pre-Middle Ordovician) composite fabric as the enveloping metasedimentary rocks of the Gander Group, and are therefore considered pre-Middle Ordovician in age.

# CHAPTER TWO

# LITHOLOGY

## INTRODUCTION

The study area is underlain by three main groups of rocks described (after Kennedy & McGonigal, 1972; McGonigal, 1972) as the gneissic basement, Gander and Davidsville Groups. Three formations are recognized in the Gander Group, and the Davidsville Group is described under three distinctive rock units.

The nature of contacts between the Gander Group and the underlying gneissic basement is not fully established, but since the composite gneissic banding of the basement can be shown to pre-date the emplacement of the garnetiferous muscovite-biotite granites, and the composite fabric (or earliest fabric) in the Gander Group can be shown to post-date the intrusion of the same granitic masses, a major angular unconformity separating the two terranes has been suggested (cf. Kennedy & McGonigal, 1972). The Gander and Davidsville Groups are separated by either a mélange, ultramafic rock or a fault.

Unlike the overlying Davidsville Group, where fossil evidence supports a Middle Ordovician age for the Group (Jenness, 1958), the Gander Group (in the study area) has not yielded any fossil shells. Since the Group has pre-Middle

Ordovician composite fabric and granitic intrusions (cf. Kennedy & McGonigal, 1972a), it is consequently pre-Middle Ordovician in age.

The stratigraphic succession and thickness of beds are difficult to ascertain as the beds are extensively deformed and metamorphosed. The formations or units in each of the Groups are therefore described in their order of structural succession.

Table 1

Table of Formations

| | | |
|---|---|---|
| Cenozoic: Pleistocene; | Glacial boulders, erratics, gravels sands and clays | |
| | Angular Unconformity | |
| Palaeozoic | Middle Ordovician or younger | Basic dykes<br>Biotite-quartz diorite |
| | Intrusive Contact | |
| | Middle Ordovician<br>Davidsville Group<br>Unit 3. Black slates<br>Unit 2. Greywacke and Conglomerate<br>Unit 1. Grey slates (and siltstones)<br>Mafic agglomerates and mafic pillow lavas | |
| | Tectonic Contact - Mélange | |
| | Pre-Middle Ordovician<br>Gander Group<br>Pyroxenites and Serpentinites<br>Garnetiferous muscovite-biotite granites | |
| | Intrusive Contact | |
| | Ladle Pt. Formation<br>Ragged Pt. Formation<br>Ragged Harbour River Formation | |
| | Angular Unconformity (?) | |
| Precambrian(?) | Gneissic Basement | |

THE GNEISSIC BASEMENT

Several patches of isolated and locally faulted outcrops of gneissic basement occur in the South Pond area some 6 km. east of Island Pond (Fig. 3). The rocks consist of psammitic banded gneiss and interbedded micaceous quartzite. The gneissic banding is formed by 1-2mm wide alternating layers of quartzofeldspathic materials constituting the light acid bands, and brownish green biotite + muscovite ± hornblende ± garnet, forming the dark coloured mafic bands. In some places there may be scaly bands of garnet (less than 2mm. wide), which are generally truncated by the gneissic banding of the rock. The latter is a composite fabric formed by transposition of an earlier one.

The mineralogical composition of the psammitic gneiss is the same throughout its outcrop. The rock contains high percentage of quartz (60%), minor plagioclase (An 5%), biotite (15%), muscovite (5%), garnet (10%), accessory iron ore, ± hornblende, fibrolite and secondary chlorite.

The quarzite consists predominantly of polygonized quartz crystals of medium grain size, and less than 5% of accessory muscovite, iron ore, garnet and secondary chlorite.

These gneisses and quartzites are the exposed part of the migmatitic gneissic terrane described elsewhere by Kennedy and McGonigal (1972), as a basement to the Gander Group. The field relationship of the two terranes is still

obscure as no contacts have been actually mapped. As the composite fabric in the basement complex pre-dates the emplacement of the garnetiferous muscovite-biotite granites (Plate 2), whereas that in the Gander metasediments post-dates the intrusion of the same granites, Kennedy and McGonigal (1972a and b), argue that the two terranes were separated by a major angular unconformity. Since the basement rocks had acquired composite fabric before they were intruded by garnetiferous muscovite-biotite granites in pre-Middle Ordovician times, they must have been deformed earlier, and the rocks can probably be safely considered to be Precambrian in age.

THE GANDER GROUP

The Gander Group comprises a clastic sequence of psammitic and semi-pelitic rocks, including minor conglomerates and greywackes, together with metavolcanic rocks and amphibolites which are well exposed in the Aspen Cove-Ladle Cove areas, but are very poorly exposed east of the ultramafic rocks near their contact with the gneissic basement in the south. The ultramafic rocks are exposed in a NE-trending belt that extends southwards into the Gander Lake area, where rocks similar to the above have also been described (Jenness, 1958; Williams, 1964b; Kennedy & McGonigal, 1972a).

The Gander Group can be divided into three main

Plate 1. Roches moutonees, Great Bear Place (semi-pelitic schist of the Ragged Pt. Formation).

Plate 2. Post-tectonic intrusive relationship of a dyke of the garnetiferous muscovite-biotite granite (Ragged Harbour pluton) with the gneissic basement, near Island Pond.

lithostratigraphic formations, viz: Ragged Harbour River Formation, Ragged Pt. Formation and Ladle Pt. Formation. The first two formations are separated by a fault, and the contact between the Ragged Pt. and Ladle Pt. Formations is unexposed, but the abrupt change in lithology and linear physiographic features in the contact zone (seen from the aerial photographs), suggest that they are separated by a fault. Since the two formations were intruded pre-tectonically by the garnetiferous muscovite-biotite granites (Fig. 3), this fault must predate the first deformation of the Gander Group and can be considered a slide (Fleuty, 1964). The Group had suffered pre-Middle Ordovician polyphase deformation and green-schist to amphibolite facies metamorphism.

1. Ragged Harbour River Formation

The name Ragged Harbour River Formation is proposed for the chlorite schists and phyllites that underlie an area of approximately 15 $km^2$ east of the ultramafic belt in the valley of the Ragged Harbour River. The rocks of this Formation are best exposed at the southern end of the Ragged Harbour River, where they are faulted against the gneissic basement. In the Island Pond area, their outcrop is truncated by a S-W trending fault separating the phyllitic rocks from the black slates of the Middle Ordovician Davidsville Group.

## The Chlorite Schist

The Chlorite Schist (structural thickness about 200m) is more extensive than the phyllites which it structurally underlies. The rock has an appearance of a "greenstone" and contains abundant chlorite, quartz, mica, and less sodic plagioclase, sphene and hematite. Most of the greenish chlorite crystals are pseudomorphs of biotite. Others have recrystallized from the breakdown of unstable minerals (probably garnet) during the later retrogressive metamorphism. No bedding is recognized in the chlorite schists, but finely laminated units can be seen in the phyllites.

## The Phyllites

The Phyllites (structural thickness about 150m) are light grey coloured rocks weathering to tarnished brown colours. They are often finely banded in pelitic and semi-pelitic layers (individual layers usually less than 5 mm thick). The rocks are highly brecciated near their contact with the ultramafic rocks having been separated from the latter by a N-E trending fault (Ragged Harbour Fault). The fault movement was associated with the re-crystallization of (a network of) quartz veins along the planes of schistosity and disoriented fractures (Plate 3).

The phyllites differ from the chlorite schist in texture, and also in containing little or no chlorite.

Plate 3. Recrystallized quartz bands in brecciated phyllite near fault zone - Ragged Pt. Formation.

Plate 4. Layered stromatic structure in the migmatitic gneissic basement.

The rock contains fine-grained mica (50% biotite > muscovite), minute grains of quartz (30%), intertitial plagioclase (5%) and minor leucoxene (5%). Garnets are absent, and in some sections, reddish leucoxene occurs as a "vein filling" mineral.

The actual age of the Ragged Harbour River Formation as well as other formations in the Gander Group is uncertain in the absence of any fossil evidence. Kennedy and McGonigal have considered the phyllites as unconformable cover rocks of the basement, while Jenness (1963), and Williams (1964) briefly described the chlorite schist as volcanic rocks into which the ultramafics intruded. The formation occupies the lowest structural level in the Gander Group, and is possibly the oldest in stratigraphic succession.

2. Ragged Pt. Formation

The term Ragged Pt. Formation is here employed to describe a thick sequence (structural thickness about 2000m) of pelitic and semipelitic schists, minor conglomerates, pebbly psammites and layered amphibolites which are well exposed along the coast in the Ragged Pt. area, and are discontinuously exposed inland between the intrusive garnetiferous muscovite-biotite granites. In the Bullrush Pond area, the formation is separated from the overlying Middle Ordovician Davidsville Group by a mélange. The stratigraphical succession in this formation is obscure,

as local overturning associated with variation in intensity and style of folding makes tops (where known) rather unreliable for regional synthesis. Altogether five distinct assemblages are recognized:

(i) biotite > muscovite + quartz + plagioclase ± garnet + tourmaline = biotite schist

(ii) muscovite > biotite + quartz + garnet + plagioclase + andalusite ± cordierite = muscovite schist

(iii) hornblende + biotite + muscovite + quartz + plagioclase ± garnet = hornblende schist

(iv) diopside + actinolite + quartz + feldspar (Pl > Or) ± calcite + chlorite = actinolite schist

(v) pyrite + quartz + muscovite = pyritiferous schist

The Mica Schists: The commonest rocks in the Ragged Pt. Formation are the pelitic and semi-pelitic schists containing red biotite, muscovite, plagioclase ($An_{22}$) and garnet porphyroblasts in a schistose groundmass of quartz, hornblende (or actinolite), tourmaline, and accessory iron ore. The dark and white micas are seen throughout the rock units but in varying proportions. A distinction is therefore made when biotite occurs in excess of muscovite as in the pelitic biotite schists, or muscovite predominates over biotite as in the semi-pelitic muscovite schists. Other schistose rocks whose mineralogy varies slightly from the above also occur in scattered outcrops within the formation.

The biotite schists are well exposed in the Ragged

Pt.-Ladle Cove area where they were intruded by the garnetiferous muscovite-biotite granite and pegmatite. The rock is strongly schistose, with plagioclase and reddish brown biotite porphyroblasts arranged in a subparallel alignment with the main schistosity in a lepidoblastic texture. Where there had been local segregation of dark and light coloured minerals the rock exhibits a banded habit. This banding is too fine to be true gneissic banding (cf. Van Hise, 1904) and the rocks will simply be described as coarse grained biotite schists. All the primary sedimentary structures are lost in these rocks, but in the adjacent, apparently interbedded psammites, finely laminated and graded units can be seen. Tops show the sequence to be facing to the east.

The muscovite schists and interbedded quartzitic psammites occur at the highest structural level of the Ragged Pt. formation. Their outcrops form topographic highs in the Round Pond - Bullrush Pond area. Their field relationships with the biotite schists, conglomerates, and metavolcanic rocks can be best examined in an outcrop southeast of Bear Place where the conglomerates are structurally overlain by the metavolcanic rocks. The conglomerates are essentially oligomictic containing psammitic (and volcanic?) pebbles which are stretched in a semipelitic matrix.

The semi-pelitic muscovite schists are massive in some isolated outcrops, but they are more generally interstratified with thin beds (1 cm - 1 m) of quartzitic psammite and narrow pinkish bands of garnet. Where the schists are extensively granitized the garnet bands stand out as the resistant paleosome which can be followed into the ungranitized country rock. The granitized fraction is weakly foliated and contains abundant sodic plagioclase (oligoclase $An_{24}$-50%)*, slightly altered biotite with pleochroic haloes (25%), quartz (20%),minor garnet and muscovite. In this area of contact migmatisation (contact zones of the Aspen Cove and Round Pond Plutons), the semipelitic schists have gradational contact with the granite, but elsewhere in the more psammitic greywacke units (Aspen Cove coast) the granite maintains an intrusive contact with the metasediments (Plate 7).

The Actinolite Schists

Two varieties of actinolite schists representing metamorphosed impure carbonate or volcanogenic sediments, and mafic volcanic rocks occur in the area. They are generally exposed at the fold cores of minor $F_2$ folds. About 200 m east of Ladle Cove, a thin (5 m) bed of diopside-actinolite schist occurs. The rock is fine-grained and contains actinolite (60%), diopside (5%), plagioclase (Andesine $An_{38}$)*, quartz (20%), minor muscovite,

* Composition of plagioclase obtained by extinction angle (Michel-Lévy) method on sections normal to (010).

Plate 5. Thinly bedded semi-pelitic schist with penetrative ($S_2$) schistosity, Ragged Pt. formation near Bear Place.

Plate 6. Granitized semi-pelitic schist between the Round Pond and Aspen Cove plutons.

sphene and iron ore. The actinolite prisms are arranged in a subparallel alignment with the main schistosity in a nematoblastic texture. Some small crystals of calcite are often seen in the schistose matrix. In one variety, which is probably metavolcanic, the rock is almost wholly composed of decussate aggregates of actinolite with lesser quartz and more plagioclase ($An_{38}$). Megascopically, the rock is fine-grained, less schistose and greyish green coloured. It overlies the conglomerates at an outcrop about 50m east of the Bear Place (near the Aspen Cove Highway).

The Hornblende Amphibolites

The amphibolitic rocks occur at the lowest structural level of the Ragged Pt. formation. Two types of amphibolites are recognized. For the purposes of general description, the term amphibolite will be restricted to schistose rocks whose constituent minerals are formed by hornblende and plagioclase, with variable amounts of quartz and accessory biotite, muscovite and iron ore (cf Moorehouse, 1964; Jackson, 1970; Turner & Verhoogen, 1960). The amount of quartz and contained iron oxide in the rock (Moorehouse, 1964) and the existence of accessory biotite or muscovite (Orville, 1969; Shaw & Kudo,1965) are frequently used in conjunction with field disposition of the amphibolites to prove a sedimentary or igneous origin for the rocks.

When the rock has a high percentage of quartz, little or no iron ore and biotite, a sedimentary origin is generally suggested (i.e. para-amphibolite). On the other hand, the amphibolites formed from metamorphosed basic lavas or intrusive igneous bodies will contain lesser quartz and muscovite and more plagioclase, iron oxide and biotite.

The para-amphibolite is a medium-grained banded rock containing hornblende (50%), plagioclase ($An_{40}$ 15%), quartz (30%), minor biotite, garnet, orthoclase and muscovite. The banding is formed by about 1-2mm thick alternating layers of dark and light coloured minerals. These are probably developed from the original bedding by recrystallization of hornblende in the dark mafic layer, and plagioclase and quartz in the light felsic layer. These layers are parallel to the bedding and were folded by $F_2$ folds.

Hornblende occurs in equant and xenoblastic crystals which are moderately pleochroic from yellowish green to green. Plagioclase (Andesine $An_{40}$) occurs as tabular polygonal aggregates in the felsic band. The crystals are generally polygonized round the $F_2$ fold hinges indicating that their recrystallization is syntectonic with respect to second deformation.

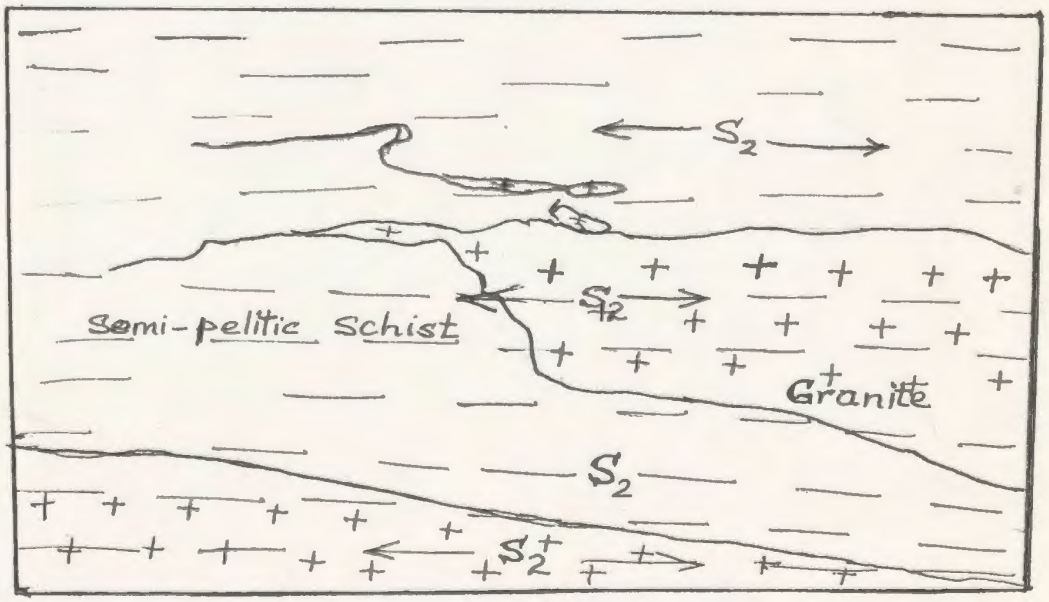
Ortho-amphibolites or metadiabases are discussed in Chapter Three.

3. Ladle Pt. Formation

The comparatively more deformed and less recrystallized rocks occurring at the highest structural level of the Gander Group are described under the new name Ladle Pt. Formation. The Formation consists of about 700 metres thick sequence of pelitic and semi-pelitic graphitic schists, feldspathic greywackes and lenticular interbeds of chert and volcanic ash, which are best exposed along the coast between Aspen Cove and Ladle Cove. In the Ladle Pt. area, a complete section across the sequence can be examined. The contact between this Formation and the (structurally) underlying Ragged Pt. Formation is not exposed, but the abrupt change in lithology and linearity of topographical features along this zone of lithologic discontinuity are suggestive of a faulted contact. The extent of the Formation westwards is unknown, but it appears to be overlain by the mélange belt whose outcrop is also seen across the bay (Aspen Cove) at two small islands immediately west of Ladle Pt. The rocks of the Ladle Pt. Formation were more folded than any other Formation in the Gander Group. This is exemplitied by the occurrence of three generations of folds which were further modified by later deformations.

The graphitic schists are dark-grey coloured rocks containing fine-grained mica (40%, muscovite > biotite),

Plate 7. Pre-tectonic intrusive relationship of the garnetiferous muscovite-biotite granite (Round Pond pluton) with semi-pelitic schist of the Gander Group near Aspen Cove. Details not well shown in the plate are illustrated below.



graphite (10%), andalusite (10%), garnet (10%), quartz (30%), minor plagioclase, cordierite, chlorite and iron ore.

The andalusite crystallizes in coarse (5 cm. along c-axis) porphyroblastic crystals across the second ($S_2$) schistosity. The mineral is coarsest and most abundant where quartzo-feldspathic pegmatitic veins cut across the graphitic schists. In some places the mineral occurs in clusters of pegmatitic chiastolite crystals (Plate 9).

The garnet porphyroblasts have inclusion trails of quartz, graphite and mica (muscovite), and the mineral is generally concentrated in the more psammitic layers in places where the rocks are thinly banded (Plate 28).

At Ladle Pt. headland, about 6m thick conglomeratic volcanogenic sediment is exposed overlying and faulted against the graphitic schist. The "clasts" in this rock are formed by silicified volcanic rock fragments and cherts, which are set in a greyish green argillaceous matrix. The rock also contains lenticular interbeds (about 7 cm wide) of yellowish-green volcanic ash. In thin section, a more basic fraction of the rock consists of greenish hornblende, plagioclase (Andesine $An_{40}$), abundant iron ore (magnetite) and minor quartz & actinolite.

The greywackes constitute the most abundant single rock unit in the Ladle Pt. formation. The rocks are interbedded with silty argillites and minor volcanic ash.

Plate 8a Andalusite porphyroblasts in the grey slates of the Davidsville Group. The $S_1$ foliation forms augen around the andalusite. (crossed nicols X 4).

Plate 8b. Cordierite (and andalusite) crystals in the "spotted" grey slates of the Davidsville Group. Note the intersection of the bedding with foliation. (crossed nicols X 4).

The beds vary in thickness from a few centimetres to several metres, and are locally graded. At the headland south of Ladle Pt., an approximately 20m thick bed of feldspathic greywacke is exposed at the core of a northerly plunging $F_2$ synform. The rock is dense and granoblastic, containing predominantly anhedral plagioclase (Andesine $An_{36}$), which are set in a medium-grained matrix of quartz, minor orthoclase and flaky mica (biotite>muscovite).

THE DAVIDSVILLE GROUP

The lithologic subdivisions in the Davidsville Group (Table 1 ) consist of mafic agglomerates and pillow lavas, black slates, minor conglomerates, greywackes, thinly bedded siltstone and grey slates.

The group underlies an area of approximately 65 $km.^2$, and stretches from the Bullrush Pond (at the centre, see Fig. 3 ) westwards to Gander Bay (about 18 km. west of Carmanville). The group has an estimated thickness of 2000 metres but no exact figures can be given as beds are repeated by folding. The folds are generally tight to isoclinal, with a single penetrative axial planar foliation. The bedding structures are lost where the slaty cleavage is strongly developed, but where deformation and recrystallization are less intensive, primary sedimentary structures like cross lamination and graded bedding can be seen. Facing directions from such units show that probably

all the members of the Davidsville Group exposed east of Carmanville were regionally overturned. In some isolated outcrops, the beds are,however, uninverted. Consequently, there are downward and upward facing structures which make the order of stratigraphical succession in the group rather unreliable. The rocks will therefore be described in their order of structural succession.

The Mafic Agglomerates

The dark-green coloured and yellowish green weathering mafic agglomerates are well exposed in the Carmanville area, where they are cut by the biotite rich quartz diorite (of pre-Devonian age), and are presumably overlain by the slates of the Davidsville Group. In this area, where the agglomerates are considered autochthonous, the contacts between them and the slates are not well exposed, but near the Bullrush Pond area, where the rocks are allochthonous and underlain by the mélange, the contacts are well exposed, and grading in the slates show them to be facing away from the agglomerates.

The agglomerates consist of graded bedded units (2-10 metres thick), that locally contain finely laminated lenticular horizons of chert (generally less than 1 metre thick) towards their tops.

Petrography:

The pyroclastics contain rounded to subrounded

clasts of earlier mafic volcanic rocks, which are in places vesicular, or amygdaloidal when the vesicles are filled by recrystallized quartz. The clasts vary in sizes from a few mm. to rarely exceeding 10 cm. The matrix is more homogeneous and fine-grained, becoming very schistose in places.

The mineralogy of the clasts and matrix is essentially the same, except that the matrix has a greater concentration of opaque iron ore and sphene, while the clasts contain less altered, medium-grained crystals of hornblende. The fine-grained crystals of hornblende and clinopyroxene (?) in the matrix are extensively chloritized. This alteration is probably a deuteric phenomenom, as the prograde thermal metamorphism associated with the emplacement of the (Rocky Bay) quartz diorite, gave rise to subsequent recrystallization of hornblende near the contact.

The Sedimentary Formations of the Davidsville Group

The sedimentary formations of the Davidsville Group may be divided into three mappable conformable units. As discussed above, these units (1, 2 and 3), will be described in their order of structural succession. No fossils are found, but elsewhere the black slates of the group has yielded Middle Ordovician brachiopods and trilobites (Jenness, 1958).

Unit 1. The Grey Slates

The grey slates (thickness about 1500 m.) underlie an area of approximately 18 $km^2$, and are discontinuously exposed on both sides of the Carmanville-North River View Club highway for a distance of 8 km. The slates are dark-grey coloured rocks which locally (near their contacts with the intrusive granitic rocks), have recrystallized to fine grained andalusite schists. They are interlayered with thinly bedded, light-grey coloured siltstones. The two rock types have basically similar mineralogy, but recrystallized siltstones contain more garnet, angular quartz grains and lesser andalusite than the finer grained slates.

The schists contain andalusite porphyroblasts, scaly micas, garnet and occasionally, zircon as accessory detrital mineral. The chiastolite porphyroblasts with characteristic cruciform internal structure are more abundant nearer to the pluton and where the quartzo-feldspathic pegmatitic veins cut across the country rocks. The 'spotted' crystals of cordierite, flaky muscovite and secondary chlorite are more commonly seen further away from the pluton, where andalusite is also less abundant (Plate 11).

The metamorphism of these rocks which is thermally induced occurred before the rocks were penetratively deformed. The single axial planar foliation can be seen to

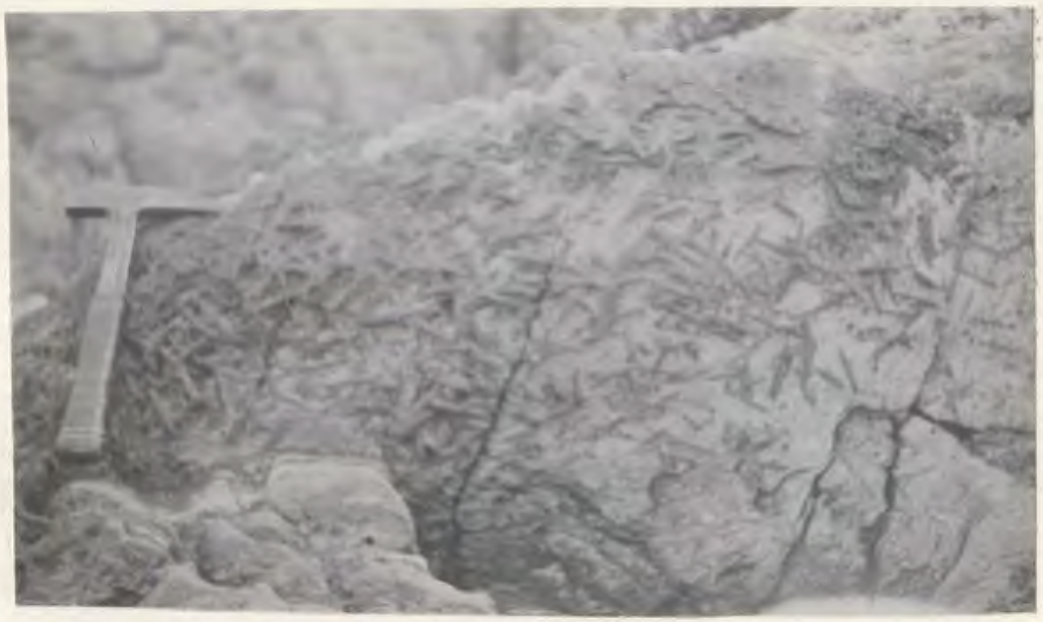


Plate 9. Andalusite (Chastolite) porphyroblasts in the graphitic schist of Ladle Pt. Formation.

Plate 10. Andalusite porphyroblast showing cruciform structure. The mineral grows across the third and second fabrics, i.e., $S_3$ and $S_2$ schistosities, graphitic schist of Ladle Pt. Formation (crossed nicols X 4).

form augen round the andalusite and cordierite porphyroblasts suggesting that recrystallization of these minerals pre-dated the first penetrative deformation of the rocks.

In the Island Pond area (about 5 km. south of Carmanville), about 10m. thick bed of siltstone is exposed in contact with the conglomerates (Plate 11). This rock is considered to form the base of the grey slate unit (i.e. Unit 1). The siltstone is fine-grained, and contains finely laminated and graded beds. Where tops are known, the beds are overturned (dipping steeply north-westerly).

Unit 2. The Greywackes and Conglomerates

Unit 2 consists of quartz-feldspar greywackes and minor conglomerates which are exposed in a narrow belt between the grey and black slates, i.e. between Units 1 and 3. The Unit has a thickness of about 100 metres, and maintains gradational contacts with slates of Units 1 and 3.

The rocks of Unit 2 are generally brecciated in their eastern thrust contact with the Gander ultramafic belt. Otherwise, the greywackes are dense grey coloured rock, containing coarse, poorly sorted, angular and subrounded grains of quartz, feldspar (mostly plagioclase), and some rock fragments, which are set in a fine-grained schistose matrix of clastic mica, quartz and calcite. The rock fragments vary in texture and composition from undeformed, well laminated siltstone lenses (about 15 cm.

Plate 11. Conglomerate of the Davidsville Group, southeast of Carmanville. The pebbles are 'virtually undeformed'. The conglomerate is in contact with siltstone bed.

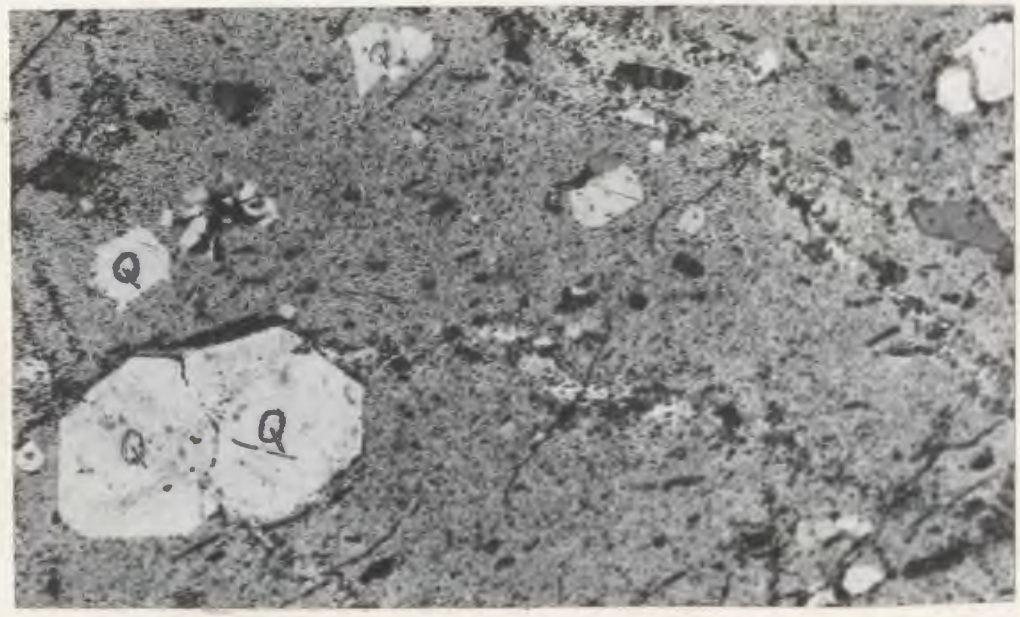



Plate 12a. Volcanic quartz (Q) in the rhyolitic pebble (whole plate) of the Davidsville conglomerate. (crossed nicols X 4).

Plate 12 (b). The same conglomerate flattened, near the melange belt, Davidsville Group (crossed nicols X 4).

Plate 13. Interlayered slates and sandstone (with sandstone dyke - see figure on page 93).

across), to pebble-size clasts of earlier tectonites (biotite schists and garnetiferous psammites). The preserved fabrics in these metamorphic tectonites predate the incorporation of these clasts in the greywackes. Kennedy and McGonigal (1972a), have suggested that the clasts were derived from the Gander Group metasediments. It seems possible too that these clasts could have been derived from any other metamorphic terrane (at present unknown), particularly as the rhyolitic, dacitic and andesitic pebbles found in the conglomerates might have been derived from a pre-Middle Ordovician island arc environment in the north-west (or nearby).

A thin layer of conglomerate separates the greywacke sequence from the siltstone bed of Unit 1. The conglomerate is poorly exposed and varies in thickness between 2-3 metres. The rock is polymictic, containing pebbles of andesite, rhyolite and mafic volcanic rocks which are set in a greywacke matrix.

Unit 3. The Black Slates

Unit 3 is a thick sequence of fine-grained, black-coloured slates and interbedded, more siliceous dark-green slates which are discontinuously exposed at the crest of ridges and isolated knolls in the Island Pond area. The dark-green variety is finely laminated and graded. Tops show the beds to be generally overturned. The thickness

of this Unit is unknown, but it appears to be the thickest of the three Units.

The black slates are less recrystallized and deformed than the rocks of the preceeding Units. They have more open structures and less pronounced slaty cleavage. Consequently, the latter has not been extensively crenulated or kinked by later deformations. At their coastal outcrops in the Carmanville area (North West Arm), the brownish weathering black slates are uninverted and folded into northerly plunging open ($F_I$) anticline. The contact between the black slates and the mafic agglomerates is not exposed.

In thin section, the black slates have usually dusty appearance with patches of opeque minerals (pyrite). The effects of contact metamorphism is very slight in this Unit as it sheltered from the intrusive (Rocky Bay) quartz diorite by the mafic agglomerates.

## The Mélange

The mélange in the Carmanville-Aspen Cove area consists of chaotic fragmented units of igneous, metamorphic and sedimentary rocks which are mixed up in a paste-like slaty to shaly matrix. The mélange is best exposed along the coast at Carmanville (North West Arm) and Rocky Pt., and inland in the One Mile Pond area (Fig. 3). It has a variable thickness (from a few metres to several metres $>$ 30m), and it is generally discontinuous along strike. In the One

Plate 14a Carmanville mélange.

Plate 14b Blocks of mafic pillow lava in the mélange.

Mile Pond area, it cuts across the stratigraphy in the Gander and Davidsville Groups which it also separates.

The matrix varies in composition and texture from being essentially slaty and schistose (e.g. along the coasts where it is more recrystallized and deformed), to locally psammitic, shaly and pebbly (especially in the inland outcrop where it is locally less metamorphosed and deformed).

The more recrystallized schistose matrix contains coarse grained crystals of chiastolite, dusty graphite, and mica flakes. In the pebbly horizon, the pebbles compose mostly of psammitic and volcanic rocks which are welded in a finer grained argillaceous matrix. These pebbles are generally angular to oval in shape, having been also flattened by later deformations.

The melange clasts vary in sizes from a few cm. to several metres, including massive blocks of metamorphic tectonites (with $F_3$folds), greywackes, serpentinized dunite breccia, altered gabbros, mafic pillow lavas and agglomerates. Fine-grained dolomitic limestone also occurs mostly as undeformed interstitial lenses in the slaty matrix. The common metasedimentary blocks are psammites and psammitic schists of the Gander Group (or older) which had acquired composite fabric before their incorporation in the melange (Plate 14). Near the tectonic base in the North West Arm area, where the psammitic schists of the Gander Group (or older?) are overlain by

mélange, the rocks are highly brecciated and locally intruded by melange matrix (along fracture zones) and some quartz veins. These slaty 'dykes' and quartz veins can be seen to cut across the schistosity in the Gander rocks. The quartz veins are probably later than the mélange, as they seem to be more closely related to the nearby Rocky Bay quartz diorite which also cuts across the melange.

At Rocky Pt., isolated blocks of graded and finely laminated psammites occur with their strikes differently oriented, but are generally oblique to the N.E. strike (by inference - see Fig. 3) of the mélange. The blocks are themselves oriented E-W, and other elongate blocks (e.g. serpentinites and gabbro sheets), have this common E-W trend, indicating that they were produced by the same mechanism. The latter can possibly be considered as a simple shear on a low angle thrust plane since gravity gliding could have brought the blocks in a common trend with the apparent N.E. strike direction of the mélange. The slump folds and disrupted stratification seen in the overlying sedimentary rocks of the Davidsville Group supports the formation of the mélange during a soft rock movement. Post-emplacement recrystallization and deformation greatly obliterated the earlier structures generated during the mélange formation.

## INTRUSIVE ROCKS

### Granites and Granitic Rocks

Several masses of granites and granitic rocks occur in the Carmanville - Ladle Cove area. They underlie an area of approximately 90Km$^2$, and are intrusive into the gneissic basement, Gander metasediments and Davidsville Group rocks. Their age relationships with the enveloping rocks have been a subject of great controversy (cf. Kennedy & McGonigal, 1972a & 1972b; Jenness, 1972; Fairbarn & Berger, 1969). Early workers (Jenness 1958 & 1963; Williams, 1963 & 1967) have described them as Devonian (?) granites in conformity with the old practice of assigning a Devonian age to every granitic body in the so-called Central Mobile Belt of Newfoundland Applachians (Williams, 1964). A significant realization by Kennedy and McGonigal (1972a) that the garnetiferous muscovite-biotite granites (the so-called leuco-granites), intruding the gneissic basement and the Gander metasediments were similarly deformed with the country rocks in Pre-Middle Ordovician times, implies that these granites are at least pre-Middle Ordovician in age. The structural and field relationships of the garnetiferous muscovite biotite granites (leuco-granites) with the enveloping rocks are clearly suggestive of their post-tectonic emplacement with respect to the gneissic basement

(Plate 2) and pre-tectonic origin with respect to the metasediments of the Gander Group. In each case, their age will be at least older than Middle Ordovician.

The name leucocratic granites used by the previous workers (Williams, 1963; Jenness, 1963; Kennedy & McGonigal, 1972a)in describing garnet-bearing granitic rocks in the area will not be used in the present communication because of its petrographical and chronological implications. Leucocratic granites are frequently referred to as mesozonal plutons with anchieutectic composition and generally occurring in the Precambrian granite-gneiss complexes (Lobach-Zhuchenko & Vusilyera, 1970). They are often pegmatitic with a low colour index (Shand's colour index for leucocratic rocks is 0 - 30%). Most of the leucocratic granites are thought to have crystallized from remobilized granitic or sialic layer (Read, 1960; Read & Watson, 1962; Lobach - Zhuchenko & Vasilyera, 1970) in a postkinematic stage. In this discussion the term "leucocratic" will be used in its original sense (Shand, 1931) to describe rocks with low colour index, and the granitic masses in the area will be described by their names:

1. (a) Ragged Harbour Granite: exposed in the east (Fig.3).
   (b) Round Pond Granite: occurring at the north-eastern margin of (2) Aspen Cove Granodiorite.

2. Rocky Bay Quartz Diorite which is a post-Middle Ordovician intrusion into the Davidsville Group, the melange, the Gander Group and the Aspen Cove Granodiorite.

(The age of emplacement of these plutons with respect to the deformation in the enveloping metasedimentary rocks is discussed further at the end of Chapter 3 ).

1. Ragged Harbour Granite

Of all the granitic masses in the area the Ragged Harbour pluton has the most variable field and petrographical characteristics. The pluton has an outcrop area of about 90Km$^2$ but only 1/3 of this is exposed in the study area. There are three recognizable phases of the pluton:

(a) the marginal biotite-rich well foliated phase;
(b) the porphyritic central phase with alligned alkaline feldspar phenocrysts;
(c) the pegmatitic phase.

These three phases have not crystallized in a distinctive pattern as to permit their description as zones. Their present inhomogeniety could be related to the cooling history of the pluton and some local remobilization during subsequent metamorphic and tectonic events.

The biotite-rich phase has crystallized at the margins and as sills, generally concordant with the metasedimentary rocks. The Round Pond Granite is probably

a diapir of the Ragged Harbour pluton, or it may have been emplaced before the latter in the early stages of plutonism. The pluton is strongly schistose and covers an area of approximately 3 $Km^2$. The margins are locally sheared and some granitic tongues were sent from the pluton into the enveloping metasedimentary rocks. The granite contains Orthoclase (27%), Andesine $An_{22}$ (13%), Quartz (43%), Biotite (11%), Muscovite (5%) and Garnet (1%).

In general, these very schistose biotite-granites contain higher percentage of plagioclase and lesser orthoclase than the porphyritic variety. Chemically, the former is also higher in CaO and lower in $SiO_2$. This type of variation may be related to a fractionation trend decreasing towards the centre of the pluton, or may be due to loss of more mobile elements from the granite to the country rock during the local metasomatism, coeval with the post-emplacement deformation and regional metamorphism. This would have destroyed all the contact metamorphic aureole which is presently not seen in the area.

In the porphyritic granite, the orthoclase megacrysts (average grain size 11 mm.) are perthites (patch and braid perthites), and their medium grained metrix is composed of interlocking crystals of quartz, feldspars and mica. Myrmekitic texture is formed at the inter-facial boundaries of orthoclase perthites and sodic plagioclase

(oligoclase $An_{13}$). Since perthites have formed by the exsolution of plagioclase lamellae from the orthoclase host,it can be argued that the associated myrmekite texture is also formed by exsolution. This problem has generally been considered (e.g. Spencer, 1945; Hubbard, 1966; Uzuakpunwa, 1967; Barker, 1970), and a theory commonly advanced is that free quartz is liberated at the same time as the plagioclase lamellae are exsolved from the orthoclase host.

In some of the studied examples, the writer notes that the liberated quartz seemed to have crystallized in the same site in the plagioclase host. It has not therefore "intergrown" with the feldspar, as this would imply a simultaneous crystallization.

The massive pegmatites (Ladle Cove Pegmatite) are essentially leucocratic with less than 5% of mafic minerals. Their field relationship with the foliated biotite granite is strongly suggestive that the pegmatites have formed as a remobilized fraction of the biotite granites. The latter can be seen as irregular xenoliths in the pegmatites, with a schistosity that is parallel to that in the main body of granite. The contact between the pegmatites and granite is gradational, and schistosity fades away as the pegmatites

become more homogeneous.

The pegmatites have giant crystals of orthoclase (some measure up to 13 cm.) and quartz, with minor coarse-grained garnet and muscovite. The rock is generally non-foliated and several of its veins can be seen to grow across the main schistosity in the foliated biotite granite. There are also some lenticular pegmatitic bodies and aplitic veins that cut across the primary mineral lineation (form line) in the porphyritic granite. This can be seen at an outcrop near the Ragged Harbour River Bridge. In this outcrop, the pegmatite contains coarse-grained dark coloured tabular crystals of tourmaline that intergrow with quartz and muscovite. In some places, the pegmatite has a graphic texture formed by the cotectic crystallization of quartz and orthoclase.

2. Aspen Cove Granodiorite

The Aspen Cove pluton has an outcrop area of about 30 $Km^2$. It is intrusive into the Gander Group metasediments and and also cuts across the Round Pond pluton. It is less deformed than the latter, and its veins can be seen (near Aspen Cove) to cut across the Round Pond pluton. At the headland near the Aspen Cove wharf, the granodiorite appears to intrude the mélange, but on close observation, it becomes evident that the material in direct contact with the intrusive rock is metasediment of the Gander Group which is overlain by the mélange. Near this area too, the intrusive veins of the Rocky Bay Quartz Diorite cut across the mélange and the Gander Group metasediments. All the rocks were themselves subsequently deformed and recrystallized,so that their present contact relationships are very obscure.

The Aspen Cove Granodiorite is grey to pinkish brown on fresh surfaces, and weathers to speckled white colours. The rock is medium grained (average grain size 2mm.), containing plagioclase (31-38%), quartz (35-44%), orthoclase (18%), biotite(3%), muscovite (3%) and garnet (1-4%). The feldspars have corroded crystal outlines and internal structures indicative of crystallization under stress. Zoning in plagioclase crystals is oscillatory and the albite twins are generally tapered and discontinuous. Some sections of orthoclase contain bent string perthites. The matrix consists of mylonitized quartz grains drawn out in a subdued fabric ($S_2$) that forms augen around the feldspar phenocrsts (Plate 15). The Aspen Cove pluton can therefore be considered syntectonic in origin, and probably derived from a remobilized

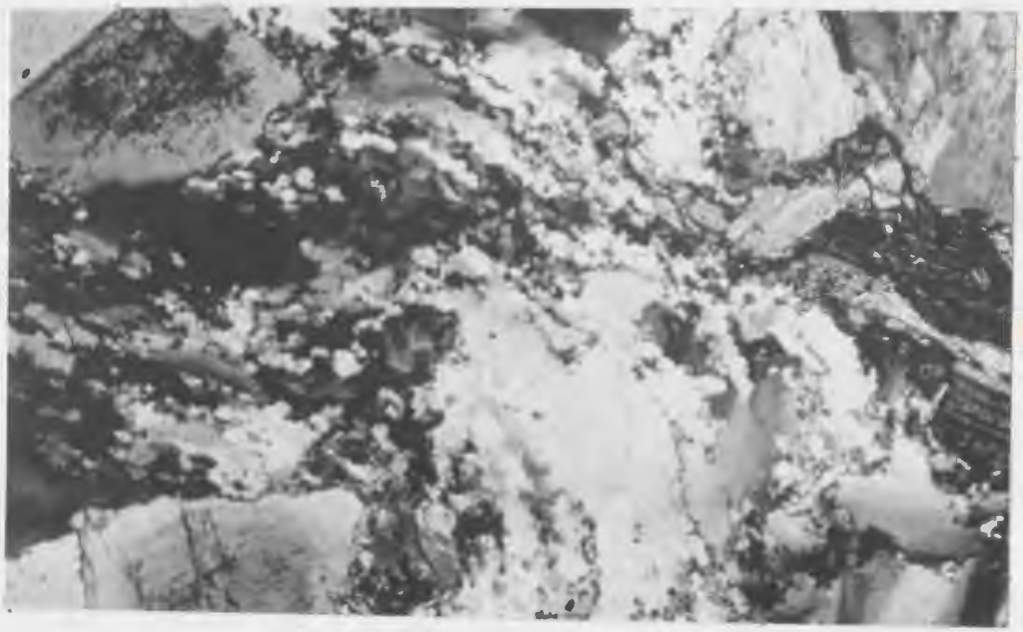


Plate 15. Cataclastic texture in the Aspen Cove pluton. The"mylonitized"quartz grains are drawn out in a less defined foliation that forms augen around the plagioclase and K-feldspar phenocrysts (crossed nicols X 4).

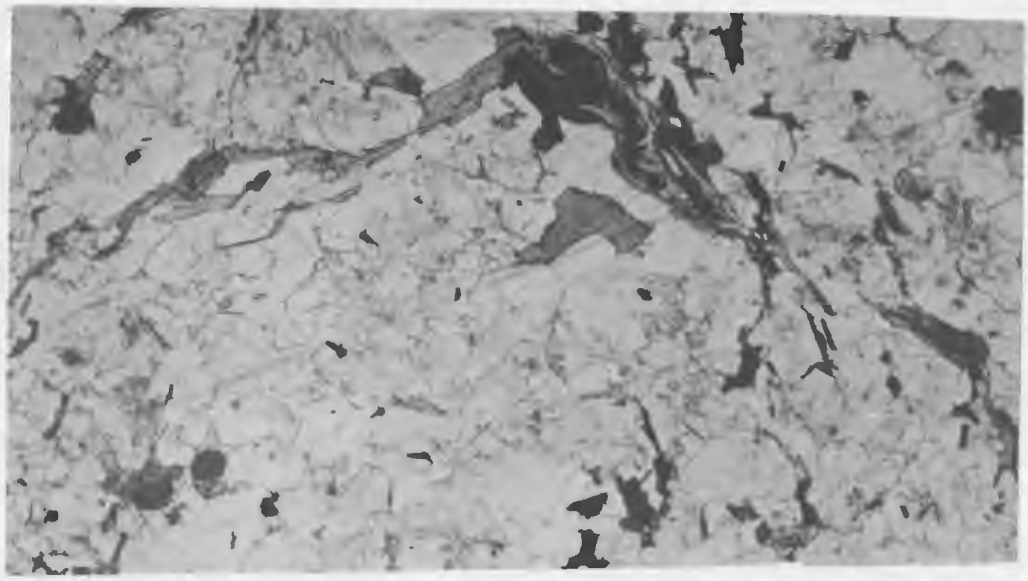


Plate 16. Folded ($S_2$) schistosity in the Round Pond Granite. (plane polarized X 4)

granitic layer with a probable affinity to the Ragged Harbour granite. The contact metamorphic effect of the Aspen Cove pluton appears to have been obliterated by the syntectonic ($D_2$?) metamorphic event. Close to the contact, the granitizing influence of the granitic body upon the eveloping semi-pelitic schists is evident. A rock intermediate in character between the two, a migmatite, is generally encountered.

3. Rocky Bay Quartz Diorite (Tonalite?).

The Rocky Bay Quartz Diorite (tonalite) has an outcrop area of about 36 $Km^2$ which is exposed between the Middle and Southwest Arms in the Rocky Bay area. The pluton has sharp intrusive contacts with the mafic volcanic agglomerate and mélange at its southern and northwestern boundaries respectively (Plate 18). It has poorly exposed and faulted contacts with the Davidsville grey slates and the Aspen Cove granodiorite in the east.

The rock is light grey coloured but has a speckled appearance resulting from the scattering of hornblende and biotite crystals between the greyish coloured plagioclase grains. A significant variation in composition and texture occurs from the margins of the pluton to its centre. The rock is commonly medium grained with a hypidiomorphic granular texture, but in the marginal zones it is finer-grained and frequently porphyritic with strong mineral lineation (Plate 17).

Plate 17. Sharp intrusive contact of the Rocky Bay Quartz Diorite with mafic agglomerates of the Davidsville Group near Carmanville.

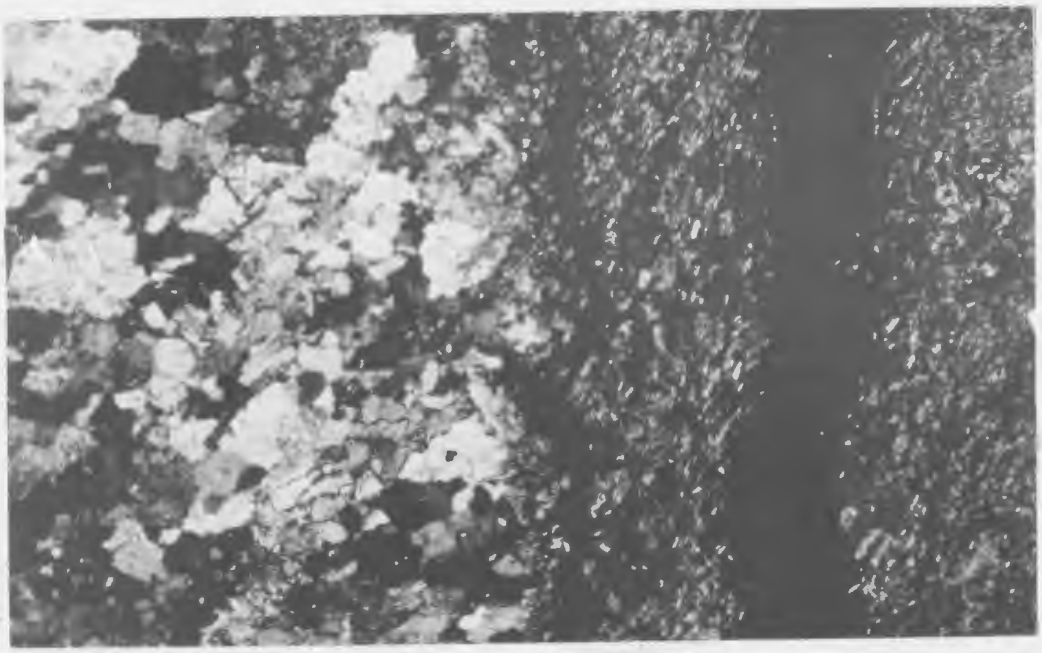


Plate 18. Contact of the mafic agglomerate (hornfels--right of photo) with dyke of Rocky Bay Quartz Diorite. Note the penetrative $S_I$ foliation, (crossed nicols X 4)

Compositionally, the mafic minerals (especially hornblende) are more abundant in the margins and decrease as the percentage of plagioclase increases towards the centre. The figures obtained from some analysed samples show this variation from (margin to centre) 50-60% plagioclase, 30-35% hornblende, 5-20% biotite and 10-12% quartz.

Plagioclase (andesine $An_{22}$) occurs in lath-shaped euhedral crystals which are often twinned according to the Albite and Pericline laws. Most sections are zoned (normal zoning), and unzoned crystals show undulose extinction. Many other crystals are fractured or bent, obviously by the same stress system that kinked the biotite crystals and also deformed the enveloping rocks.

The strongly pleochroic dark green to yellowish green hornblende is often enclosed by the brownish biotite in a corona structure. Some crystals are also twinned (simple twinning). Accessory minerals are zircon, epidote (and some allanite) and iron ore. Secondary chlorite occurs as alteration product of biotite.

The observed petrographical variation in the Rocky Bay pluton is gradational in character, and appears to be related to the cooling history of the rock. The ubiquitous zoning in plagioclase and the presence of corona structure in the mafic minerals indicate that the pluton had cooled over a short time interval and at a shallow depth. The Rocky Bay

Quartz Diorite can therefore be described as an epizonal pluton (Buddington, 1959). Its thermal metamorphic effect on the enveloping metasedimentary rocks is seen in the extensive crystallization of andalusite, cordierite and garnet porphyroblasts. The associated quartzo-feldspathic materials (pegmatites) have crystallized in the late magmatic stage.

THE ULTRAMAFIC ROCKS

The ultramafic rocks of the **Gander Group** consist dominantly of medium to coarse grained actinolite pyroxenite (diallagite) and minor chromite bearing magnetic serpentinites. They are discontinuously exposed in a narrow belt (about 300 metres wide) stretching from north-eastern end of the study area, and continuing south-westwards into the Gander Lake area (a distance of about 60 km.). Unlike the low lying granitic masses, the ultramafic rocks form isolated ridges and humocky hills which are generally elongated parallel to the main structural trend in the enveloping metasedimentary rocks. Both the ultramafic rocks and metasediments were subjected to pre-Middle Ordovician polyphase deformation and metamorphism. The latter event affected the ultramafic bodies marginally, converting them into talc-carbonate schists. Having been thus "lubricated", these recrystallized margins became potential zones of subsequent fault movements, and today the ultramafic belt is fault-bounded on its eastern and western margins (Fig. 3). The original contact of the ultramafic rocks with the enveloping metasediments is rather obscur.

The main schistosity in the ultramafic rocks is a second fabric which is steeply dipping, and locally folded into northerly plunging $F_3$ folds. At their north-eastern end, the rocks are surrounded by the biotite-hornblende schists of the Gander Group, but in their southwestern margin,

they are in faulted contacts with slates and greywacke units of the Davidsville Group.

Petrography of the Ultramafic Rocks.

The Actinolite Pyroxenite (Diallagite): The actinolite pyroxenites (diallagite) are dark-grey coloured, greenish weathering rocks containing diallagic augite (30-80%), actinolite (10-70%) and accessory magnetite. Interstitial calcite may also be present.

Diallagic augite occurs in coarse grained subhedral crystals (average grain size 1 cm.), which are generally 'poikilitic' enclosing fine to medium grained crystals of actinolite. This texture is not necessarily a primary igneous texture, as actinolites are formed by alteration of augite. No cumulate texture is shown by the rock.

Most sections of clinopyroxene with strong diallagic partings contain minute rodlets of opaque iron ore, and thin blebs of exsolution lamellae (of orthopyroxene?) parallel to their [100] crystal face.

Actinolite crystallizes as alteration product of augite, and forms an important mineral constituent of the rock. Where the alteration is more complete as in the light green coloured variety of the ultramafic rocks, the mineral accounts for more than 70% of the rock (by volume). Some crystals are fibrous (asbestiform), and faintly pleochroic, but more commonly, the mineral is neutral in plane polarized light.

The Serpentinites: The serpentinites occur in small lenses and narrow bands(from 1-20 metres wide, and up to 50 metres long), which are generally flanked by the less altered pyroxenites. The serpentinites are dark to yellowish green on fresh surfaces, and weathers to yellowish brown colours. The occurrence of high percentages of chromite and magnetite in these rocks, makes them very dense and highly magnetic. In the Shoal Pond Hill serpentinite, serpentine occurs commonly in a mesh-form as an alteration product of olivine. The original crystal outlines are marked by minute granules of magnetite.

Chromite is present in subhedral arborescent grains which interfinger with serpentine suggesting that at the time of their crystallization, they were in symplectic intergrowth with the olivines. In the Shoal Pond Hill serpentinite, chromite occurs as diseminated deposits closely associated with asbestiform chrysotile.The latter occurs in long fibrous crystals along joints and fracture zones.

The Talc-carbonate Schists: The talc-carbonate schists form poorly defined narrow bands (3-7 metres wide) that are discontinuously exposed along the eastern and western margins of the ultramafic belt. The rocks are grey coloured with a "greasy" feel on fresh surfaces, and reddish brown

when weathered. They are strongly schistose, with a steeply dipping $S_2$ schistosity which is locally folded by $F_3$ folds.

The schists vary in their mineralogical compositions from containing essentially calcite and quartz, with little or no plagioclase, talc and scaly mica (sericite), to becoming actinolite-plagioclase ($An_{30-33}$)-calcite-talc rock with minor quartz or antigorite, as they grade into less deformed and recrystallized actinolite pyroxenites. If an intrusive origin for the ultramafic rocks is considered, these schists could possibly represent the metamorphosed contact aureoles.

Petrogenesis of the Ultramafic Rocks:

The contacts between the metasedimentary and ultramafic rocks are generally obscure as they are either faulted or unexposed. Jenness (1958), has mapped one outcrop where the ultramafic rocks appear to have intruded the volcanic rocks of his Gander Lake Group. He considered the ultramafic rocks as sill-like bodies which were syntectonically emplaced as lubricated crystal aggregates in late Middle Ordovician time. Other workers (Dewey and Bird, 1971; Kennedy,1973; Strong,1973),

briefly described them as obducted slices of ophiolite, implying that they had moved as thrust sheets on to the continental margin. This selective obduction of ultramafic rocks as the only member of a pre-Middle Ordovician ophiolite succession is rather enigmatic. Obviously the emplacement of these rocks can be associated with plate motions (see Chapter 5), but their physical state (whether magmatic, submagmatic, or crystallized) at the time of emplacement is not fully known.

The ultramafic rocks have been extensively deformed, recrystallized and faulted especially at their margins where talc-actinolite-carbonate schists have been produced. The centres of the ultramafic bodies are vitually unmetamorphosed and slightly deformed. Their texture and composition are not typical of other ophiolitic masses found in well documented areas of Newfoundland (e.g., Williams, 1972; Upadhyay et al., 1972). The rocks are also different from the serpentinized dunite breccia exposed in the Davidsville mélange belt (about 1500 meters west of the ultramafic belt), which is clearly allochthonous, and can be genetically related to the deformed hornblende gabbro and mafic pillow lavas also incorporated as blocks in the mélange. The magnetic data further suggest that the ultramafic bodies are westerly dipping, as high magnetic values represented in their western flanks cannot be attributed to the less magnetic (overlying) psammites, nor

to the nearby granitic masses. It seems probable that the ultramafic rocks could have been emplaced in a submagmatic stage as segregated crystal mush. The segregated early formed olivine crystals were later serpentinized during deuteric alteration after the emplacement. The alteration produced the actinolite pyroxene rocks and isolated pods of serpentinites.

# CHAPTER THREE

## STRUCTURE

Terminology:

The following abbreviations based on those of Sander (1948), and Windley(1966) will be employed in discussing different phases of deformation, folding and associated planar and linear fabric elements:

| | Gander Group | Davidsville Group |
|---|---|---|
| Bedding | $S_o$ | $S_{\bar{o}}$ |
| First Deformation | $D_1$ | $D_{\bar{1}}$ |
| First Phase of Folding | $F_1$ | $F_{\bar{1}}$- |
| First Planar or S-fabric | $S_1$ | $S_{\bar{1}}$ |
| First Linear or L-fabric | $L_1$ | $L_{\bar{1}}$ |

The terminology for subsequent deformations $D_2$, $D_3$, ....will be as above with subscripts 2, 3,....replacing subscripts 1, e.g. $D_2$, $D_{\bar{2}}$, $D_3$, ....

$S_1$ is the earliest recognizable fabric in the Gander Group. It is commonly seen as inclusion trails in porphyroblastic garnets, and may be seen too at the nose of $F_2$ folds where it is preserved in the more psammitic layers.

The second schistosity $S_2$, is a transpositional fabric overprinting $S_1$. It is the dorminant schistosity in the Gander Group, and axial planar to $F_2$ folds. $S_2$ is deformed by $S_3$ strain slip fabric which is axial planar to $F_3$ folds.

In the Davidsville Group, $S_{\bar{1}}$ is the single penetrative

cleavage which is axial planar to $F_{\bar{1}}$ folds. It is locally kinked or buckled by $F_{\bar{2}}$ folds, and the latter may be associated with $S_{\bar{2}}$ strain slip fabric.

The terms microscopic, mesoscopic and macroscopic are used in the sense defined by Weiss and McIntyre (1957), Turner and Weiss (1963) and Windley (1966):

1. Microscopic: Structures that can only be seen under the microscope (thin section).
2. Mesoscopic: Structures that can be observed in the field ranging from hand specimen to single and continuous outcrops.
3. Macroscopic: Structures that are too large to be observed directly; the overall structure can be ascertained by reference to 1 and 2 above.

The strain indicators are deformed pebbles and ptygmatic structures. The three main axes of deformation ellipsoid are $Z > Y > X$ (Flinn, 1962), where:

Z = Long axis of the ellipsoid (= maximum strain);

Y = Intermediate axis of the ellipsoid (= intermediate strain);

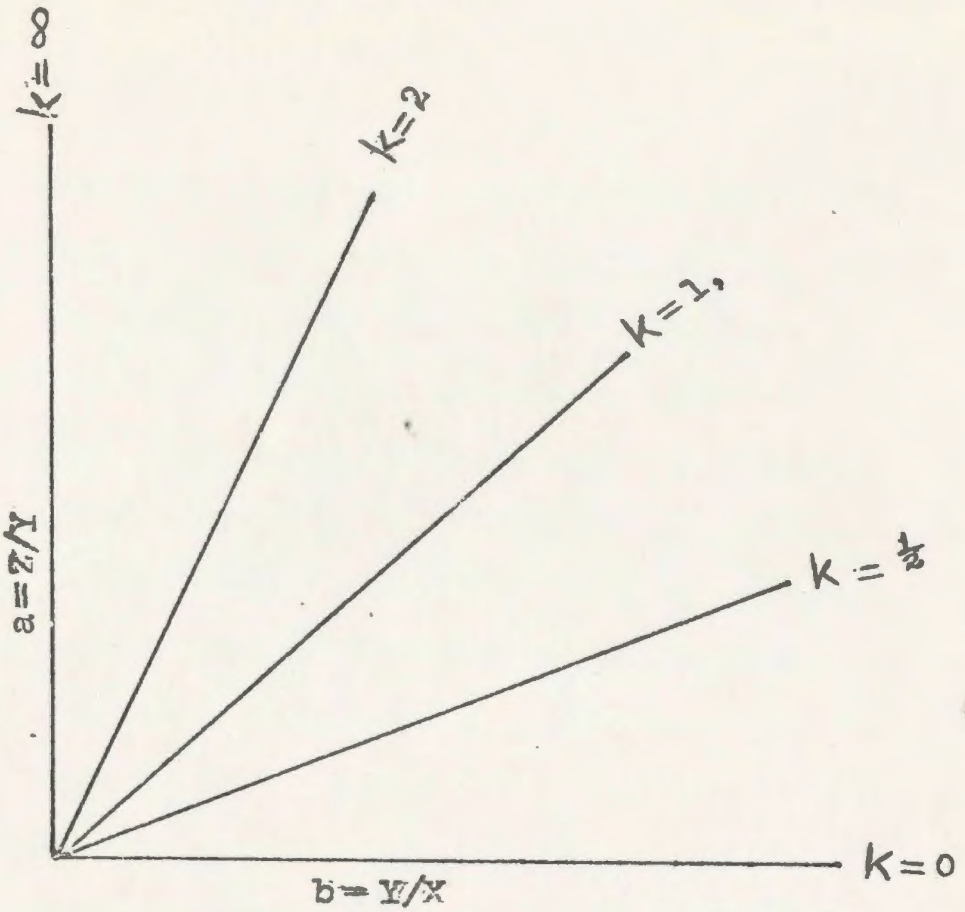
X = Short axis of the ellipsoid (= minimum strain).

Table 2

| a, $\frac{Z}{Y}$ | b, $\frac{Y}{X}$ | K, $\frac{a-1}{b-1}$ |
|---|---|---|
| 6 | 5 | 1.25 |
| 7 | 5 | 1.4 |
| 2.86 | 2.33 | 1.39 |
| 2.57 | 2 | 1.57 |
| 8 | 3 | 3.5 |
| 6.5 | 3.33 | 2.61 |
| 7 | 2 | 6 |
| 4.44 | 2.57 | 2.19 |
| 10 | 1 | |
| 6.11 | 1.8 | 6.4 |

Measurements from deformed conglomerate of the Gander Group.

Note: K-values (Flinn, 1962) could only be determined from deformed pebbles. Measurements were taken from those pebbles (10) whose principal axes (of ellipsoid) could be calculated. Some measurements were taken in the field where pebbles could be removed from the matrix. The figures were compared with those obtained from thin sections. In the latter, measurements of X and Y were made for each pebble shown on a face cut perpendicular to Z, and average $\frac{X}{Y}$ ratio calculated. For X and Z, similar calculations were made on a face cut perpendicular to Y.



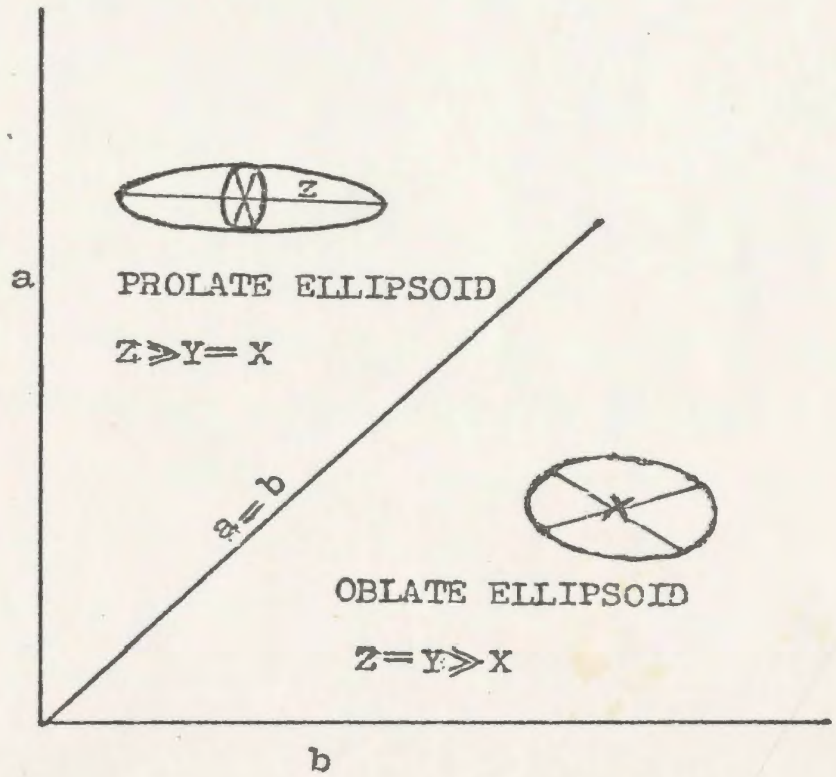




Figure 4. Deformation Plot. Z> Y > X-deformation ellipsoid axes. Modified from Flinn (1962).

Introduction.

Detailed structural studies in the Carmanville-Ladle Cove area (northeastern margin of the Central Mobile Belt of the Newfoundland Appalachians), have established the existence of four main phases of deformation in the Gander Group (and two in the Davidsville Group). The analyses of microscopic and mesoscopic structures are carried out for rocks of the Gander and Davidsville Groups. The remarkable dissimilarities in their geometry with respect to the associated macroscopic structures (in the two groups), and the time of their generation relative to the age of common metamorphic minerals clearly show that rocks of the Gander Group had acquired composite fabric before the tectonic emplacement and deformation of the Davidsville Group. The upthrusting of the Davidsville Group seemed to have been associated with a dewatering fabric which was obliterated by later deformations.

In the Gander Group, the dominant schistosity is a second fabric $S_2$, which has the same NE regional trend with the penetrative axial planar foliation $S_{\bar{1}}$ in the Davidsville Group. The two fabrics are not necessarily coplanar as they are respectively axial planar to two differently oriented and genetically unrelated sets of folds ($F_2$ and $F_{\bar{1}}$, see Fig. 5).

In the gneissic basement, an irregularly spaced foliation is developed parallel to a blurred composition banding

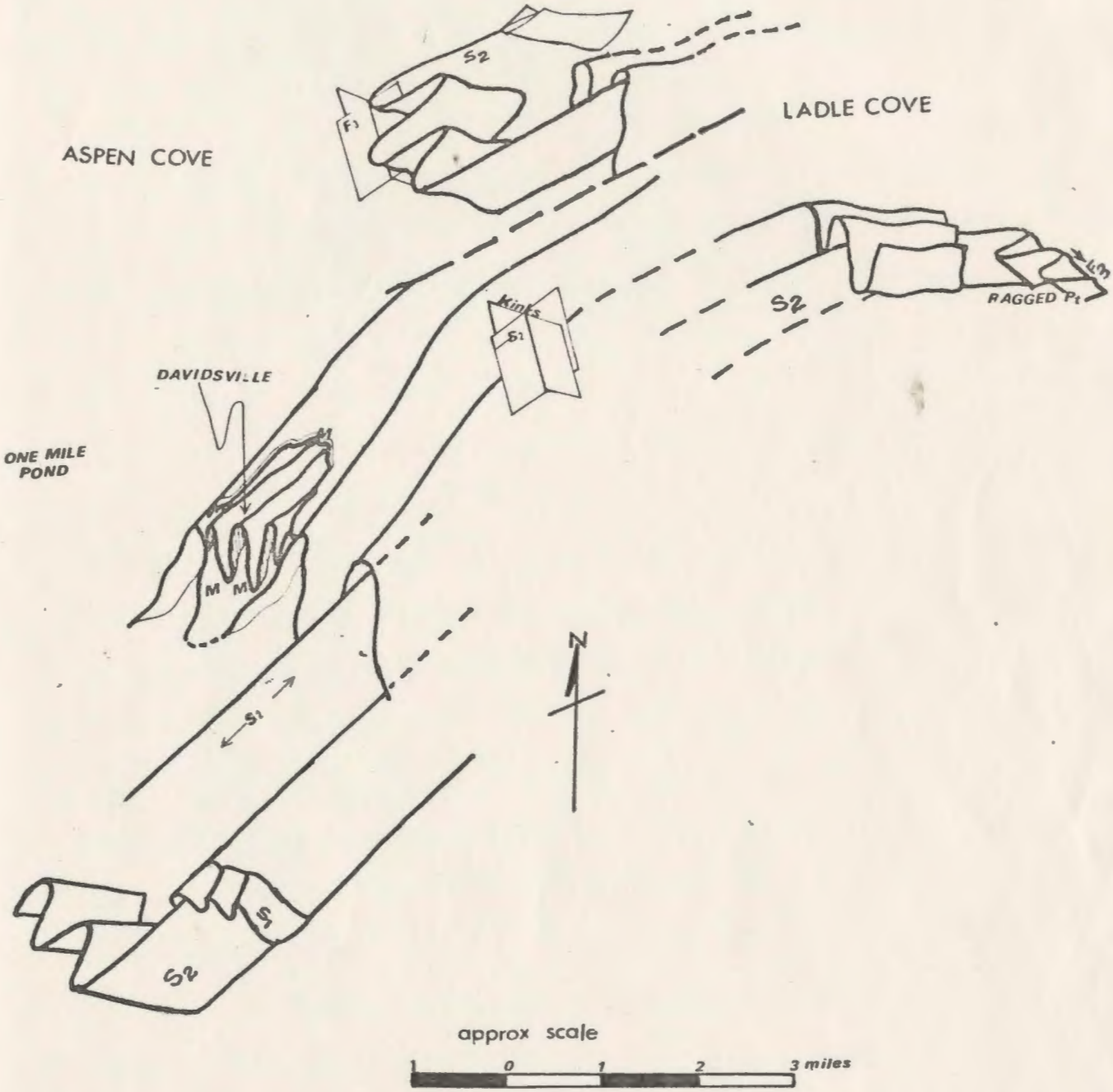



Figure 5. Structural surface diagram of the Carmanville-Ladle Cove area.

which has been complexly folded into disoriented folds. Poor outcrop and extensive late stage annealing recrystallization (cf. Turner and Weiss, 1963) have made a detailed study of the entire rock fabric difficult.

Pre-Gander Group Structures: Gneissic Basement

The banding in the gneissic basement forms a poorly defined schistosity that is irregularly folded by what may be described as "structureless" folds. This type of wild folding (Windley, 1966) with no axial plane fabric is more commonly described as flow folding (cf. Wynne-Edwards, 1963; Mehnert, 1968) in some areas of high grade metamorphism.

This gneissic banding has formed by transposition of an earlier one which is also a composite fabric as disoriented garnet porphyroblasts contain inclusion trails that can be shown to pre-date the earliest recognizable fabric in the rock. This has also been demonstrated elsewhere by Kennedy and McGonigal (1972), and since the rock was intruded post-tectonically by the Ragged Harbour granite (Plate 1) which is older than Ordovician (?), the basement must have been deformed in Cambrian or Precambrian times.

Deformations in the Gander Group

Structures Produced by the First Deformation $D_1$.

Microscopic and Mesoscopic S and L Fabric Elements: The first deformation $D_1$ in the Gander Group affected all the

metasedimentary rocks in the area, imparting upon them a subdued schistosity $S_1$ which has been overprinted by later structures. In the less recrystallized semi-pelitic units, $S_1$ may be seen at the nose of minor $F_2$ folds, but in the more recrystallized schists, it is more commonly seen as inclusion trails in post $D_1$ porphyroblasts. In the graphitic schists of Ladle Pt. formation, garnet porphyroblasts contain $S_1$ inclusion trails which are oriented at 20-30$^{\circ}$ to the $S_2$ schistosity. The latter forms augen around the garnets indicating that the mineral is MP. (pre-$D_2$) in age (Plate 35).

$D_1$ Strains: The development of an L-S fabric in the deformed conglomerates (in which the pebbles were uniformly stretched, e.g. at Bear Place and Ragged Pt. can be attributed to an earlier $D_1$ constriction type of deformation, and subsequent modifications by $D_2$ flattening strain. The pebbles which approach to prolate ellipsoids (Fig. 4 ,Table 2 ), are set in a schistose matrix in which $S_2$ forms augen round the pebbles. The stretching of these pebbles could have been produced by either $D_1$ deformation in which $1 < K < \infty$ or by $D_2$, in which the deformation path varied from $1 < K < \infty$ to $1 > K > 0$ (Flinn, 1962; Kennedy, 1969). Since $D_2$ deformation is everywhere characterized by extensive flattening, and the stretched pebbles are folded by $F_2$ fold, the stretching is unlikely to be a $D_2$ feature. It is therefore considered a $D_1$ strain.

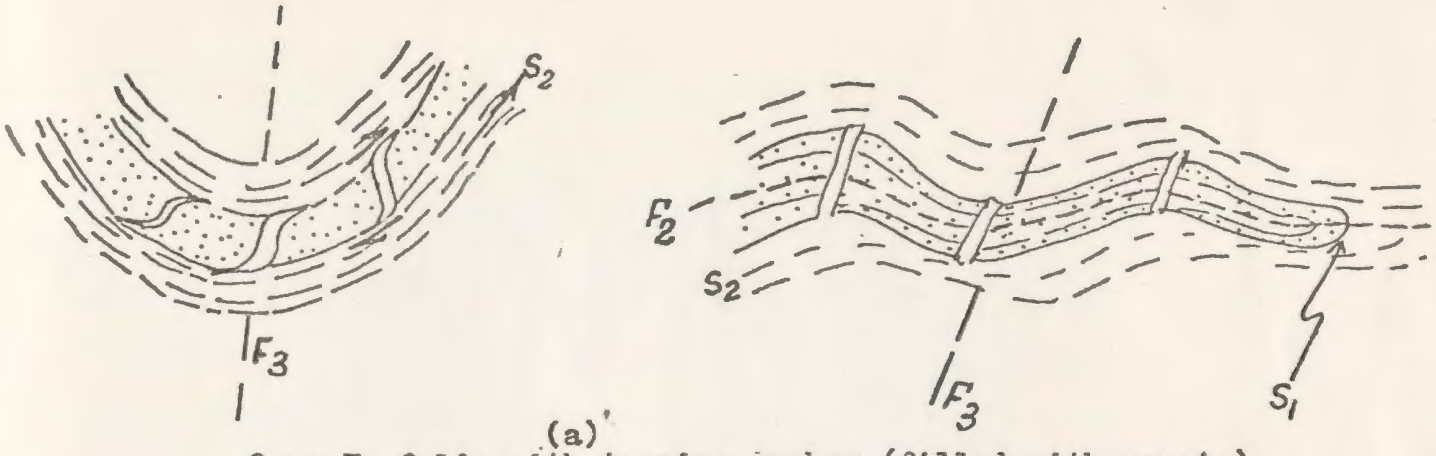
Plate 19. Stretched pebbles in deformed conglomerate near Ragged Pt. (Ragged Pt. Formation).

Plate 20. Tight $F_1$ closure (?) near $F_2$ fold hinge. Ragged Harbour River Formation (crossed nicols X 4).

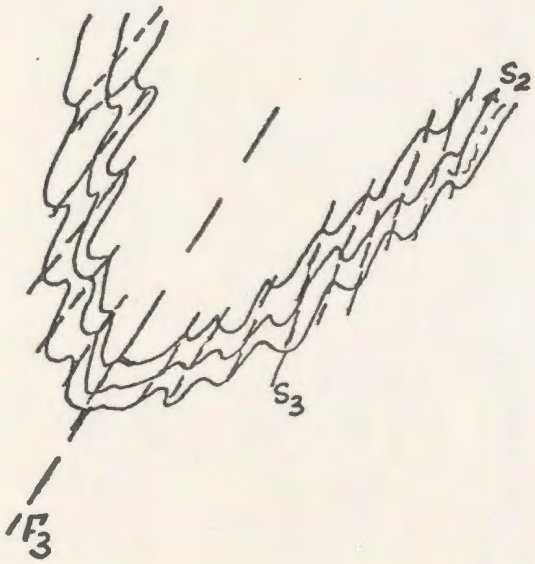
$F_1$ Folds: The $S_1$ schistosity is generally subparallel to the bedding $S_o$, and is axial planar to $F_1$ folds. The latter are not very abundant, but where they are seen (occurring at the hinges of isoclinal $F_2$ folds, as at Ladle Pt. and near Ragged Harbour River bridge), they can be said to be tight structures at the time of their generation (Fig. 6c). If they were originally open structures, they had become tightened during the subsequent episodes of folding.

Structures Produced by the Second Deformation $D_2$.

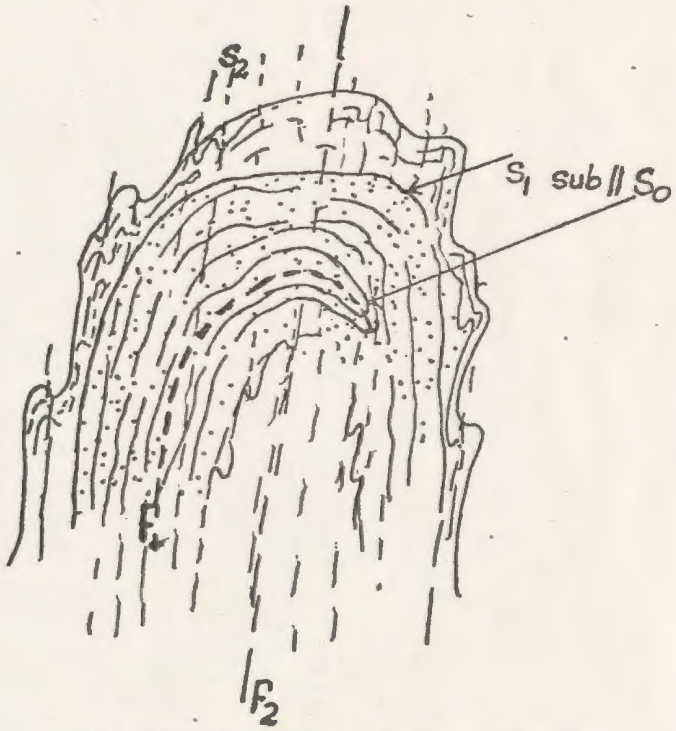
Microscopic and Mesoscopic S and L Fabric Elements: In all the metamorphic tectonites of the Gander Group, an L-S fabric (Flinn, 1958) is formed by the strong planar dimensional allignment of micas and amphiboles, and their preferred shape orientation in the plane of $S_2$ schistosity. In the pelitic and semi-pelitic schists, a penetrative shape fabric (Flinn, 1958; Watterson, 1961) is shown by the micas, but in the amphibolites and actinolite schists, a mineral fabric ($L > S$ fabric) is shown by the amphiboles. This apparent variation in the tectonite fabric is controlled by the mineralogical composition of the rocks (i.e., linear minerals tend to show linear fabric, and platy minerals show platy fabric). It is different from variation in S through L-S to L fabric often shown by some tectonites (of relatively homogeneous composition), since the latter is considered to have been produced by variation




(a)
Open $F_3$ folds with tension gashes (filled with quartz), at a headland near Aspen Cove.




(b) Tight $F_3$ fold with $S_3$ axial planar strain-slip fabric that deforms $S_2$, near Ladle Cove.




(c) $F_1$ closure at $F_2$ fold hinge. $F_1$ can be said to be tight structure at the time of its generation. Near Ragged Harbour river bridge.

Figure 6.

in deformation path (i.e., variation in K values: cf. Flinn, 1958 and 1962).

The $S_2$ schistosity has a NE-SW regional trend which is continuous throughout the three formations in the Gander Group. This second schistosity $S_2$, is axial planar to $F_2$ folds, and is gently inclined where $F_2$ folds are recumbent to gently inclined (Ladle Cove-Ragged Pt. areas), and steeply dipping where $F_2$ folds are upright or when folded by $F_3$ folds (Aspen Cove-Ladle Pt., and Island Pond areas).

$D_2$ Strains: The occurrence of boudins in the $S_2$ schistosity plane (seen at Ragged Pt., Aspen Cove and Bear Place) is indicative of high degree of stretching associated with $D_2$ deformation (cf., Flinn, 1962; Kumar and Pande, 1972). These structures occur in varying dimensions (Plate 22 ), with their axes pitching steeply where $F_2$ folds are steeply plunging. More commonly it is the psammitic layers that are stretched and boudinaged, but there are instances as in the Bear Place (Plate 21) where thin bands of amphibolites appear to have been boudinaged before being disrupted into several lenticles. The orientation of the boudinage axes shows that Z principal direction (Flinn, 1962), lies in the plane of $S_2$ schistosity (i.e., boudinage axis is subparallel to fold axis). There is therefore an increased vertical extension (normal to boudinage axis) associated with $D_2$ deformation. The minimum shortening (in X direction) calculated from five ptygmatic folds

Plate 21. Stretched, disrupted and folded amphibolitic bands in the semi-pelitic schists of the Ragged Pt. Formation, near Bullrush Pond.

Plate 22. Boudins in the semi-pelitic schists (with psammitic layers). Ragged Pt. Formation near One Mile Pond.

by comparing their presumed original lengths before deformation (following the loops), with their shortened lengths after deformation, i.e., straight line distance (normal to $S_2$) and across two ends of the ptygmatic structure, is 32-40%.

$F_2$ Folds: The folds of second generation $F_2$ are common throughout the metasedimentary rocks of the Gander Group. They are generally tight to isoclinal structures (Plates 23, 24) which may be upright, recumbent or gently inclined. The minor $F_2$ folds are more abundant in the less homogeneous rock units, and are generally found in the thinly bedded psammites. In one outcrop alone, these folds may show modifications from discordant closures with variable amplitudes along their axes, to limbless folds (Borradaile, 1972), when attenuation in the fold limbs due to extreme flattening results in disconnection of adjacent fold pairs. Most of these minor $F_2$ folds plunge at moderate angles (20-50$^{\circ}$) to the south-west.

It may be said, from the attitude of $S_2$ schistosity plane, that the axial plane surface of $F_2$ folds are slightly curvi-planar, although it is more commonly inclined to the west. The wave lengths of the folds are shorter than their amplitudes. They are generally similar folds (Ramsay, 1962).

The sense of vergence of minor $F_2$ folds in the semi-pelitic schists exposed at the north-eastern end of the ultra-

Plate 23. Isoclinal $F_2$ fold, Ragged Pt. Formation. Note the $S_2$ axial plane fabric.

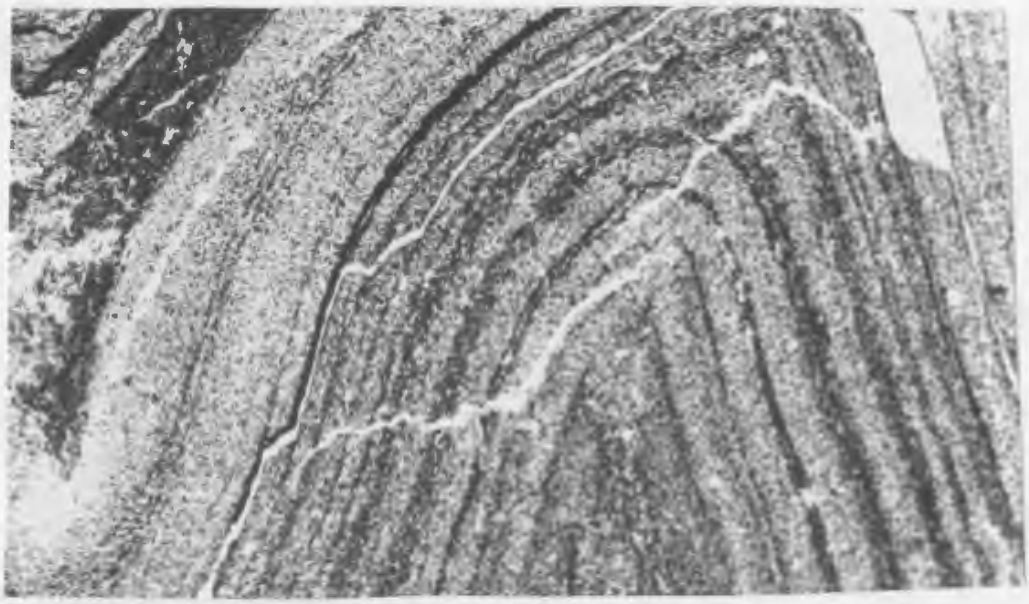


Plate 24. Tight $F_2$ fold in the psammitic layer of the banded phyllite, Ragged Harbour River Formation.

mafic belt, shows the existence of a major $F_2$ synform to the west (of this outcrop, see Fig. 3), with the ultramafic rocks partly occupying the fold core. This fold plunges moderately to the south-west (at 30-50$^{o}$). In the west, between the Bullrush Pond and One Mile Pond, a major synform of an apparent post-$D_2$ deformation in age occurs (Fig. 3). Since this synform has $S_2$ as its axial plane foliation, and minor $F_2$ folds are uniformly oriented with this major fold, it can be said that the latter had formed by refolding of an earlier $F_2$ fold (of the same order of size) about the same axis. One complementary $F_2$ antiform occurs with its axis passing north-eastwards along the ridge between two elongated masses of the Ragged Harbour granites.

The relationships between $D_1$ and $D_2$ structures show that $F_2$ folds were superimposed on $F_1$ folds, and $S_2$ schistosity (which is often strain slip fabric deforming $S_1$), had formed as a transpositional fabric.

Structures Produced by the Third Deformation $D_3$.

Microscopic and Mesoscopic S and L Fabric Elements: The third deformation $D_3$, resulted in extensive crenulation, kinking and buckling of $S_2$ schistosity by $F_3$ folds. The $F_3$ folds are generally open structures with no axial plane fabric, but where they are more tightly folded as in the graphitic schists of the Ladle Pt. Formation,(Plate 27), they are associated with $S_3$ axial plane strain slip cleavage. The $S_3$

cleavage is more prominent at the hinge zones of $F_3$ folds, where it can be seen to deform $S_2$ schistosity (Plate 26). Elsewhere, it can be described as intersection lineation $L_3$, formed by the crenulation and kinking of $S_2$ schistosity by $D_3$ deformation. In the Island Pond and Ladle Cove areas (Map 3), $L_3$ intersection lineation (with moderate plunge) is parallel to $F_3$ fold axes.

$F_3$ Folds: $F_3$ folds occur mostly in mesoscopic scales as tight to open structures. At Aspen Cove and Ragged Pt. areas, $F_3$ folds plunge at moderate angles to the north-east, but in the south (about 3 km. norther-east of Island Pond), they ($F_3$ folds) plunge at 40-45$^{\circ}$ to the north-west. This variation in the plunge direction of $F_3$ folds is often seen at a single outcrop (Ragged Pt.) where minor $F_3$ folds have curving fold axes (Fig. 7a). The occurrence of minor folds with curving fold axes have been described or mentioned by several authors (King and Rast, 1956; Knill and Knill, 1958; Ramsay, 1963; Robert, 1966; Borradaile, 1972), and they are thought to be generated during an irrotational deformation. Such deformation affecting the earlier folds has produced interference patterns (Ramsay, 1963), which are discussed below.

The geometry of minor $F_3$ folds near Aspen Cove shows that $F_3$ folds were formed by flexure and pure shear mechanism. These structures approximate to similar folds (Ramsay, 1962)

Plate 25. Faulted $F_2$ fold in the chlorite schist of Ragged Harbour River Formation (crossed nicols X 12.6).

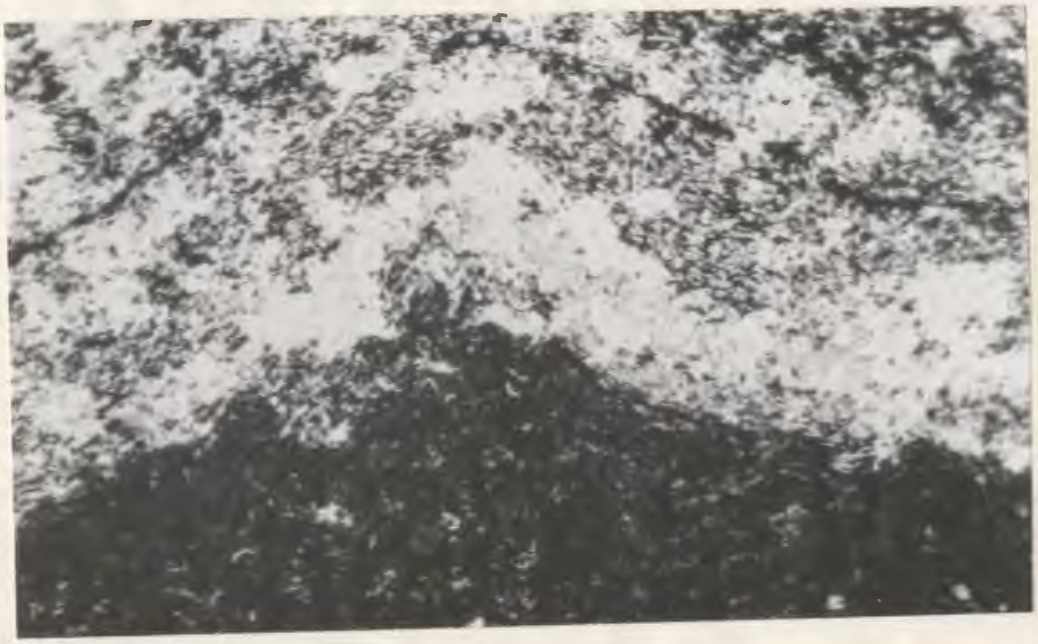


Plate 26. $S_3$-strain-slip fabric, axial planar to $F_3$ fold. Ragged Harbour River Formation (crossed nicols X 12.6).

Plate 27. Tight $F_3$ closures in the banded graphitic schist of Ladle Pt. formation - at a headland near Aspen Cove (looking down photo).

Plate 28. Open $F_3$ fold in thinly banded graphitic schist of Ladle Pt. Formation.

with thickened hinges and thinned limbs. The shear movement had produced the strain slip fabric which is axial planar to $F_3$ folds. The tension gashes seen near the fold hinges (Fig. 6a) indicate (from the way they thin out) the sense of shear movement.

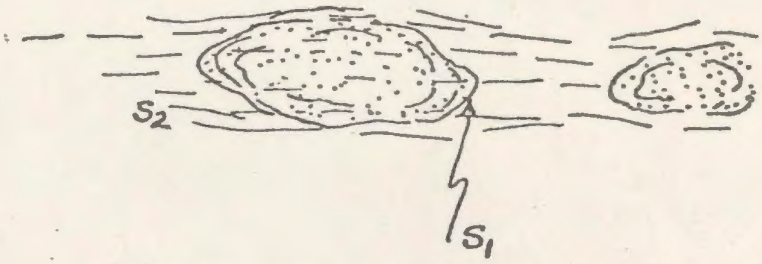
Interference Patterns.

The three types of interference patterns (Ramsay, 1963) are seen on mesoscopic scales in the semi-pelitic and banded graphitic schists of the Ragged Pt. and Ladle Pt. formations.

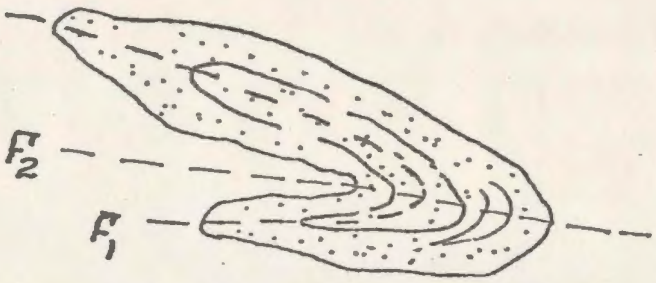
In the type 1 interference pattern, the domes are formed by the psammitic rocks with fabric ($S_1$) going round them. The domes are small scale structures with ovoidal shape. The long axes measure from 10-20 cm. (Fig. 7b ). The domes were produced where the antiforms of $F_2$ folds crossed those of the $F_1$ folds, in a manner such that the movement direction of rocks (during refolding) was close to $F_1$ fold axial plane (cf. Ramsay,1963).

Types II and III interference patterns are produced by the refolding of $F_1$ by $F_2$ folds, or $F_2$ by $F_3$ folds (Fig . 7c ). Type II can be seen at an outcrop 200 meters east of One Mile Pond (Plate 30 ), and type III at the coastal outcrop about 2000 metres east of Aspen Cove. Ramsay (1963) has suggested that if the movement direction of later deforming

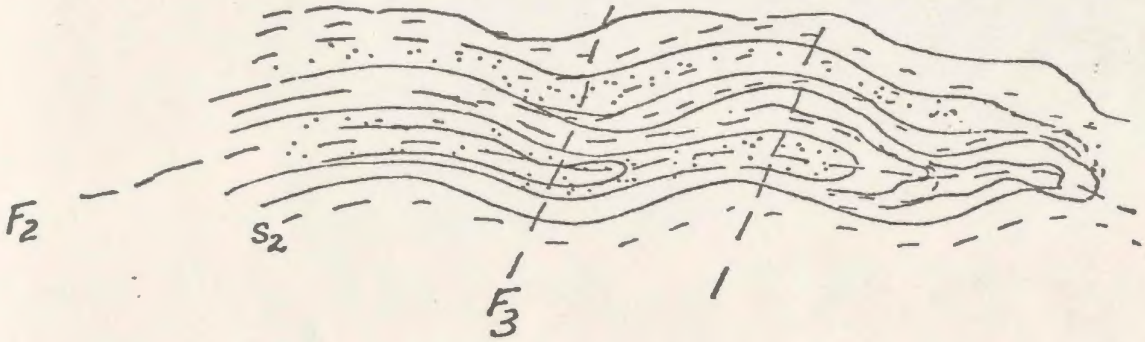
(a) curving fold axis.




(b) Type 1 interference pattern, Ragged Pt. Formation near Aspen Cove.




(c) Type 11 interference pattern, Ragged Pt. Formation near One Mile Pond (see also Plate 30).




(d) Type 111 interference pattern, Ladle Pt. Formation near Ladle Cove.

Figure 7.

Plate 29. $S_3$-strain-slip fabric deforming $S_2$ in the graphitic schist of Ladle Pt. Formation, Ladle Pt.

Plate 30. Type II interference pattern in the semi-pelitic schists (with psammitic layers). Ragged Pt. Formation near One Mile Pond (see also Fig. 7c).

folds is at high angle with axial plane of earlier folds, either type II or type III will form. For type II, the dihedral angle between the earlier and later (i.e., $F_1$ and $F_2$) fold axial planes will be large ($> 20^\circ$), and for type III, this angle will be very small ($\rightarrow 0^\circ$).

Structures Produced by the Fourth Deformation $D_4$.

The fourth deformation $D_4$, produced $L_4$ vertically plunging crenulation that deformed both the $S_3$ strain-slip fabric and the gently inclined $L_3$ intersection lineation. The $L_4$ crenulations are locally tight structures. They are best seen in the graphitic schists and greywacke units of the Ladle Pt. Formation exposed at the headland about 200 m. east of Aspen Cove. The andalusite porphyroblasts which are post-$D_3$ in age, are also deformed by $D_4$ deformation (Plates 10 &36) No macroscopic $F_4$ folds are seen, but refolding of the $F_3$ folds about the same axes may have occurred at the time $L_4$ vertical crenulation was produced. Since the kinkbands in the Gander Group (discussed below) are seen to deform $L_3$ intersection lineation, their development was later than $D_3$ deformation, and could have been a $D_4$ event.

Deformations in the Davidsville Group.

Structures Produced by $D_{\bar{1}}$ Deformation: The single penetrative cleavage $S_{\bar{1}}$ with a NE regional trend, is axial planar to $F_{\bar{1}}$ folds of the Davidsville Group. Due to the

rheological behaviour of rocks, $S_I$ foliation is not strongly developed in rocks of greater competence (e.g., mafic agglomerates, siltstones and granitic rocks etc.). Apart from this, there is also a marked variation in the intensity of deformation which can be explained by some other reasons (discussed below).

The strain condition in the north is generally higher than it is in the south. Near the mélange belt east of the South West Arm (Fig. 3), the psammitic bands in the grey slate unit are stretched and boudinaged, with the boudinage axis plunging steeply to the south. The pebbles in the conglomerates (5kilometres from the melange) are moderately flattened in the plane of $S_I$ foliation (Plate 12b). Some measurements (6) show K values varying from 0.33-0.134. The amount of minimum shortening in the X direction (calculated from ptygmatic folds (as above) is 40%. But in the south, near the Island Pond (about 10 km. from the mélange) the pebbles are virtually undeformed (Plate 11 ). No figures could be obtained for the amount of minimum shortening. This variation in intensity of deformation conforms with variation in grade of metamorphism, i.e., the more recrystallized rocks were more deformed than the less metamorphosed rocks. It seems obvious that the thermal metamorphic event associated with the emplacement of the Rocky Bay Quartz Diorite had greatly increased the ductility contrast of the rocks. It

has been shown that this thermal metamorphism preceeded $D_{\bar{1}}$ deformation, but it might be possible too, that the wave of metamorphism had not completely receded before the onset of $D_{\bar{1}}$ deformation. The rocks nearer to the pluton would be more deformed than the rocks further off from the pluton.

The flattening $D_{\bar{1}}$ strain was associated with a pronounced vertical extension and a later slip along $S_{\bar{1}}$ plane. The latter event was marked by the development of strong vertical striations on $S_{\bar{1}}$ plane, which were kinked by subsequent deformations.

The mesoscopic $F_{\bar{1}}$ folds are slightly variable in their geometry, becoming generally tight to isoclinal structures in the grey slates, and more open closures in the black slates and greywacke units. They are moderately to steeply plunging (40-65$^{\circ}$) towards west and south-west. A major $F_{\bar{1}}$ synform occurs (Fig. 3) with its axis trending NE-SW, and plunges moderately to the SW. The age of common metamorphic minerals (andalusites and cordierites) relative to various phases of deformation (discussed later), shows that $D_{\bar{1}}$ in the Davidsville Group can be correlated with $D_4$ in the Gander Group.

<u>Later Deformations (Post-$D_{\bar{1}}$) of the Davidsville Group</u>.

The $S_{\bar{1}}$ foliation in the Davidsville Group is locally crenulated and folded by moderately tight to open $F_{\bar{2}}$ fold

(Plates 31, 32). Where $F_2$ folds form tight structures as in the Bullrush Pond area, they are generally associated with $L_2$ intersection lineation which was produced by the tight crenulation of $S_1$ by $D_2$. The trend of lineation is parallel to the E-W axial trend of the $F_2$ folds. The latter plunge moderately (at 55-60°) to the west, with their axial planes gently inclined to the south.

The later deformations of the Davidsville Group were marked by local and variable strain conditions. The $S_1$ foliations in the less recrystallized slates and blastomylonitic greywackes, were deformed into open kinks (discussed below), whereas in the more recrystallized graphitic schist (and the grey slates near the mélange belt), they ($S_1$) were considerably tightly crenulated and locally folded. No major structures were produced by post-$D_1$ deformations.

Pre-$D_1$ Event.

The emplacement of the Davidsville Group (as a folded nappe), predates the first penetrative deformation $D_1$ of the group. The upthrusting event seemed to have been associated with a tectonic dewatering fabric which was superimposed by later $D_1$ structures. In the eastern thrust zone (the contact zone of the Davidsville Group and the ultramafic rocks of the Gander Group), the greywackes (of the Davidsville Group) show blastomylonitic texture in which the mylonitization

Plate 31. Open $F_2$ fold in the grey slates, Davidsville Group.

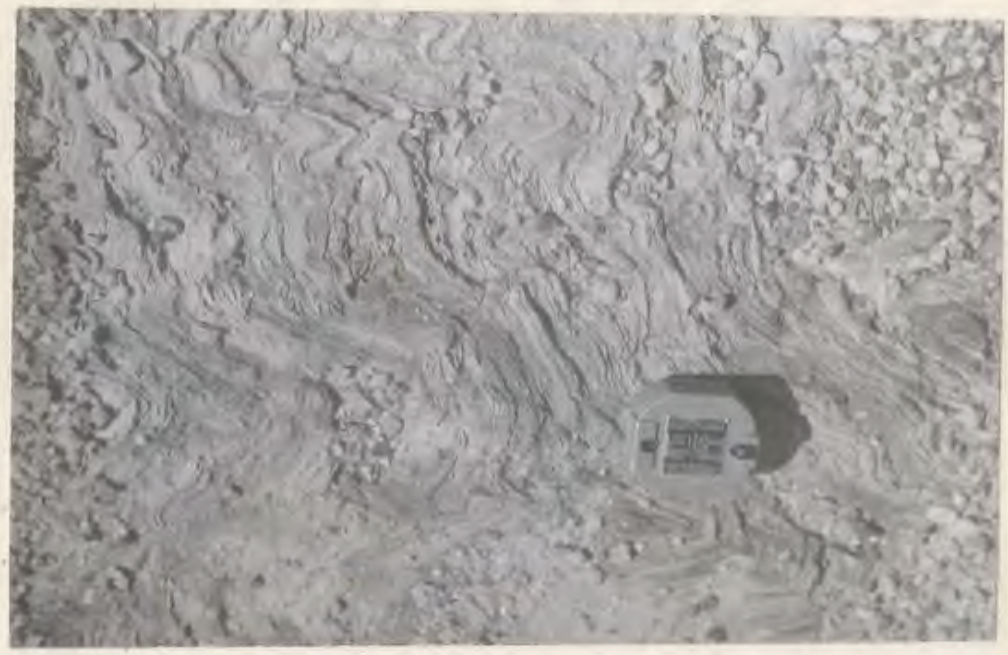


Plate 32. Local crenulation and buckling of $S_1$ by $F_2$ folds in the graphitic andalusite schist of the Davidsville Group. Close to the mélange belt, Bullrush Pond.

of the rocks can be shown to pre-date the development of $S_I$ foliation. The latter forms augen around medium to finely brecciated angular fragments of the greywackes. Some medium-grained crystals of clastic mica (biotite) were crumpled or kinked before they were subsequently flattened in the plane of $S_I$ foliation. Evidence for this is seen in the kink bands that were deformed by $S_I$ foliation. The semi-pelitic schists of the Gander Group exposed northwards on the same side of the ultramafic rocks as the mylonitized greywackes, have not been affected by this brecciation even though they were similarly affected by later (post-$D_I$) faulting. Only the Davidsville Group was affected by the mylonitization which possibly could have occurred during the upthrusting of the Group.

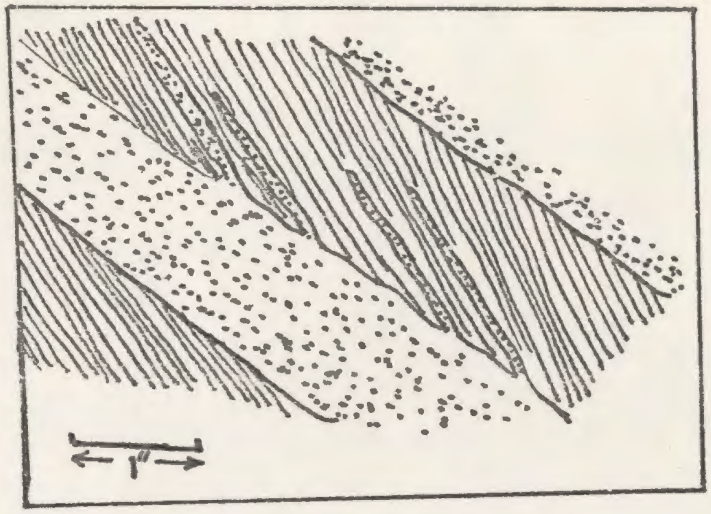
At the time of their emplacement, the beds were folded into a major recumbent anticline with an overturned eastern limb. Some minor folds and slump folds were associated with that movement, and unconsolidated sands and clays were tectonically dewatered as the excess water in the pore spaces escaped under high pore fluid pressures. The platy micaceous minerals suffered mechanical rotation into the direction of the flow defined by the escaping pore fluids. The orientation of these flaky minerals would give the rock a suddued planar anisotropy subsequently destroyed by $D_I$ deformation. The process of tectonic dewatering (Maxwell, 1962; Badgeley, 1965; Powell, 1972) is often supported by the occurrence of sandstone dykes. These are dykes usually found shooting out from a main sandstone unit into the slates, and

are generally concordant with the slaty cleavage.
In the grey slate unit of the Davidsville Group, fine-grained sandstone dykes are found, and their relationship with the cleavage (as they can be seen to be parallel to the slaty cleavage), supports the consolidation of the sandstones during the dewatering process. The contacts between the sandstones and slates are generally welded, and no cleavage refraction is apparent.

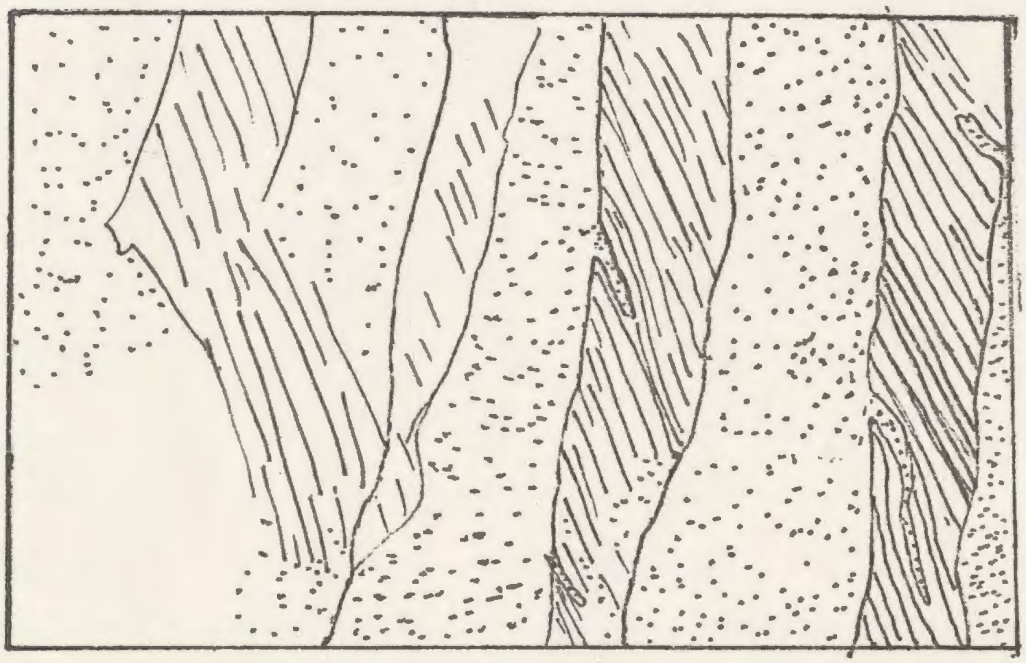
Faults

The ultramafic belt is bounded in the east by a right lateral strike-slip fault here described as the Ragged Harbour fault, and in the west by a low angle thrust fault separating it from the Davidsville Group.

The Ragged Harbour fault displaces the Ragged Harbour Granite as its eastern coastal outcrop near Ragged Harbour (Fig. 3), and trends south-westerly (parallel to the main structural trend) for a distance of 25 km. to the Island Pond area where it offsets the continuity of the western thrust fault separating the Davidsville and Gander Groups. The fault can therefore be said to post-date the emplacement of the Davidsville Group. Evidence from the associated drag folds (in the granites and phyllites), indicate that the Ragged Harbour fault is a right lateral slip fault. In some places, as in the Ragged Harbour river bridge area, a sinistral $F_3$ minor fold in the granitic rock appears to have been unfolded




Sandstone dykes in the Hudson River Group west of Poughkeepsie, New York (From Maxwell, 1962).



Sandstone dykes in the Davidsville Group south east of Carmanville. (Drawn from Plate 13. Sandstone stippled).

Figure 8

by the fault movement. Numerous quartz veins associated with the faulting have mimetically crystallized in the plane of $S_2$ schistosity, giving the phyllites a banded structure (Plate 3).

In the thrust zone between the Davidsville Group and the ultramafic rocks, the Davidsville greywackes have a blastomylonitic foliation (Lundgren and Ebblin, 1973), which is parallel to the $S_I$ regional cleavage. The blastomylonitic foliation was kinked by later deformation whose maximum stress direction (from the orientation of the kinkbands), is parallel to that producing the Ragged Harbour fault. Further more, since the kinkbands and the fault are each produced by a post-$D_I$ deformation, the two structures can be said to be very closely related.

In the thrust zone (between the ultramafic and Davidsville rocks), mesoscopic structures (orientation of drags) suggest that thrusting was easterly directed, with the root of the advancing nappe to the west. The curving attitude of the fault trace implies that this must have been a low angle thrust fault.

In the One Mile Pond area, contacts between the metasedimentary rocks, Aspen Cove and Rocky Bay plutons are marked by numerous NE to NNE trending faults. Although most of the fault planes are not exposed, the faults can be seen to dis-

place lithologic units, and the straightness of fault outlines suggests that they are probably high angle faults. The presence of these faults is also confirmed from aerial photographs by the significant controls they exerted on topography and drainage.

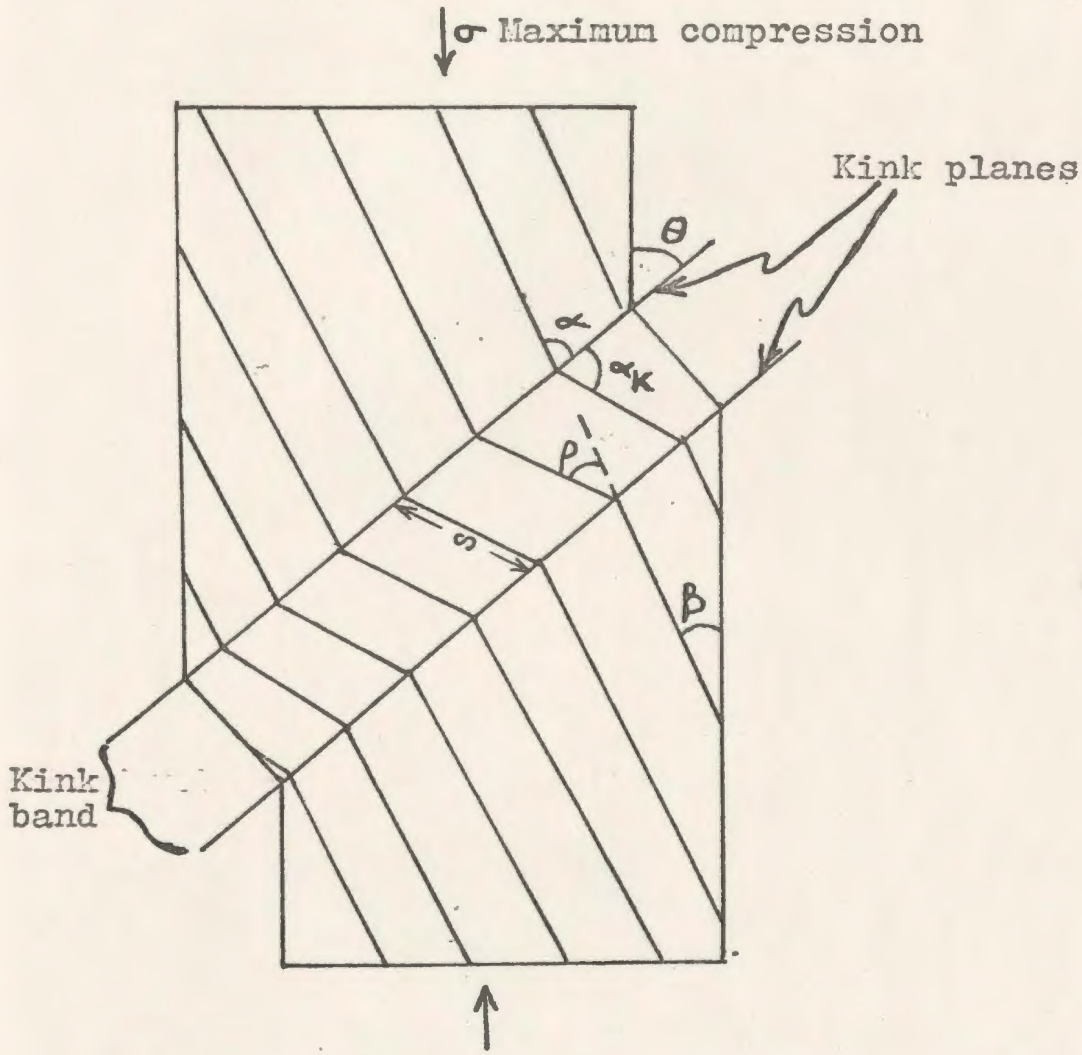
In the Ladle Pt. area, a small strike-slip fault which is sub-parallel to the coast, shows a dextral offset of post-$D_2$ E-W joints. Its displacement along strike is about 3 metres Many other high angle normal faults (often with slickensided fault planes), and joints are widely distributed in the area. Two sets of joints are most commonly seen, one trending SNW-NSE, and the other trending NNE-SSW.

Kink Bands

Kink bands are widely distributed in the area, but they are generally more abundant in the grey slates of the Davidsville Group. These kink bands are small scale fold structures with monoclinic symmetry (Fig. 9a ). Since they can be seen to deform $L_3$ and $L_{\bar{1}}$ lineations in the Gander and Davidsville groups respectively, their development post-dates the last major episodes of folding in the two groups. Two main types of kink bands are recognized:

(1) Dextral kink band in which regional foliation is rotated into obtuse angle (Fig. 9b). Shortening is parallel to the foliation.

(2) Sinistral kink band in which regional foliation




$\alpha$ angle between the kink plane and foliation outside the kink band.

$\alpha_K$ angle between the kink plane and foliation within the kink band.

$\rho$ amount of rotation of foliation within the kink band.

$\beta$ inclination of foliation (outside kink band) from direction of maximum compression ($\sigma$).

$\theta$ inclination of kink plane to direction of maximum compression.

$s$ length of foliation segment within the kink band.

Figure 9a.

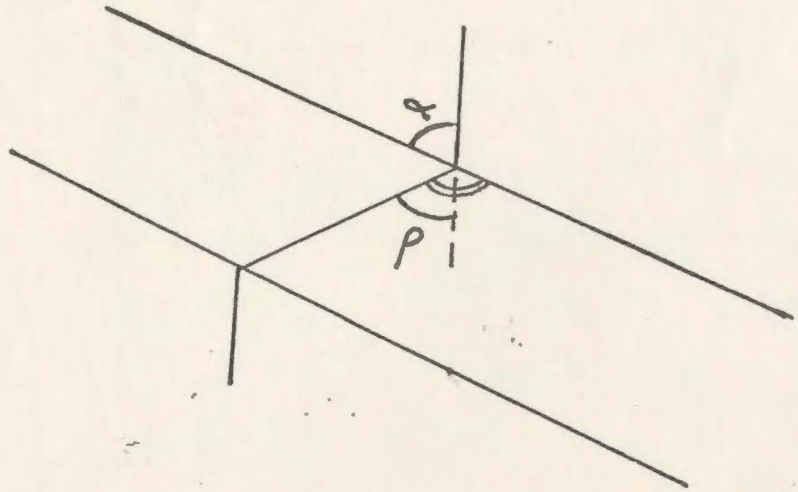



Figure 9b. Dextral kink band; foliation is rotated into obtuse angle.

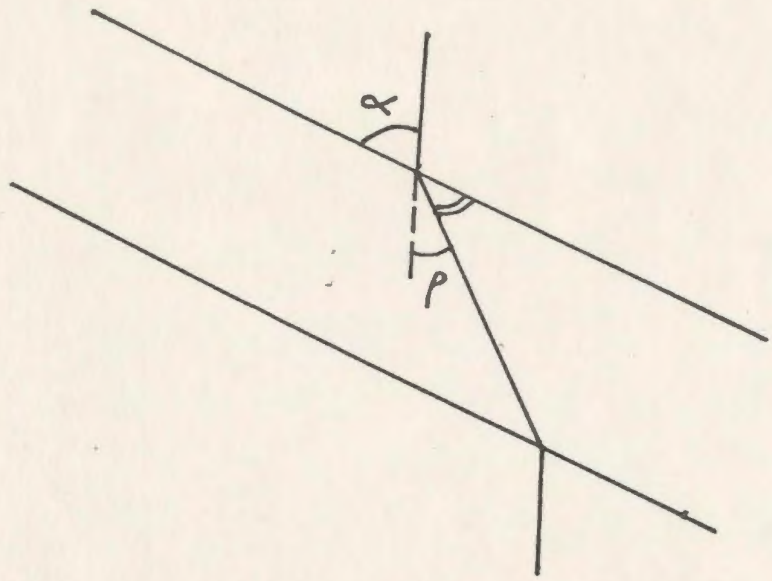



Figure 9c. Sinistral kink band, foliation is rotated acute angle.

is rotated into acute angle (Fig. 9c).
Elongation is parallel to the foliation.

In both cases, the kink plane separation varies from a few mm. in the grey slates of the Davidsville Group, to several cm. in the semi-pelitic schists of the Gander Group (Plate 33). The dextral kink bands occur mostly as segregation kink bands (Dewey, 1969), and are generally more abundant than the sinistral kink bands (ratio of 4:1). In the segregation kink bands (in the Davidsville grey slates), the slaty cleavage remains continuous across the kink plane, and a slight gain in volume change can be seen within the kink band domain. This increase (in volume) is always marked by the crystallization of quartz in the plane of cleavage. Very often, the mineral also crystallizes along the kink plane to give the structure a scalariform appearance.

In thin section, en echelon and conjugate kink bands are more commonly seen in the graphitic schists and phyllites. These seem to be more closely related to the crenulation and strain slip fabrics associated with earlier folds (Plate 29).

Plate 33. Kink band in the semi-pelitic schist of Ragged Pt. Formation, Bear Place.

Plate 34. Foliated (in $S_2$) tabular body of granitic aplite (garnetiferous muscovite biotite granite) in the semi-pelitic schist of Ragged Pt. Formation, Bullrush Pond.

## FOLDED MINOR INTRUSIONS AND AGE OF INTRUSIVE ROCKS

### Basic Dykes and Sills

Isolated thin bands and tabular bodies of meta-diabase occur at various structural levels in the meta-sedimentary rocks of the Gander Group. These minor basic intrusions appear to be similarly deformed as the enveloping country rocks, and were locally folded by $F_2$ folds. Some of the amphibolitic bands (less than 30 cm. thick) were stretched by $D_2$ strain, and disrupted into isolated lenses (Plate 9 ). The rocks are generally schistose, with $S_2$ schistosity as the earliest recognizable fabric. Their age of emplacement could have been pre- (or syn-) $D_2$ deformation of the Gander Group. Some of the diabase dykes which intruded the ultramafic rocks (e.g. in the Shoal Pond area), were less deformed and metamorphosed as they were protected by the ultramafic rocks. The latter have the same composite fabric as the flanking metasedimentary rocks of the Gander Group. They can therefore be considered pre-Middle Ordovician in age. They have not however, been cut by veins of the nearby garnetiferous muscovite-biotite granite (Ragged Harbour pluton), which intruded the Gander Group pre-tectonically (see below). The emplacement of the ultramafic rocks might be later than the intrusion of the garnetiferous muscovite-biotite granites. If the meta-diabases and the

ultramafic rocks were genetically related, they are very likely to have been emplaced at the same time.

At Ragged Pt., an approximately 7 metres wide tabular body of ortho-amphibolite (meta-microgabbro) has a recognizable intrusive contact which is fairly concordant with bedding in the enveloping semi-pelitic schists, suggesting that the body is probably a sill. The rock is well foliated ($S_2$), medium grained and dark grey coloured, containing plagioclase (48%), hornblende (19%), quartz (17%), biotite (15%) and minor muscovite and iron ore.

Plagioclase $An_{33}$ occurs in medium grained subhedral crystals which are generally unaltered and polysynthetically twinned. Some plagioclase laths of larger grain size were extensively fractured and sericitized. If these represent the original plagioclase phenocrysts, the more abundant medium-grained (and unaltered) crystals could have recrystallized during the regional metamorphism ($MS_2$) coeval with $D_2$ deformation. Hornblende crystals occur in dicussate aggregates and are moderately pleochroic from yellowish green to pale green. Most sections are polygonized with plagioclase and quartz, and the minerals appear to have recrystallized during the ($MS_2$) regional metamorphism. They are aligned parallel to $S_2$ schistosity, suggesting that the rock must have been a pre-$D_2$ intrusion.

In the Davidsville Group, a series of dolerite dykes cross-cut $S_1$ foliation as they intruded the mafic agglomerates and greywacke units, and are themselves non-foliated. They are therefore considered post-tectonic intrusions.

Five such dykes with sub-parallel orientation (at about N60°W, dipping 65°NE), and thicknesses varying from 6 in. to 10 ft., occur in the Carmanville area where they intruded the mafic agglomerates, and were subsequently displaced by local fault movement. The rocks are dark grey coloured, fine grained with subophitic texture. They contain fine grained subhedral plagioclase, medium grained euhedral crystals of hornblende and some altered (probably pyroxene) crystals.

Aplitic Dykes and Granitic Veins

Several aplitic dykes and veins of the garnetiferous muscovite-biotite granites are seen to cross-cut the metasedimentary rocks of the Gander Group. The dykes are generally less than a metre thick and occur as isolated lenses in the metasediments (away from the main granitic masses), and ptygmatically folded veins very close to the granitic pluton. They are essentially leucocratic (with less than 20% colour index), and contain high percentage of quartz (about 40%), lesser orthoclase (10-20%), plagioclase (20-10%), garnet (5%), muscovite (10%) and biotite.

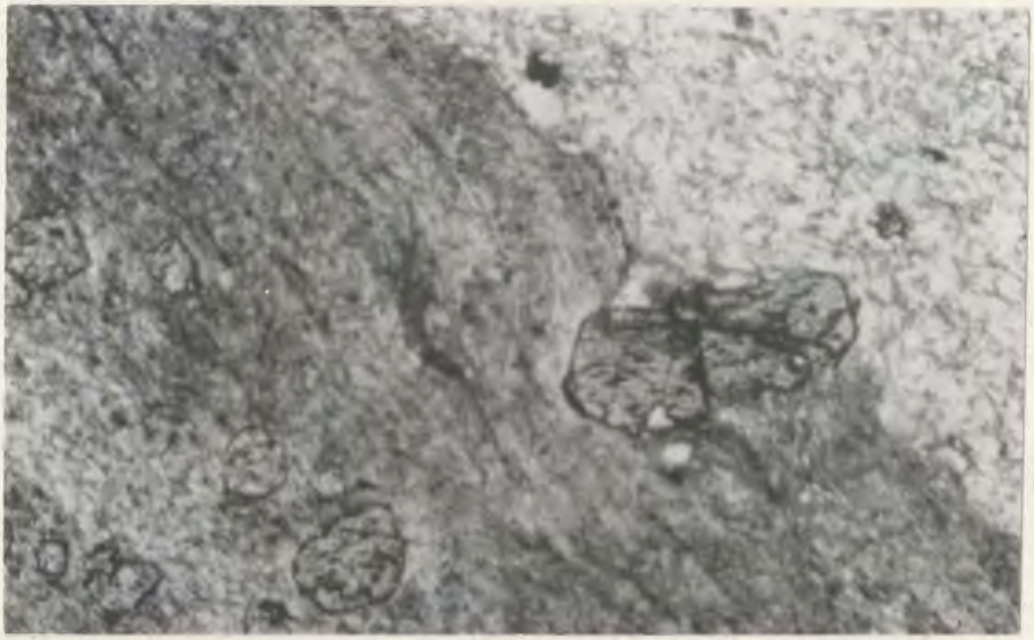


Plate 35 $MP_1$ garnet porphyroblasts with ($S_1$) inclusion trails. $S_2$ forms augen round the garnets. Graphitic schist of Ladle Pt. formation (crossed nicols X 39.385).

Plate 36 Garnet porphyroblast ($MS_2$?) in the semi-pelitic schist near Aspen Cove. The mineral is 'stretched' parallel to $S_2$ schistosity, and the inclusion trails are continuous with $S_2$ (plane polarized X40)

The rocks have the same composite fabric as the enveloping metasedimentary rocks. They were generally folded by $F_2$ folds and some more complexly deformed ptygmatic structures have relict $F_1$ closures.

In thin section, $S_2$ schistosity is seen to form augen around some altered plagioclase crystals. The latter contain inclusion trails (of flaky muscovite) which are oblique to the crystal cleavage and $S_2$ schistosity. These trails represent the earliest schistosity ($S_1$) seen in the rock, and are similar to those described in the enveloping metasediments. It can be said therefore that most of the granitic veins and dykes intruded the Gander Group before the latter was first deformed. The related garnetiferous muscovite-biotite granites (e.g., the Ragged Harbour and Round Pond plutons etc.) which have also similar structures as the flanking metasedimentary rocks (especially at their contacts) could have been emplaced before the first deformation of the Group. As the granites are themselves less homogeneous (differing in texture and composition - see above), it is probable that some of their phases could have been emplaced at a later stage. Since the second schistosity ($S_2$) is continuous throughout the metasedimentary and granitic rocks, it can be said that the latest age for such phases will be pre- or syn-$D_2$ deformation of the Gander Group.

# CHAPTER FOUR

# METAMORPHISM

The metasedimentary rocks of the Gander Group show the effects of greenschist to amphibolite facies regional metamorphism. The occurrence of pelitic rocks in all the three Formations have made the recognition of two (biotite and garnet zones) of the Barrow-Tilley Zones (Barrow, 1893; Tilley, 1925) of progressive metamorphism possible.

There is obvious difficulty in deciding whether biotite and garnet (almandine?) should be considered as critical minerals in the study area. The two minerals are seen throughout the metasedimentary rocks from low grade schist to amphibolites. They have also crystallized (together with cordierite and andalusite) as contact metamorphic minerals associated with the emplacement of both the Aspen Cove and Rocky Bay plutons. Although these later events greatly modified the metamorphic zones, the increase in grade from west to east, is still apparent in the field.

The grade of metamorphism in the gneissic basement and Gander Group are briefly described, together with the ages of common metamorphic minerals relative to various phases of deformations (Rast,1958; Ramsay, 1959 & 1963; Spry, 1969; Sturt and Harris, 1961).

The following scheme of abbreviations modified after Sturt and Harris (1961) will be employed:

| | Phase of Metamorphism | Movements |
|---|---|---|
| $MP_0$ | Pre-$D_1$, Contact metamorphism | Plutonism |
| $MS_1$ | Syntectonic ($D_1$) | $F_1$ |
| $MP_1$ | Post-tectonic | |
| $MS_2$ | Syntectonic | $F_2$ |
| $MP_2$ | Post-tectonic | |
| $MS_3$ | Syntectonic | $F_3$ |
| $MP_3$ | Post-tectonic | |

Metamorphism in the Gneissic Basement

The earliest gneissic banding in the rock is defined by the clusters of fibrolites and heavily altered biotite. Most of the fibrolites are pseudomorphous after biotite. No kyanite is seen in the rock, but elsewhere (in the Musgrave Harbour area) Kennedy (pers. comm. 1972) has described kyanites from the gneissic basement. Since this gneissic banding is cut by the dykes of the Ragged Harbour pluton (Plate 1), the crystallization of the fibrolites must pre-date the emplacement of the pluton. As the latter is associated with the migmatization of the gneissic basement, the age of the fibrolites must also pre-date the migmatization of the basement.

The medium-grained flaky crystals of brownish green

biotite lie with their long axes parallel to the composite gneissic banding of the rock. The development of the gneissic banding also pre-dates the migmatization of the basement, since the Ragged Harbour pluton cuts the gneissic banding, and the layered stromatic structure (Plate 4) shown by the granitic veins (neosome) of the Ragged Harbour pluton suggests that migmatization was coeval with the emplacement of the pluton. The slight effect of post-tectonic retrogressive metamorphism is seen in the alteration of biotite by chlorite.

The Earliest Metamorphic Events in the Gander Group

The garntiferous muscovite biotite granites intruded the Gander group pre-tectonically (see above Chapter 3) and possibly produced contact aureole in the enveloping sedimentary rocks. Subsequent deformations and metamorphisms had greatly obliterated the ($MP_0$) thermal metamorphic effects. Some dusty and fragmented garnets and cordierites seen in the partly granitized metasediments near the margins of the Round Pond and Aspen Cove plutons may be contact metamorphic minerals associated with the emplacement of these plutons. A weak $S_2$ schistosity formed by flaky muscovite and biotite crystals (which are post-$MP_0$) forms augen around these minerals (which could also be $MS_1$ growth phase), indicating that their recrystallization pre-dates $D_2$ deformation. Most of the min-

eralogical assemblages formed during the earliest recrystallizations in the Gander Group were extensively destroyed by later and stronger metamorphic events. Some $MS_1$ minerals can only be seen as inclusion trails in the $MP_1$ garnet and plagioclase porphyroblasts. These minerals which include flaky muscovite, minute crystals of quartz and graphite, generally define relic $S_1$ schistosity.

$MP_1$ Recrystallization

Garnet porphyroblasts with ($S_1$) inclusion trails of quartz and opaque minerals occur in the graphitic schists of Ladle Pt. formation. The $S_1$ in garnet is oblique to $S_2$ schistosity that form augen around the mineral (Plate 35). This clearly indicates that crystallization of garnet predates the development of $S_2$ schistosity.

Some plagioclase porphyroblasts seen in the banded amphibolites also contain inclusion trails which pre-date the second schistosity $S_2$. They are therefore considered $MP_1$ in age.

Where $S_1$ is folded by $F_2$ as in the phyllitic mica schist of Ragged Harbour River formation, the $S_1$ is defined by the flaky mica crystals and reddish leucoxene (Plate 24).

$MS_2$ Recrystallization

The climax of metamorphism occurred during the second phase of deformation, producing muscovite-biotite schists,

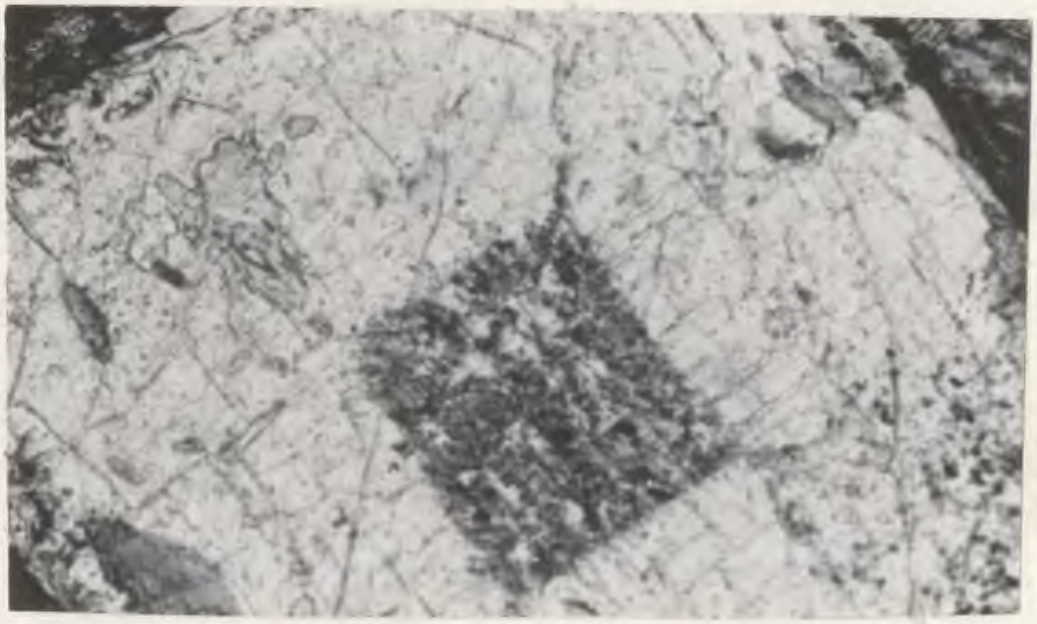


Plate 37. Rectangular inclusion in the chiastolite, graphitic andalusite schist of the Davidsville Group (crossed nicols X 40).

Plate 38 . Recrystallization of andalusite porphyroblast across the folded $S_2$ schistosity, semi-pelitic schist of Ragged Pt. Formation (crossed nicols X 4).

actinolite schists and amphibolites. This metamorphism is regional in aspect with temperature, composition and pressure as the main factors, where $PCO_2 > PH_2O$ examplified by the extensive recrystallization of graphite - a mineral known to be unstable in the presence of high $H_2O$ (Muller and Schneider, 1971; Hsu, 1968; Ramberg, 1968; Deer, Howie and Zussman, 1969).

The widespread recrystallization of biotite and muscovite during $D_2$ deformation is reponsible for the development of a penetrative $S_2$ schistosity as these minerals are aligned with their long axes parallel to $S_2$. At the $F_2$ fold hinges, they interlock in polygonal archs which suggests a syntectonic recrystallization. In the graphitic schists and muscovite schists with garnet bands, some garnets (which are probably $MS_2$ in age) are boudinaged and stretched parallel to $S_2$. They contain inclusion trails which are parallel with and continuous into the $S_2$ schistosity (Plate 36).

The L-S fabric shown by the amphibolites and actinolite schists is formed by the strong dimensional orientation of granular aggregates of hornblende, flaky biotite and spindly crystals of actinolite produced during the second deformation. The foliation thus produced is oblique to $S_1$ schistosity (banding) and parallel to $S_2$ schistosity. At the shadowed areas in the minor $F_2$ fold cores these minerals are polygonized in decussate aggregates indicating that either $MS_2$ recrys-

tallization outpaced deformation, or the texture might have been produced by a post-$D_2$ annealing recrystallization.

$MS_2$ recrystallization affected the ultramafic rocks marginally, producing talc-carbonate schists in which subhedral crystals of calcite are arranged in inequidimensional orientation parallel to $S_2$ schistosity.

$MP_2$ Recrystallization

In the semi-pelitic and actinolite schists of the Gander Group, $MP_2$ garnets, actinolite and muscovite grow across the $S_2$ schistosity which they post-date. Some of the $MP_2$ garnets have overgrowths, with clear outer zones, and centres containing inclusion trails (Plate 39). Zoning in garnet is generally considered to be developed under relatively low pressure conditions of metamorphism, whether by epitaxial growth (Powell,1966) or by alteration and nucleation around early formed crystal (Spry,1969). The garnet overgrowth on garnets is more commonly considered epitaxial, especially if the inclusion trails in the inner zone continue into the outer zone. This feature is however not seen in any of the studied examples, and it seems probable that the garnet overgrowth (in this case) could also be produced by nucleation around early formed crystals. The latter (inner zone) could have formed by epitaxial growth.

Since the $L_3$ intersection lineations are not seen in

some areas of the semi-pelitic and psammitic schists, the age of common metamorphic minerals relative to these structures is locally obscure. Some of the $MP_2$ minerals (discussed above) could possibly be $MP_3$ growth phases.

$MS_3$-recrystallization was extensively obliterated by $MP_3$ thermal metamorphic event. In the pelitic schists (e.g., the graphitic schists of Ladle Pt. Formation), some flaky biotite crystals had grown parallel to $S_3$ strain-slip fabric, and are probably $MS_3$ in age. Their recrystallization was later than the $MS_2$ biotite porphyroblasts. The latter were deformed by $S_3$ strain-slip fabric, and had been rotated in a subparallel alignment to $S_3$.

$MP_3$ (and $MP_0$ in the Davidsville Group).

This metamorphism is thermally induced and had affected rocks of the Gander and Davidsville Groups. In the Gander Group, its effect is mostly seen in the graphitic schists of the Ladle Pt. Formation, and in the muscovite biotite schists where post-$D_3$ quartz-feldspathic veins cut across the country rocks. The common $MP_3$ minerals are andalusite (chiastolite) garnet and cordierite. The preponderance of these minerals near the Rocky Bay pluton and in the areas cut by the pegmatitic veins of quartzo-feldspathic material, and the close genetic relationship of the pluton with the veins are strongly suggestive of the thermal metamorphism

originating from the emplacement of the Rocky Bay pluton. This is also supported by the age of the andalusites which post-dates $D_3$ in the Gander Group and therefore post-dates the emplacement of other granitic masses in the area.

The $MP_{\bar{0}}$ garnets in the Davidsville group occur as equant subhedral crystals with dusty appearance resulting from disoriented central inclusions of opaque minerals. The $S_{\bar{1}}$ schistosity forms augen around the garnet and andalusite porphyroblasts. The latter are more commonly represented by chastolites with characteristic cruciform internal structure and rectangular inclusions (Plate 37). The "spotted" crystals of cordierite (Plate 11), flaky muscovite and patchy chlorite are generally found further away from the pluton where recrystallization of andalusite is also less abundant. There is generally a recognizable sequence in the order of recrystallization of these minerals from chlorite $\rightarrow$ muscovite $\rightarrow$ andalusite as the pluton is approached. This relationship may be seen in one individual porphyroblast where muscovite is partially pseudomorphed by andalusite.

## The Last Metamorphic Events

The last metamorphic event is primarily retrogressive (especially in the Gander Group), and marked by the breakdown of biotite into muscovite and chlorite. It is not clear whether this retrograde metamorphism (in the Gander Group) can

be considered the regressive side of Rocky Bay (Quartz Diorite) thermal metamorphic event, or a syntectonic recrystallization ($MS_4$) coeval with $D_4$ deformation.

In the graphitic schist of the Davidsville Group, helicitic chloritoids occur as syntectonic ($MS_1$) minerals at the minor $F_1$ fold hinges in the graphitic schists of the Davidsville Group.

Post-tectonic annealing recrystallizations (Voll,1960; Turner and Weiss, 1963) have affected the rocks slightly so that most of the early fabrics are still preserved. Perfect triple junctions are developed by fine-grained polygonal crystals of quartz which recrystallized near the fold hinges and irregular fracture zones.

## Metamorphic Grades in the Gander Group

### Greenschist Facies

The chlorite schists and phyllites of the Ragged Harbour River Formation occur in a zone (chlorite-biotite zone) which is surrounded by rocks of higher metamorphic grades. The zone lies between the ultramafic belt (in the north) and the gneissic basement (in the south).

The rocks (in this zone) are fine-grained, containing chlorite, muscovite, scaly biotite and hematite. The rocks are generally devoid of garnet, but contain an unusually high

percentage of hematite. Muller and Schneider,(1971) have suggested that the absence of some garnets (e.g. almandine) in some schists containing hematite appears to be related to high oxygen fugacity. The latter is ideal for the crystallization of hematite.

Almandine-Amphibolite Facies (Turner and Verhoogen,1960) (lower part of the Garnet Zone)

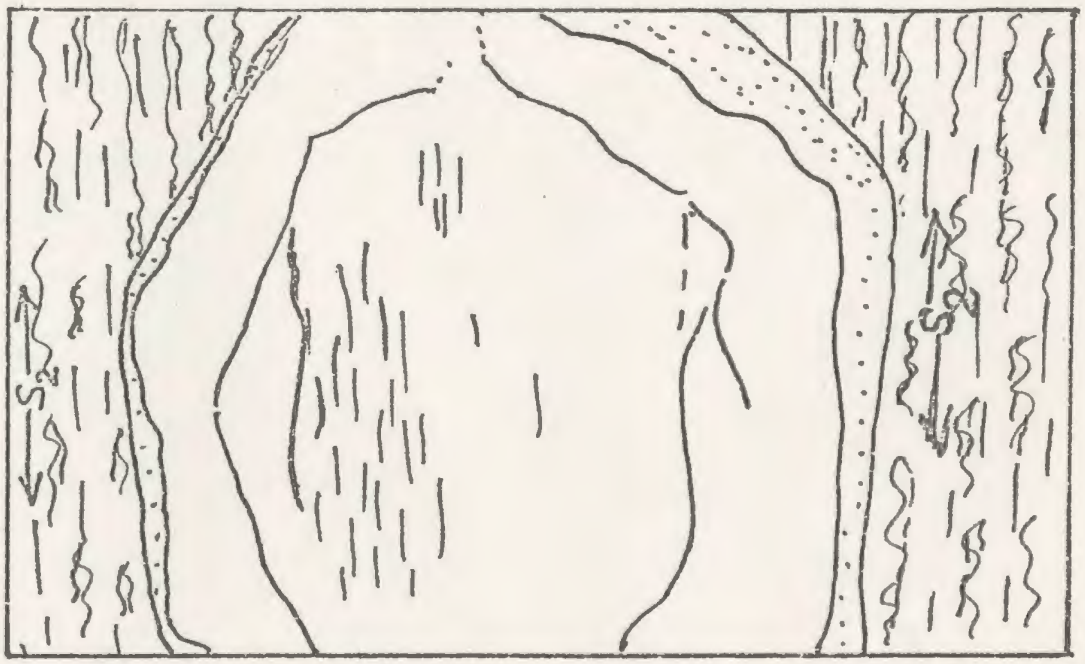
This zone lies immediately to the west of the ultramafic belt, terminating at the contact between the Gander and Davidsville Groups in the southwest, and grading northeastwards into rocks of higher metamorphic grade. It is formed by the graphitic schists of the Ladle Pt. Formation and muscovite-biotite schists (with garnet bands) of the Ragged Pt. Formation. The metavolcanic rocks are represented by the actinolite schists. The garnets in the muscovite schists are primarily contact metamorphic garnets. They are clouded with dusty inclusions of disoriented opaque minerals. In the graphitic schists however, most of the garnet porphyroblasts have crystallized during or before the $MS_2$ regional metamorphic events. The high content of graphite in these rocks suggests that the $CO_2$ partial pressure ($P_{CO_2}$) must be important in the metamorphism of the pelites. The $P_{CO_2}$ decreases the oxygen fugacity (cf., Muller and Schneider,1971; Hsu, 1968) and in-

creases the stability of almandine. In this zone therefore, the garnets have either crystallized as contact metamorphic minerals or as low temperature regional metamorphic garnets whose stability field has been modified by $P_{CO_2}$.

Almandine-Amphibolite Facies (Garnet Zone)

This zone which is restricted to the northeastern portion of the Ragged Pt. Formation contains assemblages where temperature and physical(?) conditions of formation are indicative of amphibolite facies metamorphic grade. The rocks are represented by schists and amphibolites containing garnets, diopside, reddish-brown biotite, hornblende, actinolite, plagioclase ($An_{34}$), quartz, minor K-feldspar and tourmaline. The garnets are distinctly clear without inclusions. The mineral is seen in all the rocks in this zone but in minor amounts. The rocks are medium to coarse grained. Increase in metamorphic differentiation has locally produced compositional banding in the amphibolites and biotite schists.

Plate 39 . $MP_2$ Garnet (zoned) in the biotite schist of Ragged Pt. Formation, near Bear Place (see diagram below). X 4.



# CHAPTER FIVE

## SUMMARY AND DISCUSSION

The dominant schistosity in the Gander Group is a second fabric $S_2$ which has the same NE regional trend with the single axial planar foliation $S_I$ in the Davidsville Group. This co-linearity of the two fabrics has led some workers (Jenness, 1958 & 1963) into believing that the structures in the two Groups were produced by the same deformations. Jenness (1963) has argued that deformation and metamorphism (in his Gander Lake Group) only varied in intensity, and increased from west to east. This argument oversimplifies the structural complexities in the area. The dissimilarities (in structure) between the Gander and Davidsville Groups can be seen on a mesoscopic scale. By comparing the age of common metamorphic mineral with various phases of deformation (Rast,1958; Ramsay, 1959; Spry,1969), it can be shown that the third deformation $D_3$ in the Gander Group is clearly older than the first deformation $D_I$ in the Davidsville Group. The andalusite and cordierite porphyroblasts grew across $L_3$ crenulation in the Gander Group, while $S_I$ foliation in the Davidsville Group forms augen around them. This suggests that crystallization of these minerals post-dates $D_3$ deformation in the Gander Group, and pre-dates $D_I$ deformation in the Davidsville Group. In some metamorphic fragments in the mélange, $F_3$ folds can be

seen, and their generation clearly pre-dates the incorporation of the fragments in the melange.

The two Groups (Gander and Davidsville) have also different phases of granitic intrusions. The garnetiferous muscovite-biotite granites and related aplitic veins intruded the gneissic basement and the Gander Group, while the Rocky Bay Quartz Diorite and associated pegmatitic quartzo-feldspathic veins intruded both the Gander and Davidsville Groups. No radiogenic ages for any of these granitic masses have been precisely determined. Previously, Fairbain and Berger (1969) had calculated a Rb/Sr whole rock isochron age of about 600 m.y. for the porphyritic biotite granite (Deadman's Bay pluton) which Berger (personal communication,1973) claims to cut the Ragged Harbour pluton, i.e. garnetiferous muscovite-biotite granite. In spite of several mathematical errors, the age is a close approximation. The Gander Group which the Ragged Harbour pluton intruded pre-tectonically will therefore be older (than that age), and the gneissic basement it cut post-tectonically will be much older-Precambrian.

Since the contact metamorphism of the Davidsville Group (by the Rocky Bay pluton) preceeded the first penetrative deformation $D_I$ of the Group, and pegmatitic quartzo-feldspathic veins (associated with the pluton) cut across the

second and third fabric in the Gander Group and are generally parallel to the first fabric $S_I$ in the Davidsville Group, the Rocky Bay pluton is at least older than the first deformation $D_I$ in the Davidsville Group. As the single axial foliation $S_I$ in the Davidsville Group is a Devonian (or Acadian) fabric (cf. Kennedy and McGonigal, 1972a), it means that the pluton may be older than Devonian, and may possibly be Silurian or older (Fig. 10e).

The recognition of a gneissic basement to the Gander Group (Kennedy and McGonigal, 1972a) has stimulated more discussion on the ensialic nature of the nearby Avalon Platform (Williams et al., 1972; Papezik, 1973). The assumption that the same gneissic basement possibly extends eastwards beneath the Avalon Platform has continued to gain increasing support (cf. Williams et al., 1972). Southwards along strike in the Baie d'Espoir area, similar gneissic rocks have been described as basement to the metasedimentary and poly-deformed Baie d'Espoir Group (Colman-Sadd, personal communication).

The occurrence of the metasedimentary rocks of the Gander Group on the eastern margin of the Central Mobile Belt of the Newfoundland Appalachians, and those of the Fleur de Lys Supergroup on an analogous position at the western margin of the Mobile Belt, has further amplified Williams' (1964) earlier thought of the two sided symmetry of the Newfoundland

Appalachians. Both groups possess a pre-Middle Ordovician composite fabric, and a greenschist to amphibolite facies grade of metamorphism.

The Fleur de Lys Supergroup has been interpreted as a continental rise prism deposited on a gneissic basement (M.J.de Wit in prep.), and thinned out westwards onto the Western Platform (Stevens, 1970). The Gander Group can possibly be described as a seaward thickening clastic sequence deposited on a continental rise (formed by the gneissic basement) on the Western edge of the Avalon Platform (cf. Kennedy and McGonigal, 1972a). The development of these ortho-tectonic zones at the eastern and western edges of the Central Palaeozoic Mobile Belt is of paramount importance in the construction of any plate tectonic model for the Newfoundland Appalachians. Many aspects of this problem have previously been considered (Bird & Dewey, 1970; Dewey, 1969; Dewey & Bird, 1971; Kay, 1972). The conclusions reached in the present study can further be explained in terms of actualistic plate tectonic models (Fig.10).

The Gander and Fleur de Lys rocks were first deformed in pre-Middle Ordovician times (possibly Cambrian) during Island Arc-Continent collision at the closure of proto-Atlantic Ocean (Strong, 1973; Kennedy,1973). The Gander and Burlington ultramafic rocks (pyroxinites) were emplaced along fracture and/or suture zones as segregated crystal mushes

The re-opening of Atlantic (Figure 10d) in Middle Ordovician was marked by the generations of the Betts Cove, Baie Verte, and Pelly's Island ophiolite complexes in marginal ocean basins (Dewey & Bird, 1971; Upadhyay et al., 1971; Strong, 1972), and the deposition of some members of the Davidsville Group (Figure 10d). The group contains sedimentary (pelites) and volcanic rocks typical of euogeosynclinal facies. These include slices of ophiolites (serpentinized dunites, gabbros, and mafic pillow lavas) which are now exposed in the mélange belt separating the Gander and Davidsville Groups. The mafic agglomerates (probably the oldest member of the Davidsville Group) seem to be genetically related to the mafic pillow lavas exposed at a road cut near Carmanville. Both the agglomerates and pillow lavas were incorporated as blocks in the mélange. The Davidsville polymictic conglomerates contain pebbles of andesites, rhyolites and mafic volcanic rocks of unknown source. They might have been derived from a pre-Middle Ordovician or Middle Ordovician Island Arc environment, e.g., Notre Dame Bay Island Arc (Mitchell & Reading, 1971; Strong, 1972).

The final closing of the marginal seas took place probably in Late Middle Ordovician time, during which the allochthonous rocks of western Newfoundland were transported, and the Davidsville Group moved eastwards as a folded nappe. The mélange formations on both sides are considered tectonic and

these are different from Dunnage formation which was interpreted by Dewey and Bird (1970), and Kay (1972), as a trench deposit in a westerly dipping subduction zone, but by others (Horne, 1969; Horne and Helwig, 1969), as olistostrome-mélange.

Table 3

Summary of Tectonic and Metamorphic Events in the Gander and Davidsville Groups

| Gander Group | | Davidsville Group | |
|---|---|---|---|
| Deformation | Metamorphism | Deformation | Metamorphism |
| Faults, kink bands | Annealing Recrystallization | Faults, kink bands | Annealing Recrystallization |
| $D_4$; crenulations | Retrogression (chlorite) | $D_{\bar{2}}$ local crenulation & buckling of $S_{\bar{1}}$ by $F_{\bar{2}}$.<br>$D_{\bar{1}}$: $F_{\bar{1}}$ folds & penetrative $S_{\bar{1}}$. | Chloritoids |
| (Rocky Bay pluton) | Retrograde metamorphic chlorite $MP_3$, Cordierite, andalusite, and garnet. | (Rocky Bay pluton) | $MP_{\bar{0}}$ andalusite, cordierite, garnet, biotite, muscovite. |
| $D_3$: strain-slip fabric, buckling of $S_2$ by $F_3$. | $MS_3$ biotite | Emplacement of Davidsville Nappe (?) | |
| | $MP_2$ garnet, muscovite, actinolite(?) | | |
| $D_2$; $F_2$ folds & penetrative $S_2$ schistosity. | $MS_2$ Biotite, muscovite, hornblende, feldspars, actinolite, graphite, garnet(?) | | |
| (Ultramafic rocks, diabases?) | $MP_1$ Garnet, plagioclase. | | |
| $D_1$; $F_1$ folds and $S_1$ schistosity | $MS_1$ biotite, graphite, (inclusion trails). | | |
| (Garnetiferous muscovite-biotite granites) | Contact metamorphism | | |

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# APPENDIX

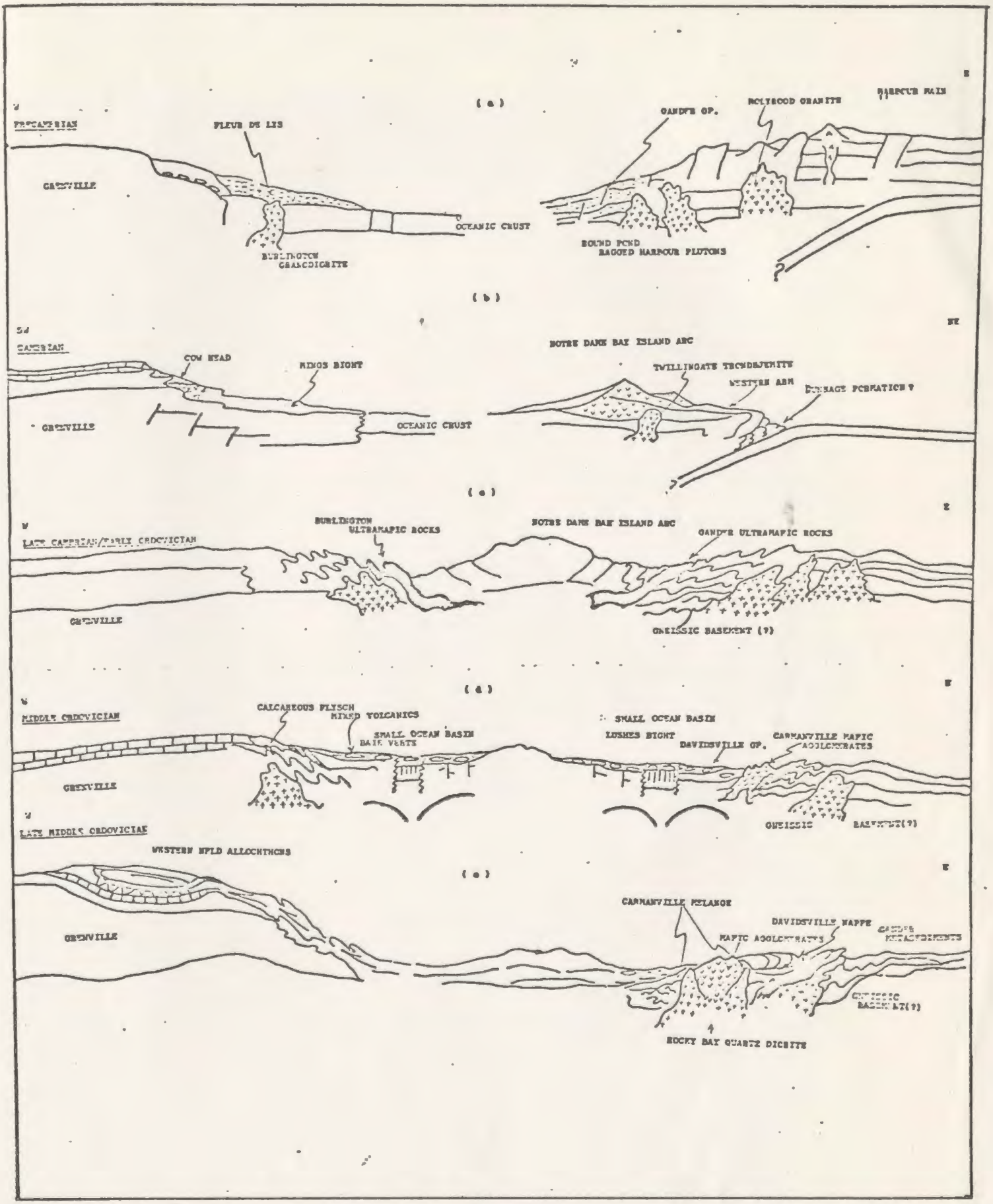



FIGURE 10. PROPOSED PLATE TECTONIC EVOLUTION OF THE GANDER AND DAVIDSVILLE GROUPS AS PART OF NEWFOUNDLAND APPALACHIANS.

Table 4

Modal Analyses of Granitic Rocks

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Quartz | 44 | 35 | 38 | 43 | 10 | 12 | 40 |
| Plagioclase | 31 | 38 | 12 | 13 | 50 | 60 | 18 |
| Orthoclase | 18 | 19 | 35 | 27 | 5* | 5* | 20 |
| Hornblende | - | - | - | - | 30 | 3 | - |
| Biotite | 3.5 | 3 | 6 | 11 | 4 | 20 | 5 |
| Muscovite | 3 | 3.75 | 7 | 5 | - | - | 10 |
| Garnet | 0.25 | 0.25 | 0.13 | 1 | - | - | 5 |
| Chlorite | - | - | - | - | 0.25 | - | - |
| Others | 0.25 | 1 | 1.87 | - | 0.75 | - | - |

*Not confirmed by staining (count to 1000 points).

1 - 2 Granodiorite (Aspen Cove pluton).

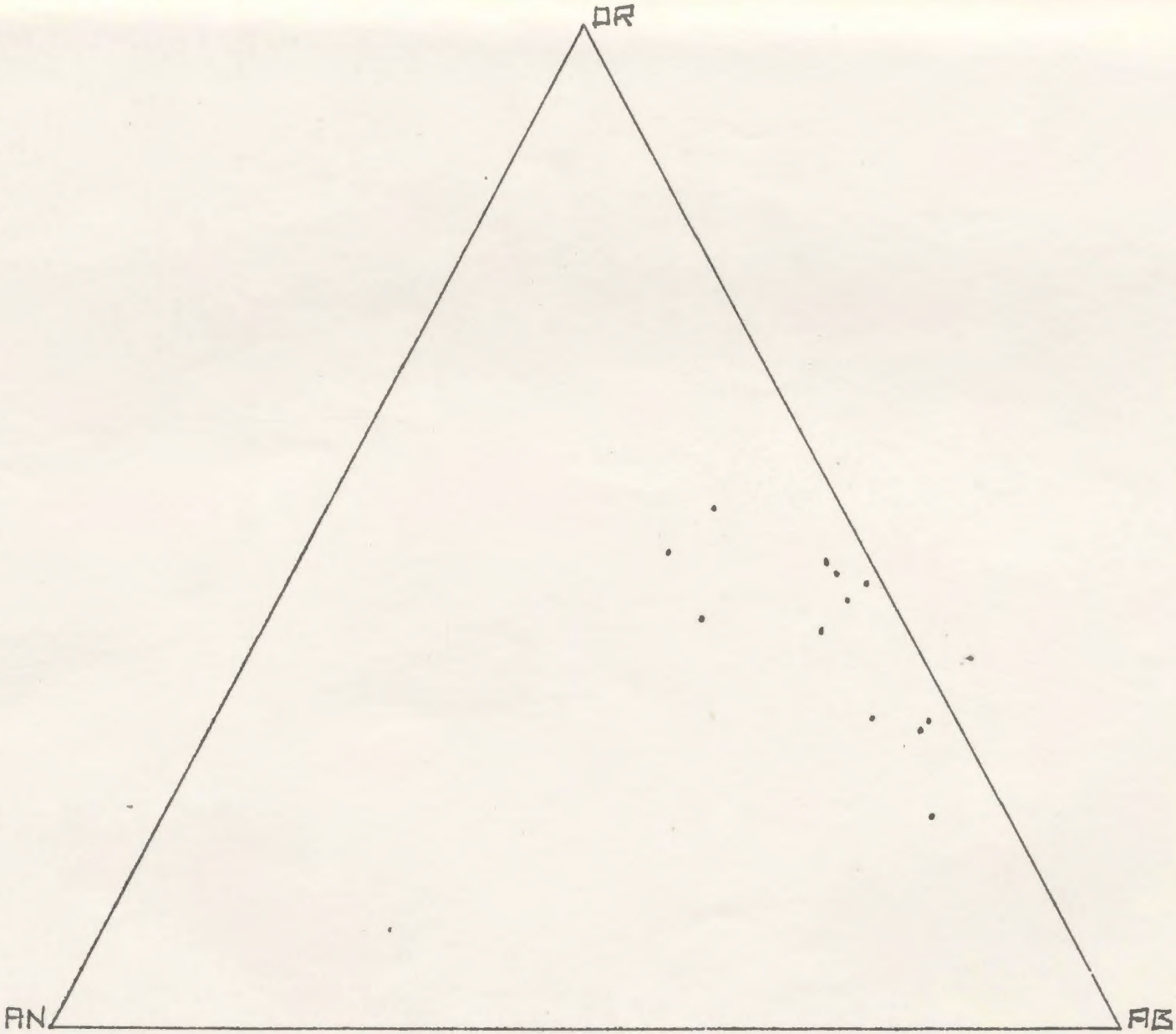
3 Granite (Ragged Harbour pluton)

4 Granite (Round Pond pluton).

5 - 6 Quartz diorite (Rocky Bay).

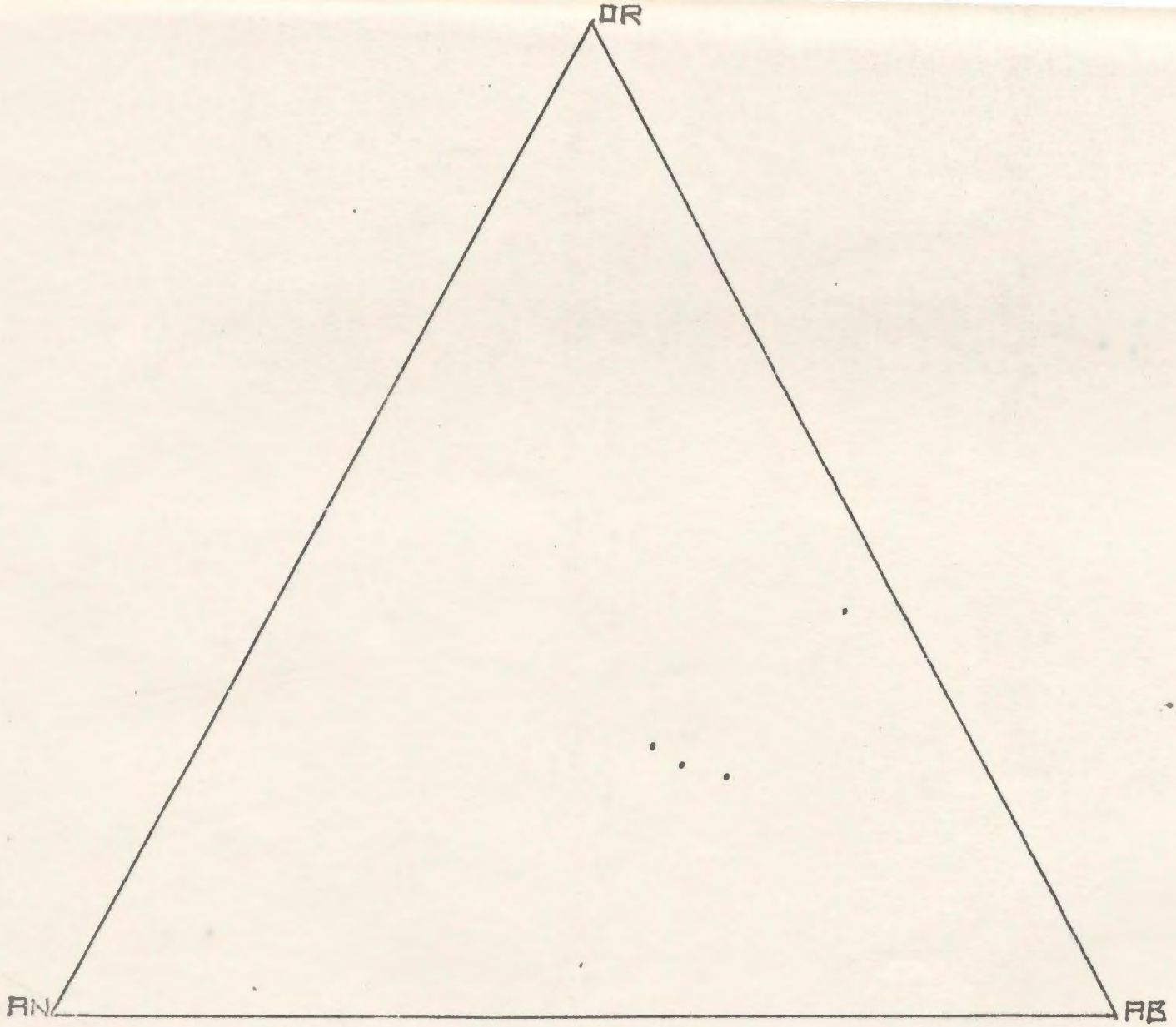
7 Granitic aplite.

Figures 11a-11e. Triangular diagrams (CIPW norms) for the granitic rocks.



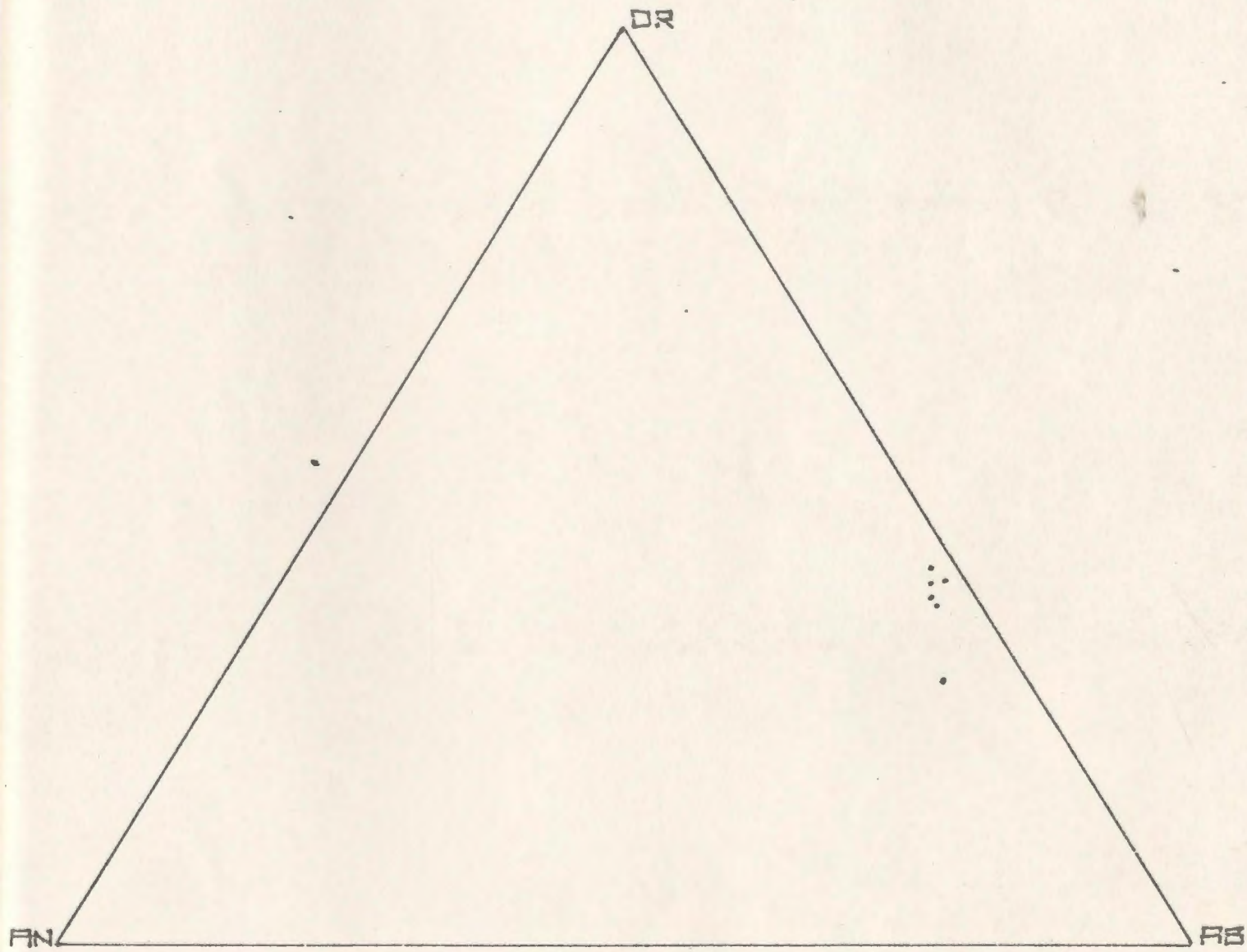

OR-AB-AN DIAGRAM FOR THE RAGGED HARBOUR GRANITE

Figure:11a



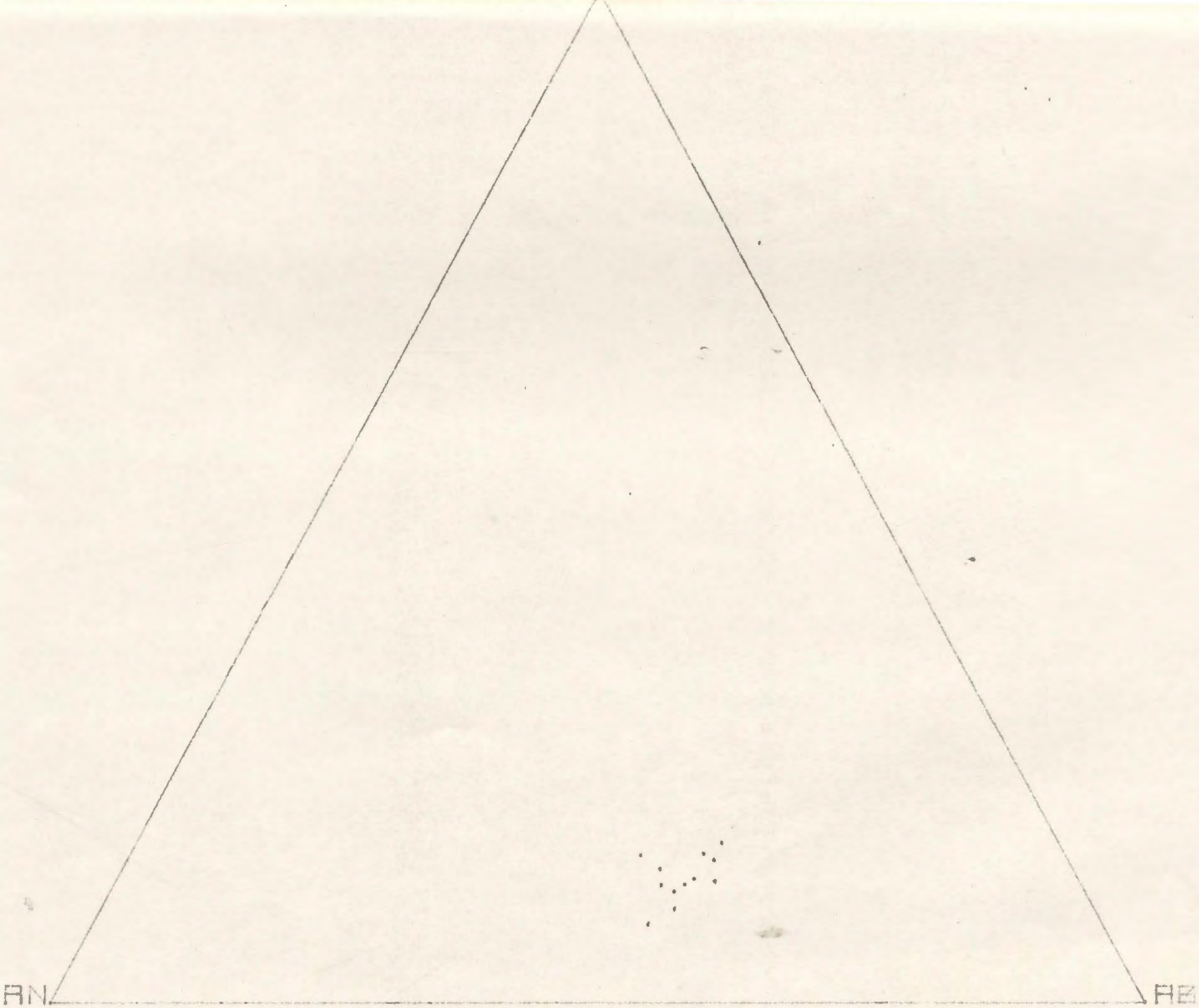

OR-AB-AN DIAGRAM FOR THE ROUND POND GRANITE

Figure:11b



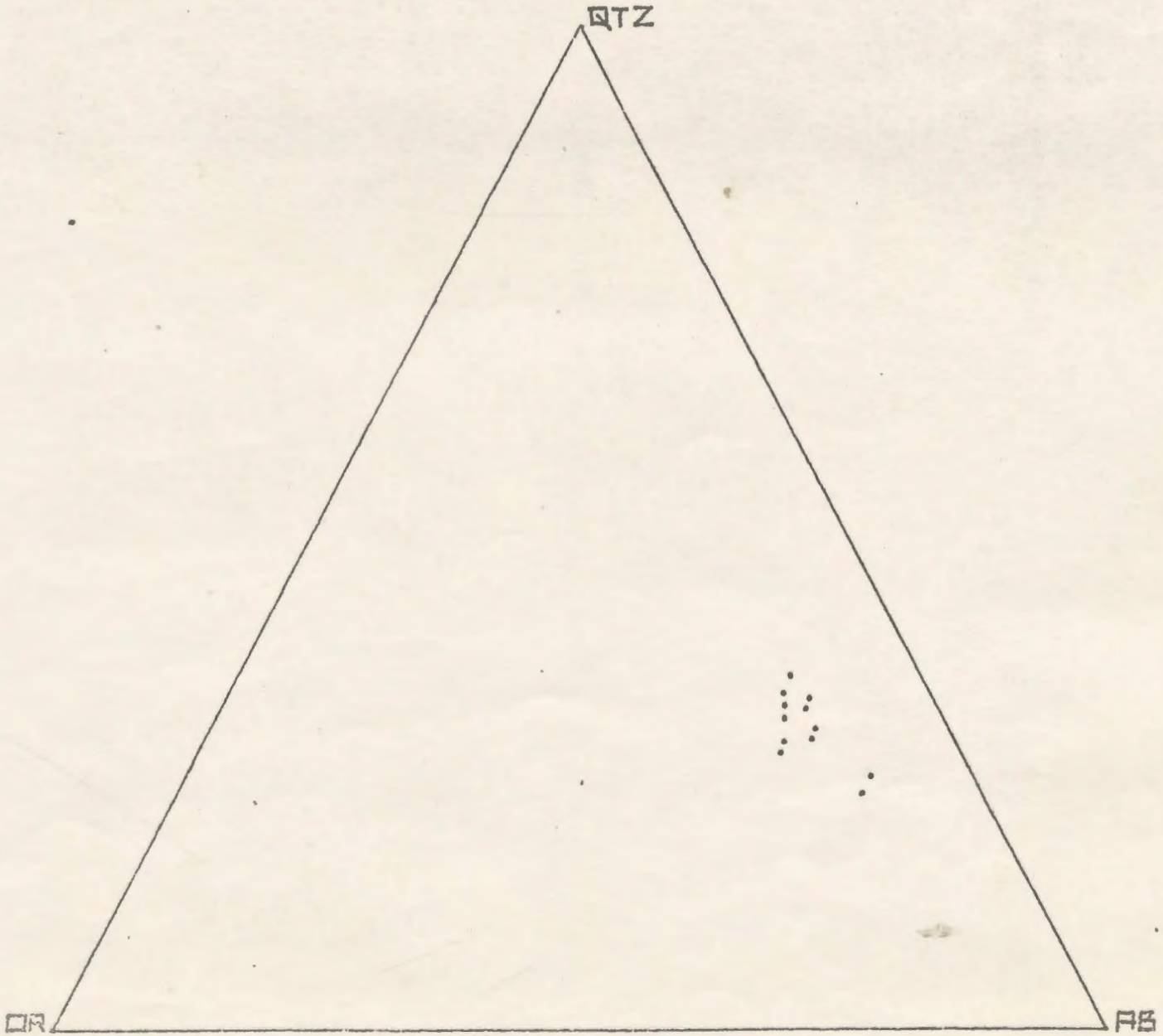

OR-AB-AN DIAGRAM FOR THE ASPEN COVE GRANODIORITE

Figure:11c



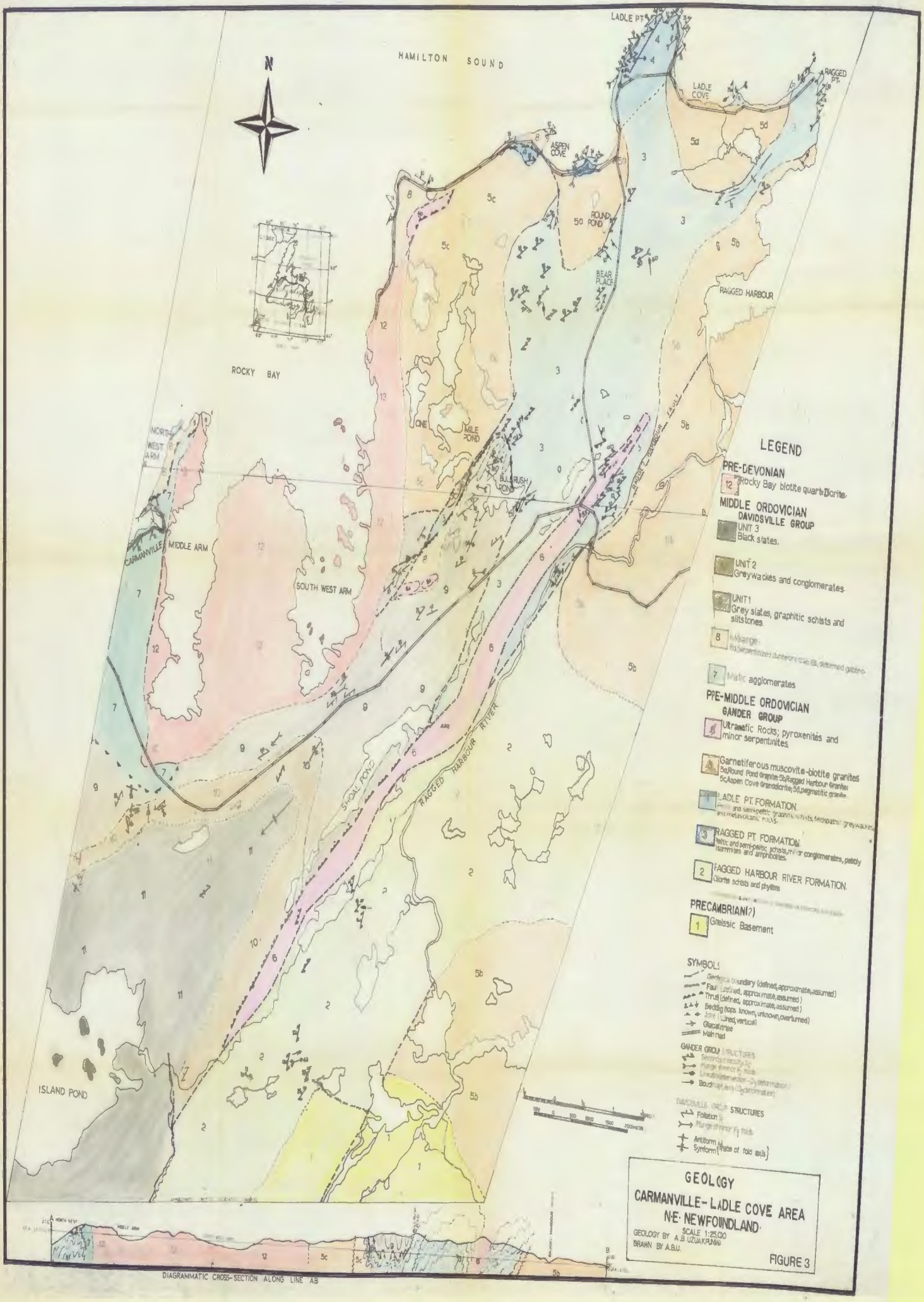

OR-AB-AN DIAGRAM FOR THE ROCKY BAY QUARTZ DIORITE

Figure:11d




OR-AB-QTZ DIAGRAM FOR THE ROCKY BAY QUARTZ DIORITE

Figure:11e


HAMILTON SOUND
N
LADLE PT.
LADLE COVE
RAGGED PT.
ASPEN COVE
ROUND POND
BEAR PLACE
RAGGED HARBOUR
ROCKY BAY
NORTH WEST ARM
CARMANVILLE
MIDDLE ARM
SOUTH WEST ARM
ONE MILE POND
BULRUSH POND
SHOAL POND
RAGGED HARBOUR RIVER
ISLAND POND
LEGEND
PRE-DEVONIAN
12 Rocky Bay biotite quartz diorite.
MIDDLE ORDOVICIAN
DAVIDSVILLE GROUP
UNIT 3
Black slates.
UNIT 2
Greywackes and conglomerates
UNIT 1
Grey slates, graphitic schists and siltstones.
8 Mélange
7 Mafic agglomerates
PRE-MIDDLE ORDOVICIAN
GANDER GROUP
6 Ultramafic Rocks; pyroxenites and minor serpentinites
Garnetiferous muscovite-biotite granites
5a Round Pond Granite; 5b Ragged Harbour Granite
5c Aspen Cove Granodiorite; 5d pegmatitic granite
4 LADLE PT. FORMATION.
3 RAGGED PT. FORMATION.
2 RAGGED HARBOUR RIVER FORMATION.
Chlorite schists and phyllites
PRECAMBRIAN(?)
1 Gneissic Basement
SYMBOLS
Geologic boundary (defined, approximate, assumed)
Fault (defined, approximate, assumed)
Thrust (defined, approximate, assumed)
Bedding (tops known, unknown, overturned)
Joint (inclined, vertical)
Glacial striae
Main road
GANDER GROUP STRUCTURES
DAVIDSVILLE GROUP STRUCTURES
Foliation
Antiform
Synform
GEOLOGY
CARMANVILLE-LADLE COVE AREA
N.E. NEWFOUNDLAND
SCALE 1:25,000
GEOLOGY BY A.B. UZUAKPUNWA
DRAWN BY A.B.U.
FIGURE 3
DIAGRAMMATIC CROSS-SECTION ALONG LINE AB