THE RELATIONSHIPS AMONG ROCK GROUPS BETWEEN THE GRAND LAKE THRUST AND CABOT FAULT, WEST NEWFOUNDLAND

YVON A. MARTINEAU

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by

© [illegible] A. [illegible], B.Sc.

A Thesis submitted in partial fulfillment

of the requirements for the degree of

Master of Science

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FRONTISPIECE: View of Glover Island on Grand Lake from the northeastern part of the study area.

"Au demeurant, je n'ai cherché de rien prouver, mais de bien peindre et d'éclairer bien ma peinture".

Gide

ABSTRACT

The area between the Grand Lake Thrust and the Cabot Fault is underlain by metamorphic rocks that separate the most easterly exposures of the west Newfoundland carbonate terrane from the most westerly exposures of ophiolitic and volcanic rocks of central Newfoundland. The major rock types present are; felsic gneisses in the west; anorthositic rocks in the southwest, semipelitic to psammitic schists in the east, and granitic intrusions within the gneisses. Mafic dykes intrude the gneisses, but are unknown within the schists. Finally, west of the Grand Lake Thrust but included within the map area, are limestones and phyllites of the west Newfoundland carbonate terrane.

The limestones and phyllites occur in the western part of the map area, west of the Grand Lake Thrust. They are deformed, and vary from unmetamorphosed to mildly metamorphosed(chlorite zone of the greenschist facies).

The felsic gneisses locally contain granulite facies mineral assemblages, but are everywhere affected by later retrograde metamorphism that increases in intensity from greenschist to amphibolite facies, from west to east. The mafic dykes intruding the gneisses exhibit the same effects of later metamorphism. The metamorphic change is accompanied

by increasing intensity of deformation from west to east across the area.

The semipelitic to psammitic schists are confined to the eastern part of the area, where they exhibit upper greenschist to amphibolite facies mineral assemblages. These rocks are polydeformed and faulted against the gneisses to the west.

The granitic intrusions occur within the gneisses only. They contain no evidence of the early granulite facies metamorphic event present in the host gneisses, and are for the most part massive.

The gneissic rocks are interpreted as Grenvillian inliers(basement), and are correlated with similar rocks of the Grenvillian Indian Head Complex,nearby to the west. The limestones, phyllites, and polydeformed schists are interpreted as a cover sequence affected by Paleozoic deformation, which also involved the basement gneisses and mafic dykes. The granitic bodies are interpreted as later intrusions, possibly related to Taconic or Acadian orogenesis. The stratigraphic and orogenic development of the area can be related to the formation of the Late Precambrian continental margin of eastern North America, and its Paleozoic destruction.

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I. INTRODUCTION

I-1 Preamble

This study is part of a project to map a transect across the western Newfoundland Humber zone(Williams,1979), from the Port au Port Peninsula to the southern tip of Grand Lake. The area described in this thesis occurs mainly between the Grand Lake Thrust and the Cabot Fault(Williams,1978), and is part of a poorly understood transitional area between the west Newfoundland Lower Paleozoic carbonate platform and the central Newfoundland volcanic belt.

The area contains, for the most part, felsic gneisses, schists, anorthositic rocks, and granitic intrusions, which have previously been mapped as undivided metamorphic and igneous rocks(Riley,1962). Imbricate thrusts of Grenvillian basement and Paleozoic cover rocks have recently been reported(Williams and St -Julien,1978), indicating the need for more detailed work in this poorly understood yet important area.

The present study delineates possible basement and cover units, and documents changes in structural and metamorphic style across this transitional zone.

I-2 Location and access

The study area is located in west Newfoundland, at the southern tip of Grand Lake(see figure -1). Two prominent topographic features, the east-west arm of Grand Lake and the Bottom Brook valley, form the northern and southern boundaries of the map area respectively. To the west, the boundary coincides roughly with a flat bogland underlain by Pleistocene sediments. The Trans-Canada Highway(Route#1) lies at the eastern margin of this bogland. To the east, the boundary coincides roughly with the Cabot Fault, a major geological feature extending from Port aux Basques to White Bay. This fault is oriented parallel to the northeast-southwest arm of Grand Lake, northeast of the map area. The center of the map area lies approximatly at 58°06′00″ longtitude and 48°36′25″ latitude.

Access to the map area is relatively easy. Route #1 (the Trans-Canada Highway) follows the western limit of the map area, while three gravel logging roads off Route #1, provide access to the interior of the map area.

The northernmost of the logging roads branches east from Route #1, opposite the Gallants turnoff, and ends at the western tip of Grand Lake, at Camp 33, an abandoned logging camp of the Bowater Pulp and Paper Company. The road is known locally as the Camp 33 road and is rapidly falling into disrepair.

About 2 kilometers to the south of the Camp 33 road, along Route #1, is the entrance to a second logging road which crosses the entire study area. This road leads to Bowater logging camp 185, and is referred to as the Camp 185 road. It is still in use and in good condition.

To the south, a third road follows Bottom Brook as far east as the Cabot Fault. This road is known locally as the Bottom Brook road and is no longer in use. It is rapidly falling into disrepair, and a bridge is washed out about halfway into the map area.

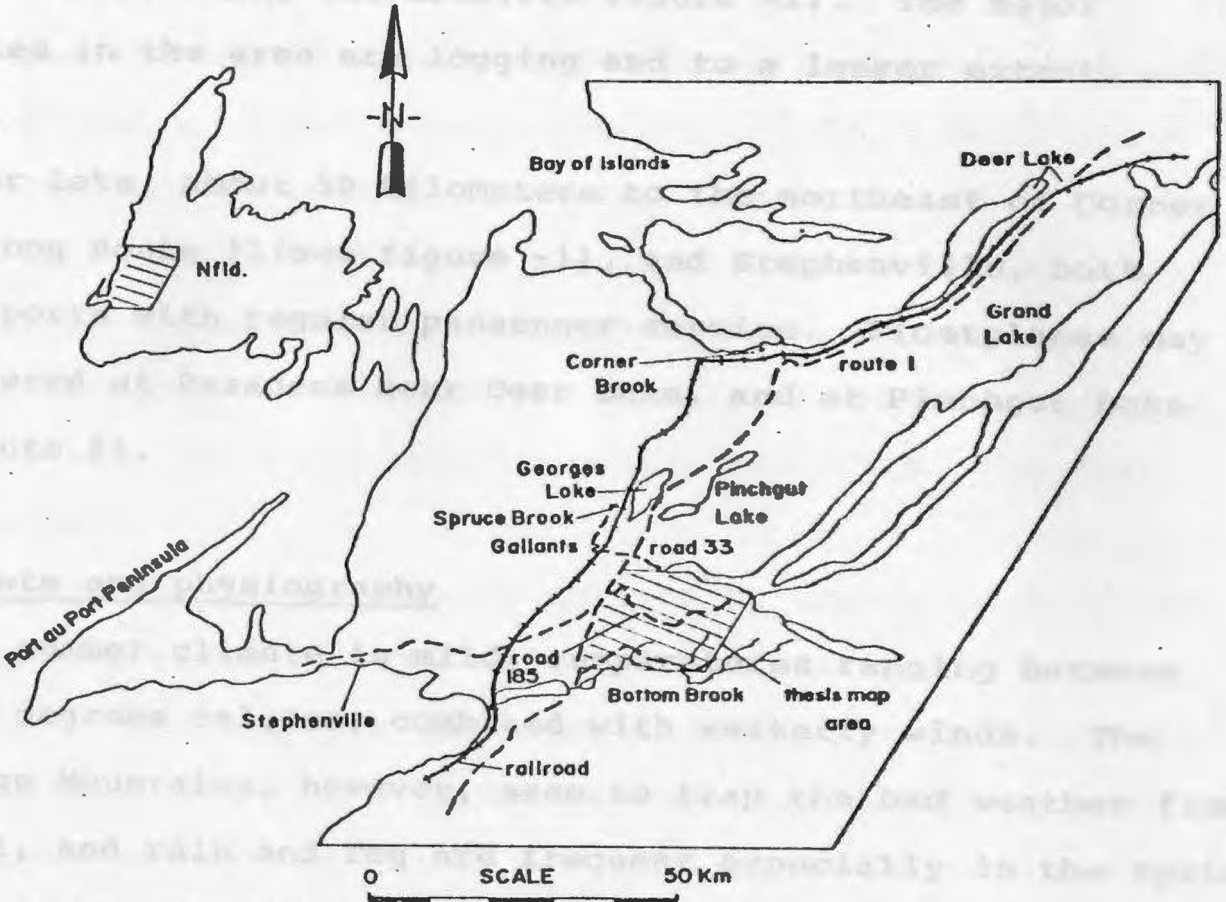


FIGURE 1 . Location map of the thesis map area showing the major settlements lakes and roads

Numerous roads branch from these major logging roads, but few are passable by car. Small boats may be launched on Grand Lake, at the Camp 33 site, giving access to the northeast margin of the map area.

Stephenville and Corner Brook are the major nearby population centers(see figure -1). Stephenville Crossing, Gallants and Spruce Brook are smaller towns along the Canadian National Railway line crossing the area(see figure -1). The major industries in the area are logging and to a lesser extent, fishing.

Deer Lake, about 50 kilometers to the northeast of Corner Brook along Route #1(see figure -1), and Stephenville, both have airports with regular passenger service. Floatplanes may be chartered at Pasadena near Deer Lake, and at Pinchgut Lake along Route #1.

I-3 <u>Climate and physiography</u>

The summer climate is mild, temperatures ranging between 5 and 23 degrees celcius, combined with westerly winds. The Long Range Mountains, however, seem to trap the bad weather from the coast, and rain and fog are frequent especially in the spring. August and September have the best weather for field work.

Most of the map area is dominated by north-south trending ridges of the Long Range Mountains. These form a dissected plateau with an average elevation of 500 meters. Individual peaks may reach 600 meters in elevation, while the valleys have an average elevation of 320 meters, yielding a relief of about 280 meters. The ridges are in all cases rounded on top, and the west flank is commonly steeper than the east flank. The valleys are, in most places, boggy with numerous small ponds. This topography reflects major faults which are common in the area.

The northwesternmost part of the map area is slightly lower topographically. The marked north-south trend of the ridges to the southeast is less pronounced here, and the terrane is more hummocky. Here again, the west flanks of the hills are steeper than the east flanks. This terrane comes to an abrupt end to the west at a north-south trending cliff, beyond which are flat boglands of roughly 250 meters elevation.

The east-west arm of Grand Lake, and the Bottom Brook valley, form major east-west depressions within the map area. These occur at elevations of 100 and 40 meters respectively, and are thus lower than tha north-south trending valleys of the dissected plateau.

The majority of the area is covered by spruce forests with a small amount of birch. Most ridges are bald on top with a dense halo of tuckamore in the upper slopes. The eastern part of the map area is covered by virgin forest. The western part, however, has been logged within the last 10 years, making it difficult to traverse. Abandoned roads, haul-off trails, and ridge tops provide the easiest traversing routes there.

The drainage system of the area is immature,possibly as a result of glaciation. It consists mainly of small brooks draining small bogs and ponds. Most of the runoff flows south into Bottom Brook and westward into St. Georges Bay. Minor brooks with smaller watersheds flow into Grand Lake to the north and

Harry's River to the west. The overall stream pattern reflects the faulting in the bedrock.

I-4 Glacial geology

A thin veneer of glacial till covers most valleys and lower slopes in the map area. This is composed mainly of rounded, poorly sorted, granitic boulders to pebbles with a sandy matrix. At the west end of Grand Lake an outwash terrace covers the shoreline bedrock exposures. Other glacial features in the map area are; hanging valleys, rounded ridge tops containing erratic boulders(plate -1), and roches moutonnées.

Saprolite occurs on the south flank of Hare Hill(see map). This saprolite can be traced for two kilometers to the south-east, and is developed exclusively in massive medium grained granite and syenite. Plate -2 shows an exposure of saprolitic medium grained syenite with a one meter diameter corestone below the rock pick. Pegmatitic veinlets, less intensely weathered than the host rock occur throughout the outcrop, showing that it is otherwise underformed. This saprolite zone must have been protected from the glacial scouring so apparent elsewhere.

Glacial striae are rare in the map area making direction of ice movements difficult to determine. However, to the west, on the Port au Port Peninsula, striae are common. The direction of these, as well as boulder tracing for the area in general, indicate east-west ice movements(Brookes,1970). This is consistent with the generally accepted view that, during the Wisconsin glaciation, Newfoundland had an independent central ice cap.

Plate-]: Erratic boulder on "Bear Ridge". Note the glacially polished outcrop.

Plate-2: Saprolite with corestone in "Tulk's Pond" syenite. Note the fresh undeformed granitic veinlets.

and ice movements were directed predominantly radially outward towards the coasts. The east-west arm of Grand Lake, and the Bottom Brook valley were probably deepened, if not formed entirely by, these ice movements. The presence of outwash deltas and moraines, both on and off shore, in the Port au Port and Bay St. George area to the west, seems to support this as well.

I-5 Geologic setting

The study area is part of the Appalachian fold belt which extends for 3000 kilometers along the eastern coast of Canada and the United States. There have been numerous attempts to subdivide this belt into zones or domains (Rodgers, 1968; Bird and Dewey, 1970; Williams and Stevens, 1974; Williams, 1978). The latest and possibly most comprehensive is incorporated in the Tectonic Lithofacies Map of the Appalachian Orogen (Williams, 1978). This map separates the fold belt into five zones: the Humber, Dunnage, Gander, Avalon, and Meguma zones. Figure #2A shows the zonal subdivisions in Newfoundland, and the location of the study area relative to these.

The study area lies at the eastern margin of the Humber zone, at the contact with the Dunnage zone. In terms of the current tectonic model for the Appalachians, the Humber zone represents the Lower Paleozoic continental margin of Eastern North America, and the Dunnage zone the remnants of the Iapetus Ocean and associated island arc(s).

The study area lies at the eastern margin, and includes part of, the western Newfoundland Lower Paleozoic carbonate platform (figure -2B). This platform is part of a Lower Cambrian to Middle Ordovician continental shelf sequence recognized the full length of the Appalachians, and consists of shallow water marine sediments, mainly carbonates(Rodgers,1968).

East of the platformal rocks and in faulted contact with these, is a terrane composed predominantly of felsic schists and gneisses and which underlies most of the study area. This terrane is part of a belt of rocks which parallels the carbonate rocks and has been referred to as the Eastern Margin Metamorphic Rocks(Williams, Kennedy and Neale,1974), or as the Ortho-Tectonic zone(Church,1969; Dewey,1969).

The belt is composed largely of metamorphosed clastic cover rocks of the Lower Paleozoic continental slope, ranging in age from Late Precambrian to Upper Cambrian, and of Grenvillian basement inliers of the ancient North American craton.

The metamorphosed cover rocks are mainly psammitic to semipelitic schist. They extend from the study area northeastward to the Burlington Peninsula and beyond to the Grey Islands, where they form the Fleur de Lys Supergroup(figure -2B; Church, 1969; Kennedy,1971; deWitt,1972; Kennedy,Williams and Smyth, 1973; Bursnall,1975; Williams,1977a).To the south similar rocks occur throughout the entire length of the Appalachian Orogen as the Rosaire and Caldwell Groups of Quebec, the Mendon Group and Pinnacle Formation of Vermont, the Glenarm series of Maryland, the Lynchburg Formation of Virginia and the Ocoee Group of Tennessee and Northern Georgia(Williams and Stevens,1974).

The basement inliers are composed mainly of psammitic to semipelitic paragneiss and schist with minor quartzite. These are intruded by granites and gneissic granites which are probably

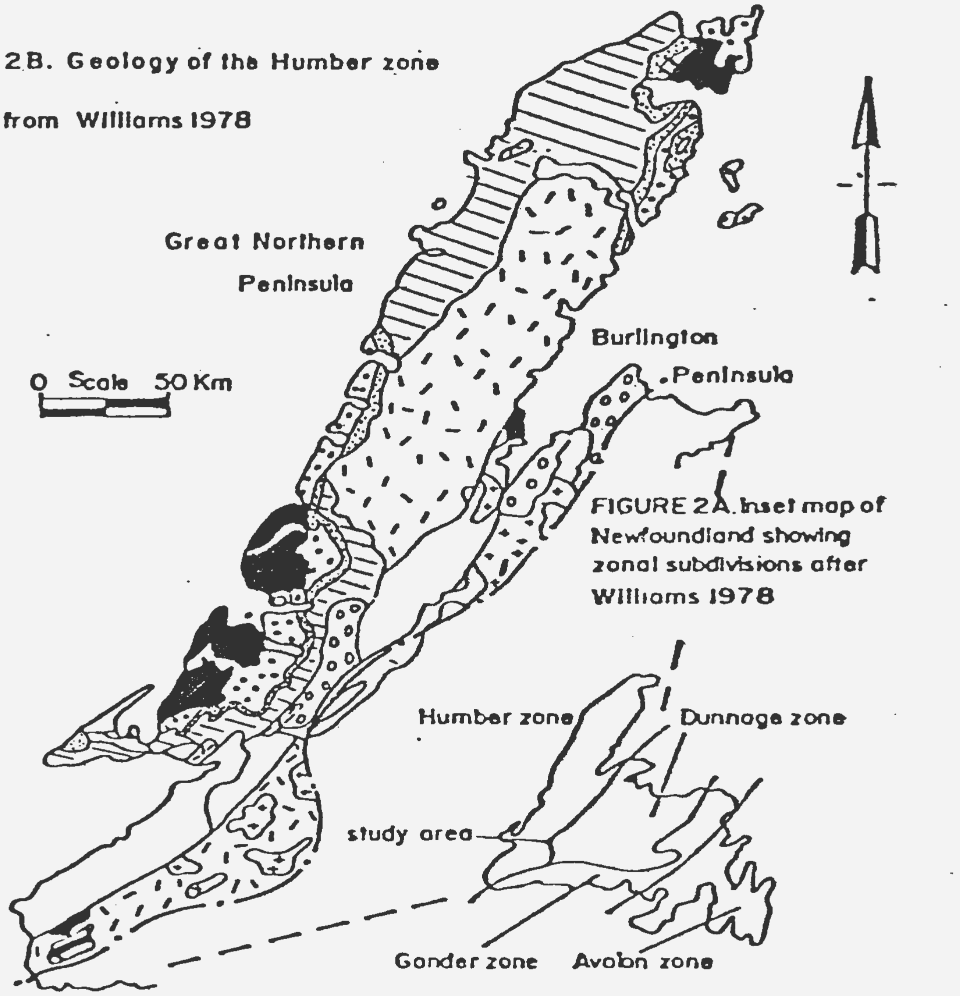


FIGURE 2B. Geology of the Humber zone modified from Williams 1978

FIGURE 2A. Inset map of Newfoundland showing zonal subdivisions after Williams 1978

East derived flysch (Ordovician)

Carbonate platform (Cambrian-Ordovician)

Rift facies clastics (Precambrian-Cambrian)

Grenvillian inliers (Precambrian)

Granites (Devonian or older)

Neoautochthonous and younger sediments (Ordovician-Carboniferous)

Transported ophiolite complexes (during the Ordovician)

Transported sedimentary rocks (during the Ordovician) related to the Grenvillian Orogeny(Lowden,1961; Lowden et al, 1963). In Newfoundland, the basement rocks are known as the Long Range Complex(Clifford,1969) which forms the core of the Long Range Mountains, and as the Indian Head Complex(Riley, 1962), to the west of the study area(see figure -2B). Remobilized basement rocks have also been reported on the Burlington Peninsula(deWitt,1972) in the core of a large anticline. Similar occurrences of Grenville basement inliers in the New England and southern Appalachians are the Green Mountains of Vermont, the Berkshire, Housatonic, New Milford and Hudson Highlands massifs from Massachusetts to eastern Pennsylvania, and the Blue Ridge farther south(Williams and Stevens,1974).

Mafic dykes intrude the Eastern Margin Metamorphic rocks. These trend northeast, and are believed to have been feeders to Late Precambrian to Lower Paleozoic flood basalts(Labrador basalts, Lighthouse Cove Formation) which locally overlie Grenvillian gneisses at the northern end of the Great Northern Peninsula of Newfoundland(Clifford,1965; Williams and Stevens,1969; Bird and Dewey,1970; Pringle, Miller and Warrell,1971; Strong and Williams,1972; Strong,1974).

East of the study area, lie the mafic igneous rocks of the Dunnage zone(oceanic domain). The boundary of the Humber zone with the rocks of the oceanic domain is a zone of co-mingled, metamorphosed felsic and mafic rocks related to the Early Paleozoic deformation of the Iapetus Ocean. A prominent ophiolite belt at its eastern margin is referred to as the Baie Verte-Brompton Line, and has been traced from Baie Verte through to the Eastern Townships of Quebec(see figure -2B)(Williams and St-Julien,1978). At the northeast corner of the map area, the Baie Verte-Brompton Line is roughly coincident with the Cabot

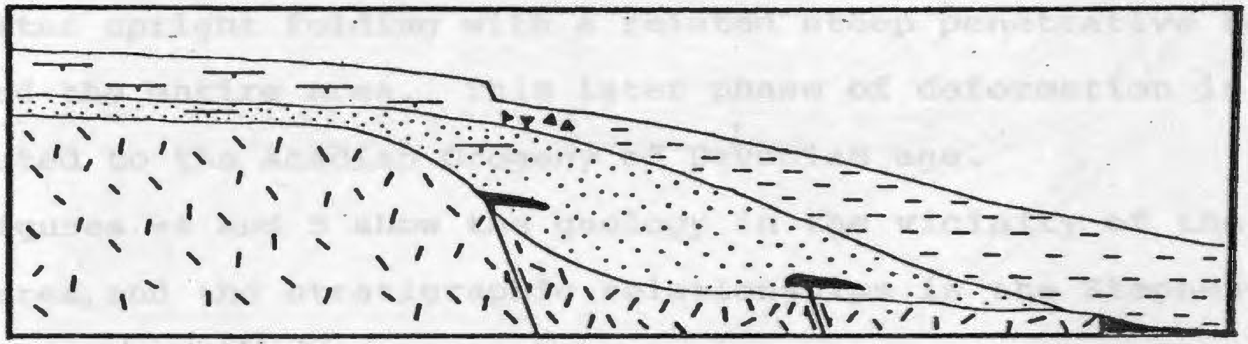
Fault, a major feature extending from Port aux Basques north-east to White Bay in Newfoundland. South of Grand Lake this line swings sharply east and felsic rocks and granite plutons occur on the east side of the Cabot Fault.

Figure -3 shows a possible facies reconstruction of the lithologies present within the map area before the destruction of the ancient continental margin of North America. The Gren-villian inliers form a rifted basement upon which eastward thickening clastic cover rocks of the continental slope were deposited. These include greywacke derived from the rifted basement as well as deep sea pelitic sediments to the east. The mafic dykes and plateau basalts were probably deposited during this initial rifting phase. As the margin continued to develop, the carbonate bank was formed along with a bank edge breccia at its eastern margin. This cut off the source of coarse clastics to the west(craton), and a thin pelitic sedi-mentary layer accumulated to the east of the bank on rift related clastics or on new oceanic lithosphere(Iapetus Ocean).

Much of the metamorphism and structure present in the study area, as well as in the Humber zone in general, is related to the Early Ordovician Taconic Orogeny, which marked the destruction of the ancient continental margin of eastern North America and closing of the Iapetus ocean. Earlier structure and metamorphism(Grenvillian or older) are present in the Gren-ville inliers, although in places these are masked by later deformations.

The Taconic Orogeny involved the displacement of oceanic lithosphere(i.e. emplacement of the Humber Arm and Hare Bay

FIGURE 3. Facies distribution during the constructional phase of the ancient continental margin of Eastern North America



modified after Williams and Stevens, 1974

LEGEND

Carbonate platform (Ordovician)

Carbonate bank margin breccia (Ordovician)

Pelagic sediments (Cambrian-Ordovician)

Clastic sediment wedge with rift facies volcanic rocks (Precambrian-Cambrian)

Ocean crust (Ordovician)

Rifted basement (Precambrian)

allochthons) and the transport of continental slope and rise supracrustal rocks across the ancient continental margin of eastern North America. This was accompanied by intense deformation and metamorphism farther east so that the rocks at the disturbed margin were telescoped into a series of westward directed thrust sheets.

Later upright folding with a related steep penetrative fabric affected the entire area. This later phase of deformation is attributed to the Acadian Orogeny of Devonian age.

Figures #4 and 5 show the geology in the vicinity of the study area, and the stratigraphic relationships in the Stephenville and Grand Lake areas respectively.

I-6 Previous work in the area

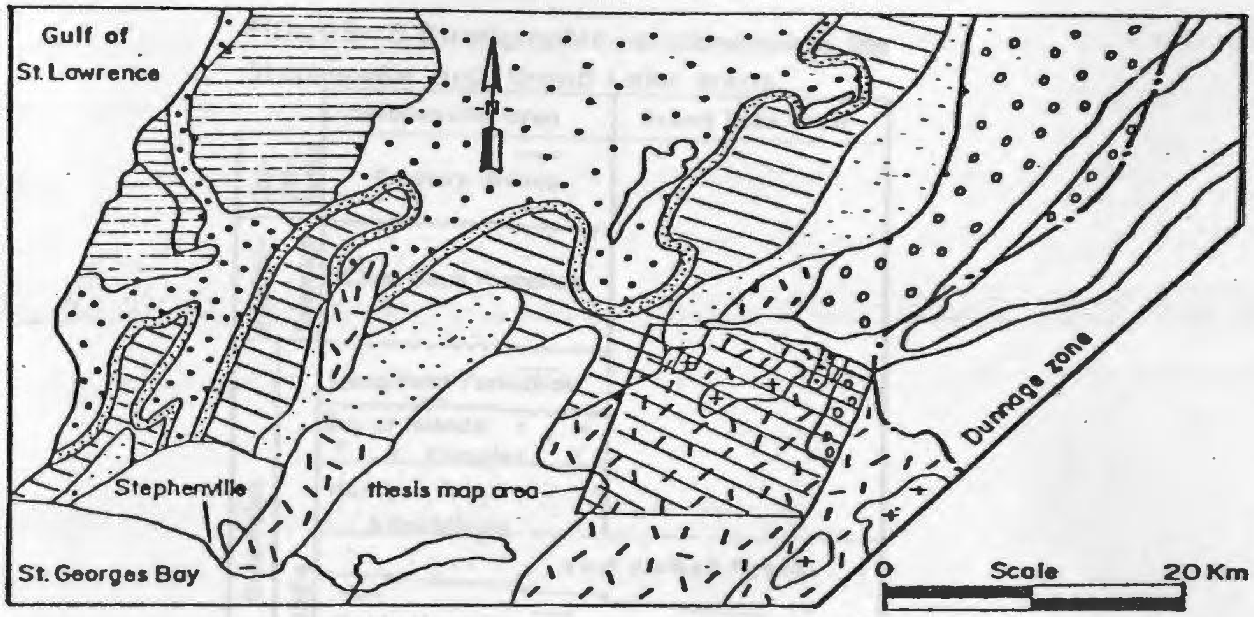
Little work has been done in the study area. The earliest work is that of Walthier (1949) who mapped the area between Corner Brook and Stephenville for the Geological Survey of Newfoundland. His results are given on a 1:38,500 scale map, which includes only the platformal rocks of the northwestern part of the study area.

Riley (1957; 1962) mapped a large portion of western Newfoundland, including the study area. His results are given on two 1:253,440 scale reconnaissance maps. He referred the rocks of the study area to the Long Range Igneous and Metamorphic Complex and described them as Devonian or older in age.

The significance of the crystalline rocks of the study area became more apparent when they were correlated with the

FIGURE 4. Geology of the Humber zone near the thesis map area

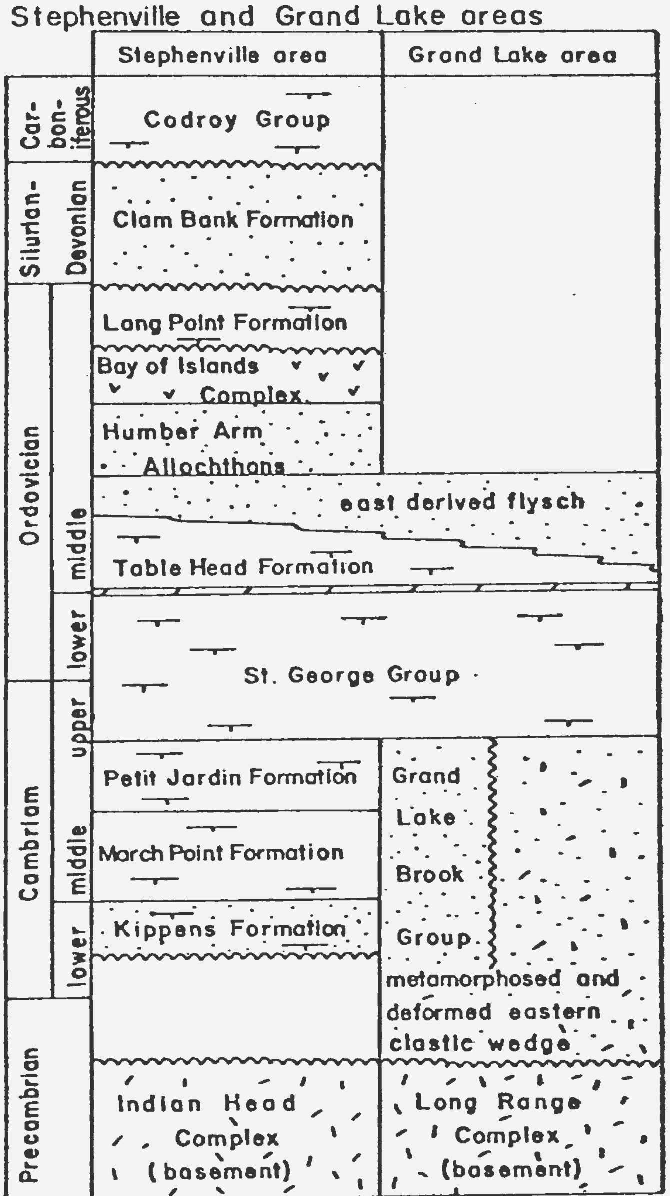
modified from Williams 1978



LEGEND

- Carboniferous sediments
- Granites (Devonian or older)
- Transported ophiolite complexes (during the Ordovician)
- Transported sedimentary rocks (during the Ordovician)
- East derived flysch (Ordovician)
- Carbonate platform (Ordovician)
- Cambrian sediments
- Rift facies clastics (Precambrian-Cambrian)
- Grenvillian inliers (Precambrian)

FIGURE-5. Stratigraphic relationships in the Stephenville and Grand Lake areas



modified after Malpas, 1974

LEGEND

carbonate rocks

clastic rocks

crystalline metamorphic rocks

metasediments

layered mafic igneous rocks

unconformity/disconformity

rift related Fleur de Lys Supergroup of the Burlington Peninsula(Church,1969). More recently, imbricate thrusting of Grenvillian basement and rift related cover rocks has been reported(Williams and St-Julien,1978) in the study area. The same conclusion was obtained for similar rocks to the north of the study area(Kennedy,1978).

Work is presently being done in similar rocks to the southeast of the study area, by the Geological Survey of Canada (Herd,1978; Herd and Dunning,1979) and to the north by D.P. Kennedy, as part of a masters degree at Memorial University of Newfoundland.

I-7 Purpose and scope of the present study

The study area lies at the eastern margin of the Humber zone in a poorly understood terrane between the Lower Paleozoic carbonate platform and the remnants of the Iapetus ocean farther east. The area is part of a corridor presently being mapped across the ancient continental margin of eastern North America, in west Newfoundland.

The primary purpose of the study is to map and interpret the geology of this intermediate terrane, so important in documenting the destruction of the ancient continental margin of eastern North America. In doing so, an attempt is made to separate the Grenvillian basement from its Late Precambrian to Early Paleozoic cover rocks. The work also involves a documentation of the changes in intensity and style of deformation and metamorphism across the study area, and a comparison of these with features of the Indian Head Complex, a dated little deformed (by Paleozoic orogenesis) Grenvillian inlier farther west.

The results are compared with changes in metamorphism and structural style across the better known Grenvillian inliers of the Berkshire and Reading Prong massifs in the New England Appalachians.

Rough structural and petrological descriptions are included here, but it should be remembered that the main focus of the work lies in regional field mapping, and that much detailed follow-up work is now required in light of the results obtained.

I-8 Field work

The field work for this thesis was done during the months of June through August, 1978. An area of about 195 square kilometers was mapped during this period.

Most of the area is covered by a thin veneer of till, and exposures, which form less than about 5 percent of the surface area, occur mainly in stream beds, along ridge tops, along logging roads and haul-off trails, and along the shore of Grand Lake.

Exposures along the shore of Grand Lake were mapped using a small boat, and with the help of E. Stander. Most other field work was done independently. The data was plotted on 1:50,000 scale topographic maps. Black and white air photos for the area are available, but these are 11 years old, and do not show the main logging roads or recent features.

I-9 Terminology

Location names:

The thesis map area contains very few location names which appear on the National Topographic System 1:50,000 scale maps. To aid in localizing noteworthy geological features, many streams, ridges, and ponds are informally named by the author. Where possible, the names used by the Bowater Pulp and Paper Company are used. Informal names(those not shown on the 1:50,000 scale maps) are in quotation marks both on the map and in the text, to distinguish them from formal names.

Rock names:

Qualifiers such as mineral names are added to the rock names. In these cases the qualifier nearest the rock name designates the most abundant mineral, such that for hornblende-plagioclase gneiss, plagioclase is more abundant than hornblende in the rock.

Mylonitic texture, as used in this thesis, refers to a highly strained, recrystallized, foliated or lineated fabric, and has no genetic implications.

II. GENERAL GEOLOGY

II-1 Introduction

The study area consists of a carbonate sequence forming part of the western Newfoundland Lower Paleozoic carbonate platform in the west, and crystalline rocks forming part of the Eastern Margin Metamorphic Rocks in the east.

The carbonate sequence is mainly limestone, dolostone, and marble, with phyllite at the base of the section. The carbonates are a tightly folded and mildly recrystallized equivalent of the little-deformed St. George Group and Table Head Formation to the west near the Port au Port Peninsula (Riley,1962). The phyllite at the base of the sequence is a southward continuation of the Grand Lake Brook Group to the north of the study area(Walthier,1949), in turn possibly equivalent to the Kippens, March Point and Petit Jardin Formations to the west near Stephenville(see figure -5).

The crystalline rocks to the east are in faulted contact with the carbonate sequence and consist mainly of poly-deformed and metamorphosed felsic gneisses and schists. These are subdivided into the Long Range Complex and Loon Pond metasediments.

The Long Range Complex contains, granitic and hornblende-plagioclase gneisses, calc-silicates interlayered with quartzites, and anorthositic rocks including anorthosite gabbro and pyroxenite. Relict granulite facies mineral assemblages partially retrogressed during Paleozoic deformation occur locally within the granitic gneisses. The occurrence of these relict high grade assemblages implies that these gneisses are part of the basement gneisses forming the core of the Long Range Mountains, and are correlative to other Grenvillian basement inliers such as the Indian Head Complex to the west.

The Long Range Complex is host to both granitic and mafic intrusions. The mafic intrusions consist of northeast trending diabase dykes now altered by Paleozoic deformation and metamorphism. The felsic intrusions consist of granite and syenite, for the most part massive and post-dating most of the deformation affecting the host rocks.

The Loon Pond metasediments occur in the eastern part of the map area, and are everywhere faulted against rocks of the Long Range Complex. Rock types found within this unit are psammitic to semipelitic schists, marble and quartzite. These rocks are polydeformed and exhibit upper greenschist to lower amphibolite facies mineral assemblages. The Loon Pond Metasediments are correlated with the Fleur de Lys Supergroup to the northeast in the Burlington Peninsula and represent Late Precambrian to Lower Paleozoic cover sediments deformed along with the Long Range Complex basement during Paleozoic orogenesis.

Paleozoic deformation and metamorphism increase from west to east across the map area. The rocks of the carbonate sequence in the east, although tightly folded, show only low grade metamorphic effects consisting mainly of recrystallization of some limestone beds, and the formation of sub-biotite zone greenschist facies assemblages in phyllites of the Grand Lake Brook Group.

Farther east, the rocks of the carbonate sequence are juxtaposed with gneisses of the Long Range Complex by a major northeast trending fault forming the southward continuation of the Grand Lake Thrust(Williams,1978). The gneisses to the east of this fault contain mainly biotite to garnet zone greenschist facies assemblages(with locally occurring relict granulite facies assemblages) in the west, to amphibolite facies assemblages in the east. The same metamorphic variation is developed within mafic dykes that cut the gneisses.

As well as varying in intensity across the area, the metamorphic minerals define a major northeast striking southeast dipping foliation axial planar to a set of folds,both of which are best developed in the east. A related northeast striking southeast dipping schistosity defined by upper greenschist to lower amphibolite facies assemblage minerals, with associated folds, is also developed in the Loon Pond Metasediments in the east of the map area.

The eastern boundary of the map area coincides roughly with the Cabot Fault(Wilson,1962; Webb,1969;Williams,Kennedy and Neale,1970) In the northeast of the study area, this fault forms a north-south trending fault zone intruded by granite(Knapp,Kennedy and Martineau,1979) which separates metasediments to the west from lower grade mafic volcanics of the Dunnage zone to the east. The Humber-Dunnage zone boundary, the Baie Verte-Brompton line(Williams and St-Julien,1978) is nearly coincident with the Cabot Fault in the northeast of the map area, but diverges sharply east in the vicinity of Little Grand Lake and southward. The latest movement along the Cabot Fault occurred in the Carboniferous, since the fault displaces rocks of this age in the Deer Lake Basin to the north.

Other late features include high angle block faults which now form the contacts between most of the map units.

The Paleozoic deformational history for the area may be summarized as deep seated deformation involving both basement and cover in the east decreasing in intensity to the west such that the metamorphic effects become lower grade, and the structures die out in the basement gneisses. The deformed basement and cover rocks were than thrust against the lower grade carbonate sequence rocks, followed by high angle block faulting.

II-2A The Long Range Complex, Introduction

The Long Range Complex is subdivided into five units although a large variety of lithic types are present. The units are granitic gneisses(map unit 1a), hornblende-plagioclase gneisses(map unit 1b), calc-silicates and quartzites(map unit 1c), anorthositic rocks(map unit 1d), and foliated granite (map unit 1e).

The above units are rough compositional groupings only, and contain both lithic and textural variations unseparated on the accompanying map. Textures are of little use as parameters in delineating sub-units, since these are observed to change on an outcrop scale. Yet another problem in choosing sub-units is that of transposition of contacts, which has obscured most original relationships between rock types.

The rough distribution of rock types within the Long Range Complex is as follows: granitic gneisses(map unit 1a) are juxtaposed against platformal rocks in the west, hornblende-plagioclase gneisses(map unit 1b) contain fault bound slices of cover metasediments(Loon Pond metasediments)in the east, and a block of anorthositic rocks(map unit 1d)is surrounded by granitic gneisses in the southwest.

Almost all contacts between the units of the Long Range Complex are faults, except locally on "Bear Ridge" where an intrusive breccia(plate-3)occurs between granitic gneisses(map unit 1a) and foliated granite(map unit 1e). The breccia occurs in a zone of low finite strain, and indicates that the foliated granite is igneous in origin and intrudes the granitic gneisses. Elsewhere the foliated granite appears to grade into the granitic gneisses. The age relationships among the other units of the Long Range Complex are unknown.

A systematic description of each of the units,including rough microscopic descriptions where available,follows. Few mineral compositions are given,however,because the units represent rough groupings probably of varied origins, and because of their complex alteration history. More sampling of the units is needed for a more detailed petrographic description of these units.

II-2B Granitic gneisses

The granitic gneiss unit(map unit 1a)is named after its most common lithology,although a variety of different rock types, unmappable at the map scale,are included within the unit as well. The unit is the most extensive of the Long Range Complex,and although grouped into one unit here,the different occurrences are certainly not all genetically related.

In the west of the map area, the granitic gneisses occur as a thin band separating a younger granite(Hare Hill granite) map unit 5a) from the carbonate rocks to the west, across the Grand Lake Thrust. The layer has an outcrop width of approximatly 1/2 kilometer in the north, to two kilometers at the southern tip of the granite body(see map). South of this, the

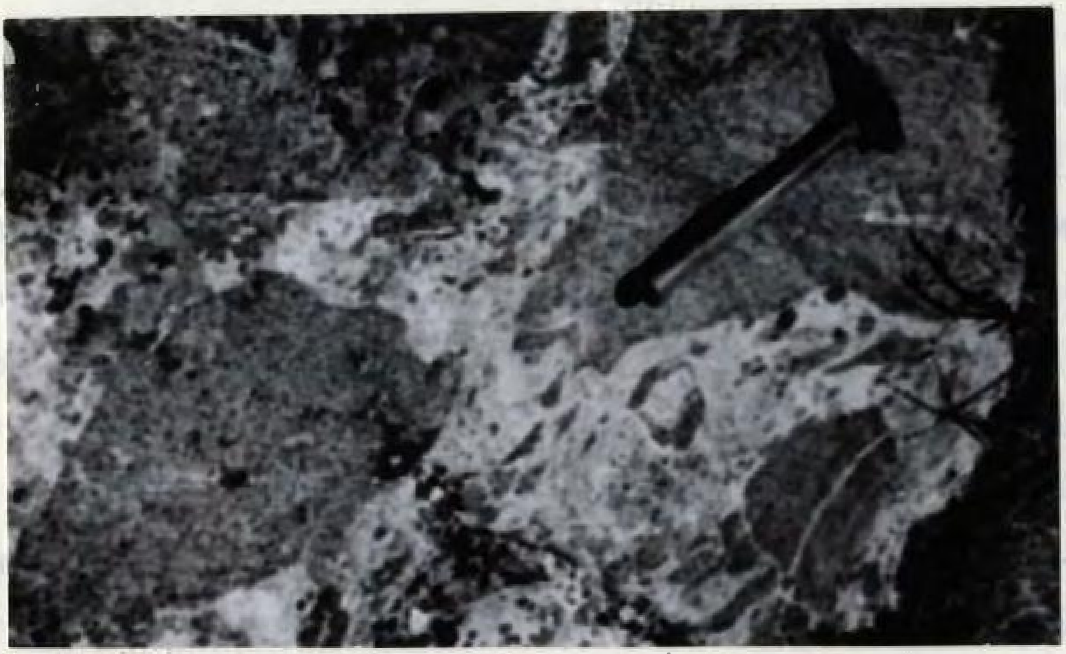


Plate-3: Intrusive breccia on "Bear Ridge" showing foliated granite(white) containing granular granitic gneiss blocks(grey).

carbonate platform rocks are displaced westward by faulting, and the granitic gneisses extend to the western edge of the map area.

In the central part of the study area, the granitic gneisses are the host to granite and syenite intrusions("Goose Hill" granite, map unit 5b, and "Tulk's Pond" syenite, map unit 5c) and surround the fault bound anorthositic rock unit (map unit 1d) to the south.

In the east of the study area, granitic gneisses are less abundant, and hornblende-plagioclase gneisses(map unit 1b), and rocks of the Loon Pond metasediments dominate. Some granitic gneisses outcrop at the eastern extremity of the study area, near the Cabot Fault.

The unit is mapped as part of the basement Long Range Complex primarily because of locally occurring relict granulite facies mineral assemblages, unknown within any of the other units. Most commonly however, the granitic gneisses contain only greenschist facies mineral assemblages locally containing textural evidence of retrogression from higher grade assemblages. The relict assemblages probably reflect an early(Grenvillian) metamorphic event, retrogressed in most places by lower grade later possibly Paleozioc metamorphism(see section IV-6).

The relict granulite facies mineral assemblages occur at "Disappointment Hill" in gabbroic to granitic gneisses. Here, both orthopyroxene and clinopyroxene occur along with plagioclase, forming a relict granoblastic texture. Biotite,hornblende and chlorite grains occur around pyroxenes, and albite rims and epidote inclusions are developed on the plagioclase(An_{40-50}),indicating later retrogression.

More commonly the granitic gneisses contain quartz, alkali feldspar, plagioclase, biotite, and muscovite. Epidote, sphene, and iron oxides(magnetite or ilmenite) are common accessories. Zircon, clinozoisite, and garnet occur locally. The abundances of these constituent minerals vary, but generally fall within the range of granitic composition.

The gneisses are generally pink due to the alkali feldspar, and vary from fine to medium grained. Textures vary from granular to well foliated, the fabric varying from cataclastic (with well developed augen) to mylonitic. The textures are described below.

The granular granitic gneisses are commonly fine grained equigranular, locally containing a poorly developed foliation due to the orientation of the micas. Generally the texture appears to be a metamorphic equilibrium texture, but locally is cataclastic in nature. These gneisses are most common east of "Bear Ridge".

The granitic augen gneisses vary in texture from cataclastic with little interstitial material, to well developed lense shaped feldspar augen which define a foliation and are floating in a finer grained mafic rich groundmass, to pinstriped granitic gneisses where compositional segregation has occurred such that the cataclastic feldspar and quartz grains lie in thin layers alternating with mica rich layers.

The augen are commonly pink feldspar, or more rarely quartz, and vary in size from about 2 centimeters to about 2 millimeters. The larger augen may be composite fragments of quartz and feldspar as well as individual minerals. The composite augen show every gradation from lense shaped(occurring widely) to sub-angular clasts formed by brecciation of granular gneisses(most common near "Marathon Pond").

Where compositional segregation has occurred, the felsic layers are generally 1 to 3 centimeters thick and the mafic rich layers 1 to 2 centimeters thick. The felsic layers are commonly pink and composed of 1 millimeter large alkali feld-spar and quartz, and the mafic rich layers are commonly a fine grained mixture of feldspar, quartz and micas. The pinstriped gneisses are best exposed along the shore of Grand Lake near "First Falls". Gneissic banding, two to five centimeters thick, occurs on "Bear Ridge", and at the northern tip of "Tulk's Pond".

The mylonitic gneisses consistently contain 1 millimeter thick bands of alternating pink feldspar and quartz. In some places an L-fabric defined by rod shaped quartz, is developed. These gneisses are most common on the west flank of Hare Hill, and along road 185 south of "Bear Ridge", where they are associated with augen gneisses.

The textural variations described above may reflect different protoliths for the granitic gneisses. However, the variability of textures over short distances is interpreted, here, as reflecting variations in finite strain rather than different protoliths, although both of these factors almost certainly contributed to the variety of granitic gneisses observed. Plates -4,5,6 and 7 show samples exhibiting some of these textures.

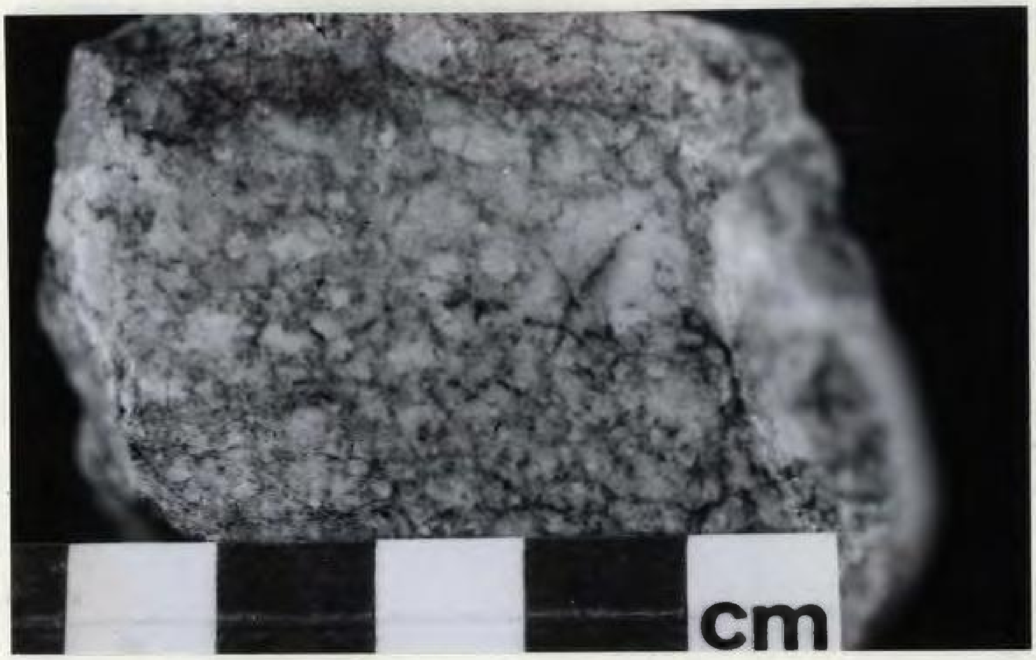


Plate-4: Brecciated granitic gneiss sample.

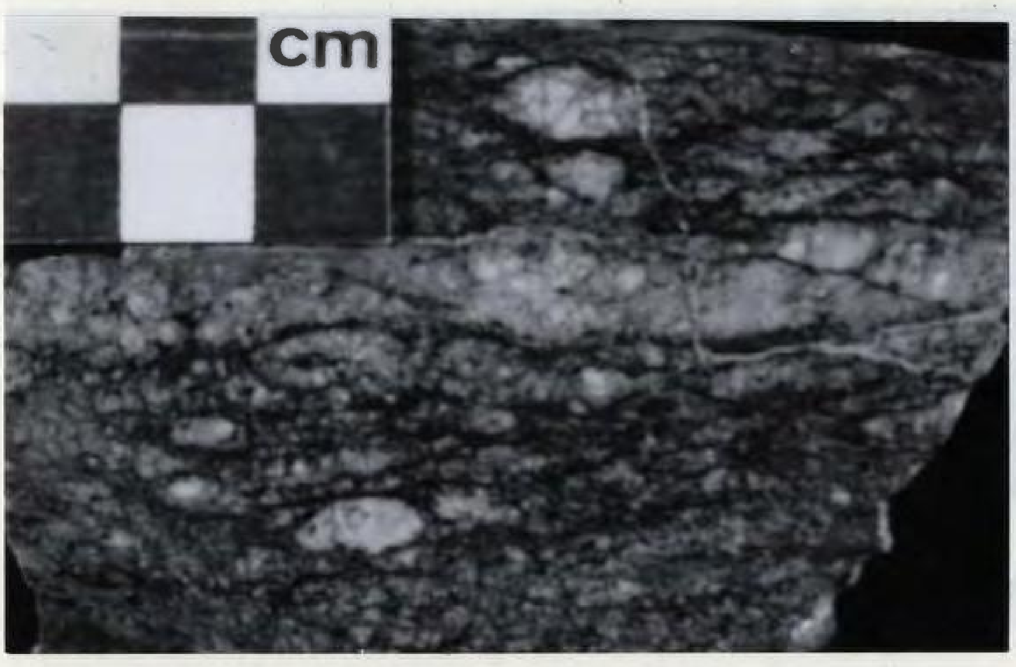


Plate-5: Augened granitic gneiss sample showing lense-shaped felsic augen in a mafic rich matrix.

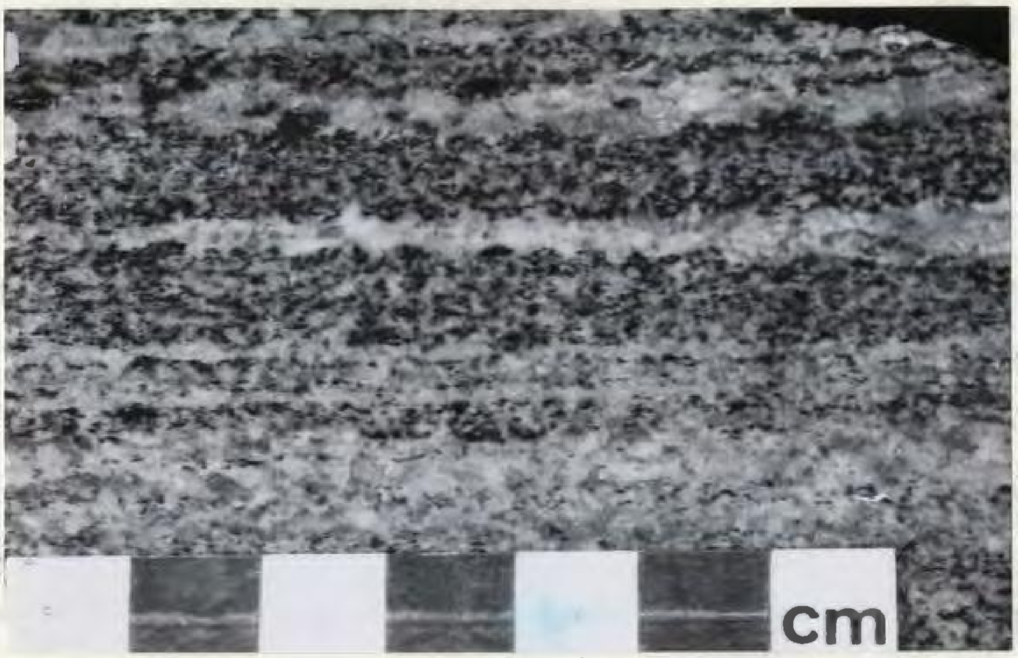


Plate-6: Pinstriped granitic gneiss sample showing 2 to 10 millimeter thick compositional banding.

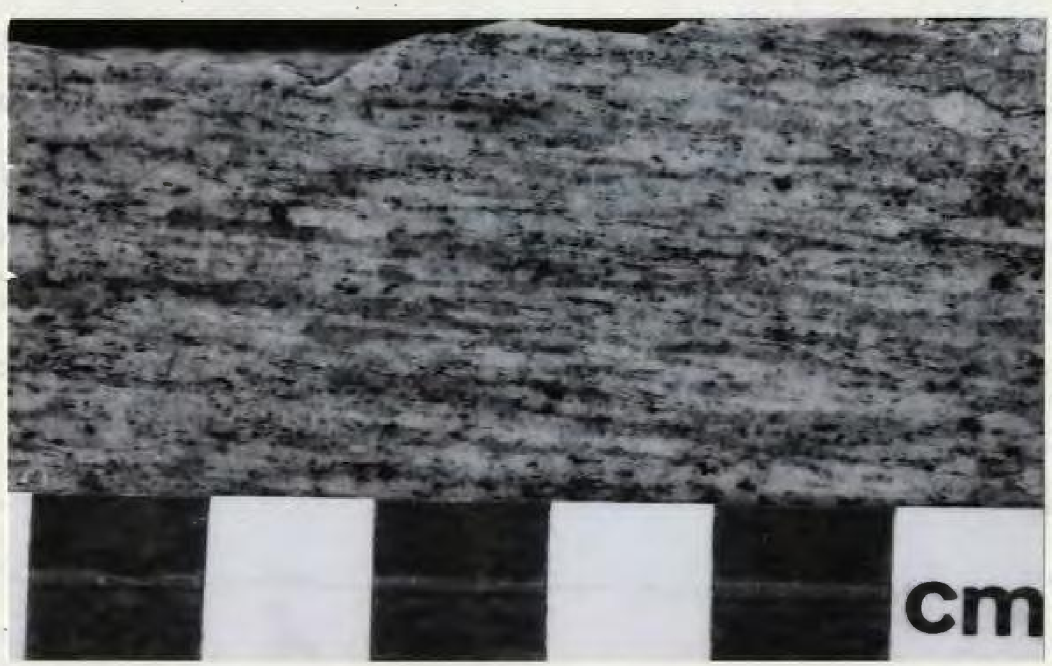


Plate-7: Mylonitic granitic gneiss sample showing rod-shaped quartz.

Microscopically the alkali feldspars(microcline or orthoclase) are generally porphyroclastic,may show cross-hatched twinning or perthitic exsolutions, or have a featureless turbid appearance. The plagioclase(An_{30-50})is generally smaller looks fractured , and contains polysynthetic twinning. Evidence of later retrogression of these grains consists of: patches of small polygonal grains, albite rims, and muscovite and epidote inclusions in plagioclase. Locally, plagioclase is completely sericitized.

Quartz forms granoblastic layers, or patches developed in pressure shadows of feldspar augen. In the more deformed varieties, quartz forms elongate grains defining a foliation, or fine polygonal grains(recrystallized) forming layers. The larger quartz grains commonly show undulose extinction indicating strain, and in places show good subgrain development.

The micas occur mainly in elongate patches defining a foliation parallel to the layering. The long axis of the individual grains, however is generally sub-parallel, or at an oblique angle to the foliation defined by the elongate mafic rich patches, indicating the elongate patches may represent a relict metamorphic texture(possibly related to the relict granulites). Biotite is much more abundant than muscovite. It is pleochroic in shades of brown, and less commonly green. At "Disappointment Hill", biotite and chlorite rim pyroxene in the gabbroic gneisses, and biotite, hornblende and magnetite form patches possibly replacing pyroxene in the granitic gneisses. In each case the biotite may represent later,possibly Paleozoic (see section IV-6) retrogression of the older Grenvillian granulites

The accessory minerals tend to occur in the mafic rich patches. Sphene forms individual small prisms or xenomorphic masses around iron oxides , chlorite forms as an alteration product around biotite , and epidote occurs as inclusions in plagioclase , or as discrete grains in mafic rich patches.

Compositional as well as textural variations occur within the granitic gneiss unit. In places, such as the east flank of Hare Hill, some gneisses contain up to 40% quartz, possibly indicating a sedimentary protolith for these. As well , gneisses of granodioritic composition occur on the west flank of Hare Hill , at the eastern tip of "Tulks Pond", and on the shore of Grand Lake at "Second Falls".

Finally , pegmatite veins about 5 to 40 centimeters thick occur throughout the granitic gneiss unit. These are parallel to the foliation in places , cross-cut it in others , and locally are folded.

The granitic gneiss unit is , therefore , a rough grouping of mainly granitic gneisses with localized occurrences of different lithologies unmappable at this scale. The grouping does not imply similar origin or even age. The composition of these gneisses, however, is in general close to that of granite , and much of the unit may be igneous in origin . Localized zones of low finite strain , where the gneisses seem to grade into granite , support this interpretation .

The occurrence of quartz rich gneisses near Hare Hill, however, may indicate some of these had a sedimentary protolith.

In summary, the unit contains evidence of a complex deformational history described more fully in later chapters. This apparently involves the formation of the commonly occurring gneissosity, possibly associated with granulite grade metamorphism(indicated by the "Disappointment Hill" samples, see plates -8 and 9) during Grenvillian times. The gneisses were then retrogressed by a later event, possibly Paleozoic in age(see section IV-6),to the present greenschist facies mineral assemblages which are also related to a foliation(produced by the oblique orientation of the micas within the elongate patches related to the gneissosity).

The unit contains lithologies and textures comparable to those of the isotopically dated, Grenvillian,Indian Head Complex (see Chapter V),which also contains relict granulites. This similarity further supports its interpretation as basement.

II-2C Hornblende-plagioclase gneisses

The hornblende-plagioclase gneiss unit(map unit 1b) is named after its most commonly occurring lithology,although a variety of other lithologies unmappable at the map scale are included. The hornblende-plagioclase gneisses themselves show considerable variation in relative mineral abundances compared to the granitic gneisses, and are certainly not all genetically related.

The unit is the second most extensive of the Long Range Complex. It forms a band in the east, extending the entire

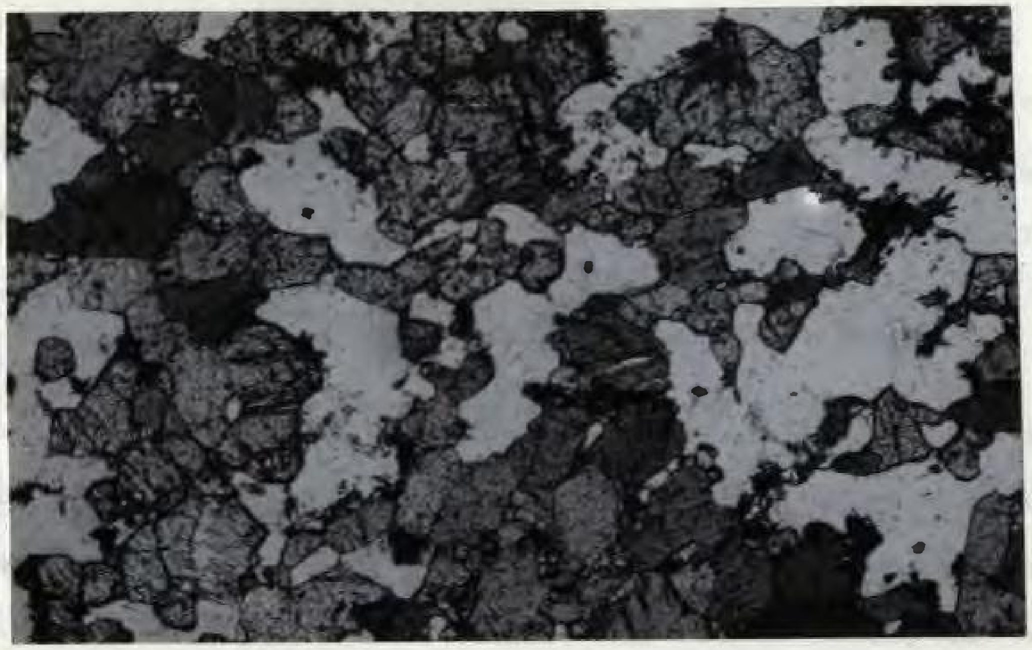


Plate-8: Photomicrograph(plane light) of a relict granulite from "Disappointment Hill". The height of the photograph represents 1.8 millimeters.

Plate-9: Photomicrograph(plane light) of a relict granulite from "Disappointment Hill". The height of the photograph represents 0.46 millimeters.

length of the study area, from Grand Lake in the north to the confluence of "Falls Brook" and Bottom Brook in the south. The band is 3 1/2 kilometers wide at its widest, due east of Beaver Pond, and 1/2 kilometer wide at its narrowest along Grand Lake. Some hornblende-plagioclase gneisses also occur on the west flank of "Bear Ridge"(see map).

The contacts of the hornblende-plagioclase gneisses with the granitic gneisses to the west are unexposed, and minor exposures of the granitic gneisses occur throughout the hornblende-plagioclase gneiss unit. Along Grand Lake, an almost continuous exposure through the hornblende-plagioclase gneiss band shows layers of granitic gneiss with northeast trends, parallel to the foliation in the gneisses and overall structural trend for the area. Whatever the original nature of the contacts(intrusive or interlayered), it appears, from their present orientation parallel to the structural trend, that they have been transposed during deformation. The major contact between the granitic and hornblende-plagioclase gneiss units also has a northeast trend(see map) and is probably structural in nature. The nature of the hornblende-plagioclase gneiss contacts occurring west of "Bear Ridge" are unknown.

The eastern contact of this unit with the Loon Pond metasediments(map unit 2) is a south-southwest trending fault, only exposed along Grand Lake, where it forms a steeply dipping three meter thick shear zone(plate -10). The fault may be a thrust fault similar to the Grand Lake Thrust, juxtaposing cover metasediments(Loon Pond metasediments) with Long Range Complex basement,or related to the late block faulting.

The hornblende-plagioclase gneisses are mapped as part of the basement Long Range Complex primarily due to the occurrence of relict textures and mineral assemblages, and because of their close association with the granitic gneisses. The Paleozoic metamorphic event, here, as indicated by mineral assemblages in the mafic dykes, is higher grade(amphibolite facies) than in the granitic gneisses to the west, masking much of the earlier features. No relict granulites were found in this unit, and evidence of relict Grenvillian metamorphism occurs as an early hornblende-plagioclase assemblage locally present in the gneisses but absent in the cover metasediments.

The hornblende-plagioclase gneisses generally contain plagioclase forming 40 to 60 percent of the rock, hornblende and biotite forming 10 to 20 percent of the rock, and quartz forming about 10 percent of the rock. Epidote, garnet, muscovite, sphene and iron oxides are common accessories forming about 10 to 15 percent of the rock. Zircon, alkali feldspar and clinozoisite occur rarely.

These gneisses are fine to medium grained, white, and have a "salt and pepper" appearance. Textures vary from granular to foliated to banded. Mylonitic textures occur rarely. The textures are interpreted as reflecting local finite strain, and as is the case for the granitic gneiss unit, are not used to delineate sub-units.

The granular hornblende-plagioclase gneisses have metamorphic equilibrium textures, and show a complete gradation to foliated gneisses where the mafic phases define a foliation.

Plate-10: Fault related shear zone separating the Loon Pond Metasediments from the Long Range Complex. Note the folded psammitic layer(white) floating in a sheared pelitic matrix(dark).

Plate-11: Minor folds in hornblende-plagioclase gneiss along the shore of Grand Lake. Note the intense mineral segregation.

The banded hornblende-plagioclase gneisses contain bands which vary from 1 to 3 centimeters(plates -11 and 12) in thickness. This gneissosity varies from mildly developed, where even the mafic rich bands are leucocratic, to extreme, where the mafic rich bands(melanosomes) are black(see plate -11). In general, the gneissosity in these is not so marked as that of the granitic gneisses. These banded gneisses are best developed on the west flank of "Bear Ridge", and in places along the shores of Grand Lake.

Mylonitic hornblende-plagioclase gneisses are rare. These show poorly developed gneissosity with layers of approximately 1 centimeter thickness. The constituent minerals such as hornblende,plagioclase, biotite and quartz are elongate, and define a lineation.

Microscopically,the plagioclase(An_{30-40}) in these gneisses generally form polysynthetically twinned granoblastic grains, and in places may be slightly porphyroclastic. Epidote and/or clinozoisite are common in plagioclase as alteration products. Small round quartz inclusions occur as well.

Quartz forms patches of small recrystallized polygonal grains in places, but is commonly xenoblastic. Where mylonitic textures are developed, the quartz forms recrystallized elongate grains defining a L-fabric. In all cases undulose extinction is common.

Two generations of hornblende are present. The earlier hornblende generally forms porphyroblasts, is pleochroic in shades of green, and in places contains very fine exsolved iron oxide needles in the core of the grains. Quartz and plagioclase

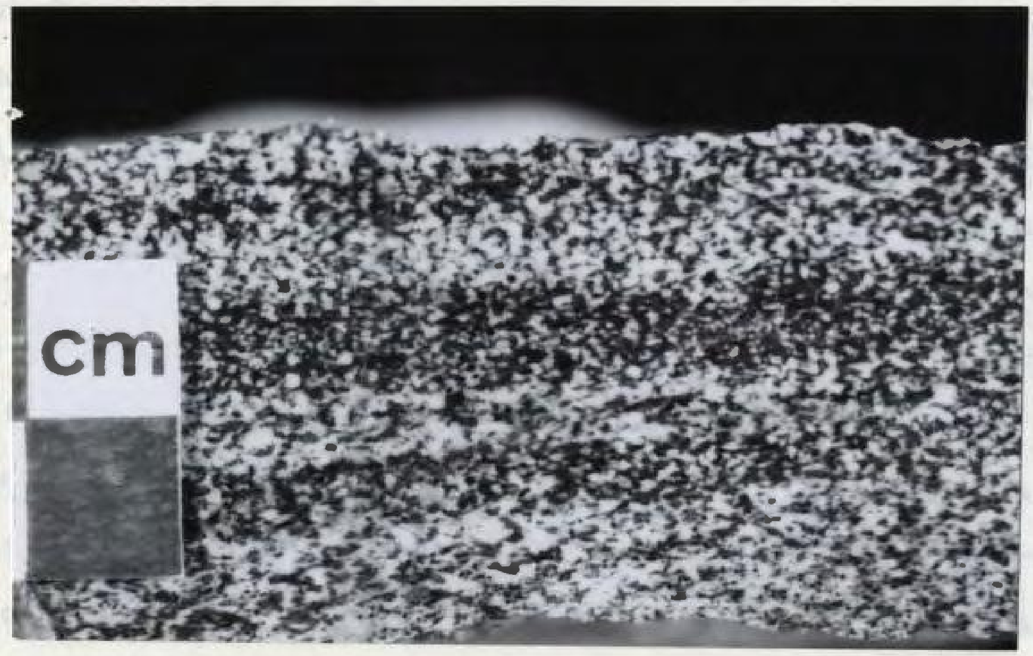


Plate-12: Banded hornblende-plagioclase gneiss sample. (M8-2-4) exsolutions occur in some grains. The later hornblende is fresher and commonly forms idioblastic grains. These are pleochroic in shades of green, but of lighter colour than the earlier hornblende. Both generations are oriented(their long axes) parallel to the gneissosity, where present(plate -13).

Biotite is pleochroic in shades of brown, and muscovite is colourless. Both micas, along with accessory minerals such as epidote, sphene, and iron oxides, commonly occur in elongate patches parallel to the gneissosity. The micas within these patches, however, locally define a second foliation at an oblique angle to that of the elongate patches. A second generation of biotite forming fresh decussate prophyroblasts is present and occurs throughout the area.

Accessory minerals include epidote, chlorite, garnet, alkali feldspar, iron oxide, and sphene. Epidote forms discrete grains concentrated in mafic rich patches, or as an alteration product in plagioclase. Chlorite forms as an alteration product on the mafic minerals. Sphene forms small prism shaped grains or anhedral masses around iron oxides(ilmenite or magnetite). Garnet forms fragmented masses, probably representing fragmented porphyroblasts, or less commonly inclusions in hornblende grains.

It appears, therefore, that the hornblende-plagioclase gneisses have as complex a history as do the granitic gneisses. The earlier hornblende gneration along with the porphyroclastic plagioclase, may form part of an early(Grenvillian?) amphibolite facies mineral assemblage, while the later hornblende along with the granoblastic plagioclase and possibly garnet represent a later,

Plate-13: Photomicrograph of a hornblende-plagioclase gneiss showing two hornblende generations. The early hornblende occurs in the center and contains quartz, epidote, and iron oxide inclusions. The later hornblende grains occur as fresh idioblastic grains around the early hornblende. The height of the photograph represents 1.8 millimeters.

Paleozoic, mineral assemblage. Both assemblages are associated with a foliation(northeast striking, southeast dipping). Finally, the epidote alteration on plagioclase and the formation of biotite, muscovite and chlorite in the mafic rich layers may indicate yet another metamorphic event.

Some of the hornblende-plagioclase gneisses, particularly those on the west flank of "Bear Ridge", have compositions close to that of gabbro and granodiorite, and may have had igneous protoliths. Within the main band of hornblende-plagioclase gneisses to the east, however, the abundances of the constituent minerals are more variable. In a few places, the gneisses contain up to 60 percent quartz. This may indicate a sedimentary protolith for these, or less likely strain induced segregation. The former interpretation is favored here. If this is so, the transposed granitic gneiss bands may indicate that the granitic gneisses, interpreted as dominantly igneous in origin(see section II-2B), intrude the hornblende-plagioclase gneisses and are thus younger. The transposed nature of the contacts between these makes definite proof of this impossible.

Whether the above speculation on the genesis of the gneisses is correct or not, the hornblende-plagioclase gneiss unit shows evidence of a complex structural and metamorphic history not present in the cover(Loon Pond metasediments), and is interpreted as Grenvillian basement. The earliest metamorphic assemblage and associated gneissosity may be broadly correlative to the gneissosity and related relict granulite facies mineral assemblages described earlier for the granitic gneisses. In this case, however, the post Grenville structural and metamorphic history appears to be more complex and higher grade, indicating more intense later remobilization.

II-2D Calc-silicates and Quartzites

This unit(map unit 1c) occurs in two places; along the southern shore of Grand Lake 1/2 kilometer east of "Second Falls", and at the top of "Bear Ridge".

The Grand Lake occurrence(see map) contains both calc-silicate and quartzite layers trending northeast, parallel to the regional structural trend, and dipping vertically. The contacts of the unit are unexposed, but almost certainly faulted. The exposed width of the unit is about 20 meters. The rock types occurring here are, from west to east, calc-silicates, phyllites, and quartzites.

The total thickness of the calc-silicate layers is about 10 meters. These layers are fine to medium grained, and show compositional variations probably reflecting original bedding. Calcite, tremolite, and chlorite are the most common minerals, while biotite, talc, and iron oxides occur locally, in minor amounts. The textures are granular to mildly foliated.

The phyllite layer has a total thickness of about 2 meters, is black, and contains large(about 5 millimeters) pyrite porphyroblasts forming about 3 percent of the rock.

Farthest east are quartzite layers totalling about 15 meters in thickness. These are composed of almost pure, fine to medium grained quartz.

Microscopically the Grand Lake calc-silicates are composed of colourless idioblastic tremolite grains some of which are partially altered to chlorite, dispersed in granoblastic calcite. Biotite rich bands occur in places, possibly representing more pelitic laminations in the protolith.

The "Bear Ridge" occurrence consists of a thin band of about 5 meters in thickness which trends north-south on top of "Bear Ridge". Only calc-silicates occur here. To the west the unit is faulted against banded granitic gneisses, and to the east against granular granitic gneisses. These calc-silicates contain much more biotite(defining a foliation) than those on Grand Lake. Microscopically the biotite is pleochroic in shades of brown, and in places is bent and altered to chlorite. Zircon inclusions, surrounded by pleochroic haloes, occur in biotite in some places. Tremolite occurs here as well, but is generally altered to chlorite. Calcite fills the interstices , and has sharp boundaries.

Both calc-silicate occurrences may represent metamorphosed impure limestones. In the Grand Lake occurrence, these were probably interlayered with sandstones(now quartzites) and siltstones(now phyllite). The relationship of these occurrences to one another, however, is unknown.

The fact that this unit occurs entirely within gneisses, and that calc-silicates have been reported to both north and southeast of the map area(Kennedy,1978; Herd,1978) where they have been interpreted as Grenvillian in age, implies a Grenvillian age for this unit. If this is so, the occurrence of Grenvillian age metasediments in the map area, lends credibility to the metasedimentary origin suggested for some of the gneisses.

II-2E Anorthositic rocks

The anorthositic rock unit(map unit 1d) occurs within the granitic gneisses in the southwestern part of the Long Range Complex. It occurs in two places: forming a small hill along road 185 near "Steve's Pond", and underlying a large block centered about Lost Pond in the south(see map). Rock types occurring within this unit are gabbro, anorthosite and pyroxenite.

The northern block is less than a square kilometer in area. The contacts are unexposed, but the topography suggests faulted contacts with the granitic gneisses around it. The rocks are sheared toward the margins, also supporting this inference.

The southern block is wedge shaped, about 6 kilometers wide at the southern boundary of the map area, and narrowing to about 1 kilometer at its northern termination. To the west, the block is in faulted contact with the granitic gneisses, the fault following roughly the Caribou Brook valley. The eastern boundary is a fault as well, which, in the south near Bottom Brook, follows a small brook along which anorthositic rocks are in contact with granitic gneisses. Sheared granitic and mafic dykes occur along this fault contact.

The nature of the northern boundary is unknown. Dykes of both granitic and syenitic composition occur, which may be related to the anorthositic rock unit or to the syenitic intrusion to the north("Tulk's Pond" syenite).

In the northern block, the gabbro is medium grained, contains mainly plagioclase and hornblende, and has an ophitic texture. Toward the edges of the northern block, the gabbros are progressively deformed until they show mylonitic textures (plate -14).

The anorthosite, here, is less common than the gabbro, occurring as 10 centimeter to 1 meter large rounded inclusions in the gabbro. In places, the anorthosite blocks form up to 80 percent of the rock, making it look like an intrusive breccia. Fine grained anorthosite veins(2 centimeters thick) cut the gabbro in places.

In the southern block near Lost Pond, the gabbro is slightly more plagioclase rich and contains mafic rich bands. The bands are about 5 centimeters thick, have a sharp base, and decrease in mafic mineral content gradationally upward indicating that they may be magmatic segregation features. Black, fine to medium grained gabbroic rock also occurs near "Fog Pond", and near the northern contact of the southern block. These may be sills or dykes.

The anorthosite in the southern block is a medium grained rock composed of about 90 percent plagioclase and 10 percent interstitial mafic minerals(pyroxene or its alteration products). Near the eastern fault contact, coarse grained anorthosite(3 millimeter large grains) occurs showing a cataclastic texture.

The pyroxenite in both blocks is medium to coarse grained and contains 70 to 95 percent pyroxene(or pyroxene alteration products). In the northern block, the pyroxenites occur as 3 to 10 centimeter thick veins cutting the gabbro. In the southern block, pyroxenite is restricted to the northern tip of the block, where it is the major rock type. Unlike that of the northern block, the pyroxenite here is foliated. The above rock types have been grouped into one unit because all are common in anorthositic terranes. Their genetic association seems likely, since in the northern block, gabbro containing anorthosite inclusions is cut by pyroxenite and anorthosite dykes and veins.

The exact relationship of the anorthositic rock unit to the surrounding granititc gneisses is unknown, due to the probable faulted nature of the contacts. The fact that anorthosites are typical of the nearby Grenvillian Indian Head Complex, Steel Mountain anorthosite (Murthy and Rao, 1975), and Grenville structural province in general, and that Paleozoic examples are rare (Foland and Muessig, 1978), indicates that the unit is most likely part of the basement complex (Long Range Complex). The unit's presence within the granitic gneisses also strengthens the attempted correlation of these to the isotopically dated Indian Head Complex gneisses.

II-2F Foliated granite

The foliated granite (map unit 1e) resembles the granitic gneisses of unit 1a, and could be included within it. It is treated independently, primarily because it is mappable at this scale, and because its intrusive origin can be proven.

The unit occurs at the top of "Bear Ridge", forming a narrow (½ to 1½ kilometers wide) north-south trending band about 4 kilometers long. The western contact of the unit is probably a fault which follows the crest of "Bear Ridge" to its summit. Here, the contact diverges from the fault and forms an intrusive breccia into the granular granitic gneisses of unit 1a (plate -3). The nature of the other contacts is unknown. To the north and north-west, the exposure is relatively good, but the distinction between foliated granite and granular granitic gneiss is difficult to make. The boundary may be gradational, and the location of that shown on the map is arbitrary.

The foliated granite contains quartz, alkali feldspar, plagioclase (An_{30-40}), and biotite. The alkali feldspar is usually pink and forms about 60 percent of the rock. Quartz forms about 20 percent of the rock, while plagioclase and biotite form about 10 percent each. The unit is fine grained and the foliation is defined by the orientation of biotite.

The unit is interpreted as part of the basement Long Range Complex. The preservation of the intrusive breccia contact (from transposition) and the lack of gneissosity in this unit, may indicate that the unit occupies a zone of low finite strain within the Long Range Complex. Some deformation has occurred, however, producing a foliation present in both the intrusive breccia unit (foliated granite) and in the included blocks of the host (granular granite gneiss).

II-2G <u>Long Range Complex, Conclusion</u>

All rock units assigned to the Long Range Complex are interpreted as Grenvillian basement. The relationships between the units, however, are a problem. It appears that the hornblende-plagioclase gneisses which occur in the east of the complex may have had a dominantly sedimentary protolith. The granitic gneisses to the west of the complex, however, appear to have had a dominantly igneous protolith, and occurrences of these in the hornblende-plagioclase gneiss unit may indicate that they intrude the latter. The calc-silicate and quartzite unit which is in fault contact with the surrounding gneisses, forms the only definitely metasedimentary unit of the complex.

The relationship of the anorthositic rock unit in the south to the surrounding gneisses is unknown, but its presence suggests a Grenvillian age for the complex. The presence of anorthositic rocks also supports the tentative correlation of the gneisses of the map area to those of the Indian Head Complex, which also contains anorthosite.

II-3A Loon Pond Metasediments, Introduction

The Loon Pond metasediments (map unit 2) occur as two, polydeformed and metamorphosed, fault bound slices in the east of the map area. Lithologies within the unit are; semipelitic to psammitic schists, quartzites, and marbles. These form sub-units which are extended for a short distance inland on the map, using unpublished data furnished by E. Stander.

The author's work within the Loon Pond metasediments is limited to the shoreline exposures along Grand Lake, and to a few inland traverses on the western slice. Much of the unit is, therefore, left undivided, although exposures are sufficient to extend the sub-units to the south (E. Stander, pers. comm., 1979). The schistosities in both slices strike to the northeast and dip to the southeast, parallel to the trend of both the bounding faults and sub-units.

II-3B Western slice

The western slice is centered about "Loop Pond", and forms a narrow band (less than 1/2 kilometer) trending about 4 kilometers to the southwest from Grand Lake. The eastern contact is a fault striking 035° and dipping 60° to the southeast, along the shore of Grand Lake. The western contact is also a fault containing a granite fault breccia(described in section II-5C). The nature of the southern contact with granitic gneisses is unknown. It is most likely a fault as well.

The sub-units within the western slice trend parallel to the faults bounding the slice. A 3 meter thick layer of pink marble interlayered with highly folded micaceous schists occurs on the west side of the slice. This is followed eastward by about 200 meters(exposure width) of mica schists containing minor amounts of quartz, garnet and small amphibole prisms lying on the schistosity. These schists are in sharp contact(possibly faulted) with a roughly 200 meter wide band of granitic gneisses followed eastward by schists and marble repeating a similar sequence to that described above. In this case, the mica schists contain larger amphibole prisms (up to 6 centimeters long) on the schistosity.

II-3C Eastern slice

The eastern slice is much more extensive than the western one. It trends southeast from Grand Lake, and extends almost to the southern boundary of the map area(about 11 kilometers in length), with an average width of about 1 1/2 kilometers. Both east and west contacts with the felsic gneisses are faulted. The fault at the western contact of the slice with the hornblende-plagioclase gneisses, strikes 190^{o} and dips 55^{o} to the east at Grand Lake. Here, a roughly 5 meter thick shear zone is developed along the fault where gneiss and psammitic schist blocks are floating in a sheared pelitic matrix(plate -10). The stratigraphic sequence for the sub-units within the slice is unknown because of the complex folding and faulting present, and the lack of facing data. The order of occurrence of the sub-units from west to east along Grand Lake is given below.

a) tan weathering marble containing disrupted pelitic laminations. The laminations weather out giving the rock a "swiss cheese" texture(1/2 kilometer exposed width).

b) garnet-mica schist with minor marble and quartzite beds. Aside from garnet and mica, the schist contains quartz, feldspar and amphibole prisms which lie parallel to the schistosity(1/2 kilometer exposed width).

c) quartzite, locally containing mica partings and small garnet crystals(1 kilometer exposed width).

d) semipelitic to psammitic schist. The semipelitic layers contain quartz,garnet and biotite with locally occurring large kyanite,albite and garnet porphyroblasts, as well as small(2 millimeter) amphibole prisms lying on the schistosity. The psammitic layers are interlayered with pelitic schists and contain mainly quartz amphibole and garnet(1 1/2 kilometers exposed width).

e) quartzites, locally containing large(1 centimeter) garnet porphyroblasts(1 kilometer exposed width).

The nature of the contacts between the above sub-units, aside from the faults bounding the slice, are unknown. The contact between sub-units(a) and (b) may be gradational since marble beds resembling those of sub-unit(a) occur within sub-unit(b).

II-3D Loon Pond Metasediments, Conclusion

The Loon Pond metasediments represent semipelitic to psammitic sediments, deformed and metamorphosed to produce a dominant northeast striking southeast dipping schistosity with associated upper greenschist to lower amphibolite facies mineral assemblages. They occur as two fault bounded slices within the Long Range Complex; and the orientation of the schistosity in these, parallel to the late foliation in the host gneisses, as well as the similar grades of the associated mineral assemblages, imply that both units were deformed together.

The Loon Pond metasediments may be correlated with the Late Precambrian to Early Paleozoic Fleur de Lys Supergroup of the Burlington Peninsula (Church, 1969; Williams and St-Julien, 1978; Knapp, Kennedy and Martineau, 1979). If this is correct, the deformation common to both the Loon Pond metasediments and surrounding Long Range Complex must be of Paleozoic age. No earlier higher grade mineral assemblages or textures occur in this unit, and it is interpreted, here, as a cover sequence to the Long Range Complex.

Exposures along the north shore of the east-west arm of Grand Lake indicate that the sub-units may be continuous across the lake and to the northeast (Knapp, Kennedy and Martineau, 1979).

II-4A Carbonate sequence, Introduction

The rocks of the carbonate sequence (map units 3 and 4) lie on the west side of the Grand Lake Thrust which juxtaposes them against granitic gneisses. Their western limit in the map area is a series of offset north-south trending cliffs (probably faults) followed westward by Pleistocene sediments. The southern contact of the sequence is a major northeast trending fault, possibly related to more minor northeast trending faults which produce the offsets in the cliffs at the western limit of the sequence.

In the study area these rocks are subdivided into two units; a basal black phyllite unit(map unit 3), and an overlying carbonate unit(map unit 4).The lower unit forms the southward continuation of the Cambrian Grand Lake Brook Group(Walthier,1949;Riley, 1962) described to the north of the map area. This unit may be equivalent in age to the upper part of the Loon Pond metasediments to the east, and to the Kippens, March Point, and Petit Jardin Formations to the west, near Stephenville (see figure -5; Riley,1962). The upper carbonate unit forms the most easterly exposures of the St. George Group and/or Table Head Formation(Riley,1962) to the west.

II-4B Grand Lake Brook Group

The Grand Lake Brook Group(map unit 3) occurs to the north of Hare Hill, forming a 1 kilometer wide band which extends northward beyond the western tip of Grand Lake. The unit is juxtaposed against granitic gneisses to the east by the Grand Lake Thrust, and against the Hare Hill granite to the south by a northeast trending fault, possibly related to the northeast trending faults producing the offsets in the cliffs at the western edge of the carbonate sequence. The western contact of the unit with the carbonate rocks is probably conformable in nature.

The unit is composed mainly of isoclinally folded black phyllite, locally containing 1 millimeter large pyrite cubes. In places, thin(about 2 millimeters thick) tan weathering dolostone layers occur within the phyllite. Folded quartz veins are common.

A 1 meter thick layer of tan weathering limestone occurs at the contact of this unit with the carbonates near the northeast tip of "Boundary Pond". This layer contains disrupted pelitic layers which weather out producing a "swiss cheese" texture(similar to unit 2a). The presence of this bed near the margin with the carbonate unit may indicate that the phyllites become calcareous toward the west, and grade into the carbonate unit.

The association of black phyllites and "swiss cheese" limestone observed here, is reminiscent of the Loon Pond metasediments to the east, where semipelitic schists and "swiss cheese" limestone occur. The units may in fact be of similar age and composition, differing only in metamorphic grade (upper greenschist to lower amphibolite facies for the Loon Pond metasediments, and lower greenschist facies for the Grand Lake Brook Group). This inference is consistent with the west to east increase in intensity of Paleozoic metamorphism observed in the map area.

II-4C Carbonate Rocks

The carbonate rock unit(map unit 4) is an eastern equivalent of the St. George Group and/or Table Head Formation to the west near Stephenville(Riley,1962). In the map area, the unit is composed of tightly folded, well bedded limestone and dolostone, and no attempt is made to separate the St. George Group from the Table Head Formation.

The unit lies in the northwest of the map area. Its western limit of exposure is the north-south trending cliffs (probably faults) described earlier, and its southern limit is a northest trending fault. The eastern contact with the Grand Lake Brook Group is unexposed but probably gradational. To the south, the unit is juxtaposed on its eastern side against granitic gneisses by the Grand Lake Thrust.

Grey limestone is the most common lithology. It is composed of fine sparite and generally forms meter-thick beds, commonly containing such primary features as algal laminations, mud cracks, burrowing, channel fill, and soft sediment deformation. Locally, mud cracks and channel fill indicate the facing directions.

The section contains limestone breccia in places. These are composed of subangular 1 1/2 centimeter large clasts of grey limestone in a limestone matrix, possibly indicating periodic subaerial exposure during deposition. Stylolites are common in the unit obscuring many of the primary features. In a few places, sinkholes occur. These are about 30 centimeters in diameter, and are now filled with glacial material. The holes are spaced about 3 meters apart, and disposed in a linear pattern possibly related to jointing.

Dolostone is the next most common lithology. It may form meter-thick massive beds, or units of 10 centimeter thick pink dolostone interlayered with 1 centimeter thick green phyllite.

Black phyllite occurs in only one place within this unit, about 2 kilometers to the southwest of "Button Pond". This consists of a small outcrop of folded black phyllite in sharp unfaulted contact with grey limestone. The outcrop occurs on the exterior of the limb of a major syncline, and may represent the top of the Grand Lake Brook Group, or more likely indicate that the limestone becomes interbedded with black phyllite layers at the base of this unit. If this is so, it may serve as further evidence that the contact between this unit and the Grand Lake Brook Group is gradational.

II-4D Carbonate sequence, Conclusion

The rocks west of the Grand Lake Thrust form the eastern limit of the west Newfoundland carbonate sequence near the map area. The basal Grand Lake Brook Group may be correlative in age to part of the Cambrian Kippens, March Point, and Petit Jardin Formations, to the west near Stephenville, and to the upper part of the Loon Pond metasediments to the east(see figure-5). The carbonate unit forms the eastern limit of exposure of the Lower Paleozoic St. George Group and Table Head Formation. The unit occurs to the east of the type sections, and its structural style inhibits stratigraphic subdivision. The nature of the contact(sharp or gradational) between the two units is unknown, but the increasing occurrence of limestone in the Grand Lake Brook Group toward the carbonate unit seems to indicate a gradational change.

A metamorphic contrast occurs between the rocks of the carbonate sequence and the rocks east of the Grand Lake Thrust. The carbonate sequence rocks show sub-biotite zone greenschist facies metamorphism with no evidence of retrogression from higher grades. The granitic gneisses to the east, however, show middle to upper greenshcist facies metamorphism with evidence of retrogression from granulite facies in places. This contrast in metamorphism across the Grand Lake Thrust, as well as the contrasting lithologies on each side, implies the fault is a major feature, possibly involving a large amount of displacement. This is consistent with the fault's interpretation as a thrust.

II-5A <u>Felsic intrusions, Introduction</u>

Three major felsic intrusive bodies are mapped in the study area. They are massive, medium to coarse grained, pink, and are probably genetically related. The bodies are informally named the Hare Hill granite(map unit 5a), "Goose Hill" granite(map unit 5b), and "Tulk's Pond" syenite(map unit 5c), and are described separately. No mafic dykes occur within these.

Aside from the three main felsic intrusions, massive granite also occurs at "First Falls" along Grand Lake. This granite grades laterally into granitic gneisses to the east, however, and it is not known whether it is a related intrusion or represents a zone of low finite strain within the granitic gneiss unit.

II-5B Hare Hill granite

The Hare Hill granite (using the Streckeisen classification; Streckeisen, 1976) underlies Hare Hill. It forms a roughly rectangular body about 1 ½ by 2 kilometers. The granite's western contact with the granitic gneisses is unexposed and its nature is unknown. To the north and south, the granite's contacts with units 3 and 1a respectively, are inferred to be northeast trending faults. The eastern contact with the granitic gneisses is a fault which is exposed at the northeast tip of the body. The fault is vertical and trends about 350^{o}.

The granite contains perthitic orthoclase (forming about 40 % of the rock), quartz (25%), plagioclase (15%), amphibole and biotite (15%) and accessory minerals (5%). It is medium to coarse grained, pink, massive to mildly foliated, and generally has an equigranular igneous texture.

The perthite grains are commonly slightly larger than the other minerals, and are surrounded by clean quartz grains. Plagioclase (An_{10-30}) is roughly the same size as quartz, shows polysynthetic twinning, and contains epidote inclusions. The amphibole, microscopically indentified as hastingsite (R.P. Taylor, pers comm., 1979) is dark green, pleochroic, and occurs along with biotite in patches containing such accessory minerals as sphene, calcite, apatite, and iron oxide.

The body is compositionally homogeneous except at its southern contact. Here, a deeply weathered more mafic rich phase occurs which is intruded by veinlets of the main Hare Hill granite and therefore slightly older. This more mafic rich phase is coarse grained, contains up to 40% mafic minerals, and in places contains less than 10% quartz (quartz syenite).

II-5C "Goose Hill" granite

The "Goose Hill" granite occurs around "Beaver Pond". Its contact with the host rock is only seen on the east side of the body, where it is a fault forming a well exposed breccia zone which is traceable from the shore of Grand Lake southwest for a length of 6 kilometers. The north and east contacts of the body are inferred from the topography since it forms a marked topographic high. The southern contact of the body with the "Tulk's Pond" syenite, is only seen in one place, near the northwest tip of "Mud Pond", where saprolitic syenite is intruded by a stockwork of granite veins belonging to the "Goose Hill" granite.

The "Goose Hill" granite is compositionally and texturally similar to the Hare Hill granite. It contains northeast trending shear zones in places, and 50 centimeter thick white quartz veins are common along the eastern margin.

Also noteworthy are a few outcrops of calc-silicates within the "Goose Hill" granite, occurring in a northwest-southeast trending valley containing "Beaver Pond".

These may be rafts of calc-silicates related to map unit lc described earlier(see section II-2D).

The breccia zone on the east side of the body is about 10 meters wide. It is mainly composed of lense shaped 5 centimeters large, sub-rounded fragments of granite in a matrix of medium grained fragmented granite. Sub-rounded equant clasts of white quartz are also common.

The breccia shows a gradational decrease in deformation westward most obvious where quartz clasts are abundant. These

Plate-14: Photomicrograph of a mylonitic gabbro showing two foliations, from the north block of the anorthositic rock unit. The height of the photograph represents 1.8 millimeters. (M6-25-3) can be traced from sub-rounded clasts in the breccia zone, to larger angular clasts, to disrupted veins, and finally to underformed veins, westward away from the breccia zone.

The breccia also occurs on the south shore of Grand Lake where it consists of granitic material and rounded white quartz clasts, although the host there is the granite gneiss-calc-silicate contact. This occurrence is about 2 kilometers north of the last surface exposure of the granite indicating that the granite occurs below surface, or less likely that the movement which produced the breccia had a considerable strike-slip component.

II-5D "Tulk's Pond" syenite

The "Tulk's Pond" syenite occurs around "Tulk's Pond", and forms a topographic low with few outcrops, many of which are saprolitic(plate -2). The contacts of this body are unexposed, and its shape is inferred mainly from the topography.

The syenite contains perthitic orthoclase(forming about 40 % of the rock), plagioclase(20%, An_{10-30}), biotite and hornblende (35%), and accessory minerals(5%). It is medium to coarse grained, pink, massive to mildly foliated, and generally has an igneous texture. In places, this unit is mafic rich and resembles the mafic rich phase(quartz syenite) which occurs at the south tip of the Hare Hill granite. Northeast trending shear zones occur, along which a local foliation is commonly developed.

II-5E Felsic intrusions, Conclusion

The Hare Hill and "Goose Hill" granites are texturally and compositionally similar, and are almost certainly related. The "Tulk's Pond" syenite is probably also related to these, but may be an earlier phase. Evidence for this is the stockwork of veins of "Goose Hill" granite which intrude the syenite near its margin at "Mud Pond". The older mafic phase occurring at the south tip of the Hare Hill granite may be related to the "Tulk's Pond" syenite, and if so, also supports this interpretation.

The bodies are massive or only locally foliated, indicating that the bodies are younger than the deformations affecting the other units, or that the gneisses acted as a buttress protecting the intrusions from deformation. The former interpretation is favoured here since the bodies,unlike the granitic gneiss host,contain primarily igneous textures with no relict granulite facies assemblages,and contain no mafic dykes(which predate the deformation.Also, although intrusive contacts are rarely seen, the bodies are obviously discordant and do not grade into gneisses at their boundaries as does the foliated granite unit (map unit le). Finally, the mineralogy(occurrence of hastingsite) appears similar to that of some phases found in the Paleozoic Topsails Batholith to the northeast(R. Taylor, pers. comm.,1979) which also suggests a post deformation Paleozoic age for these.

II-6A Mafic dykes, Introduction

The mafic dykes are confined to the Long Range Complex, and occur most commonly in the central part of the map area. They are 1 to 3 meters thick, generally fine grained, locally folded, but are more commonly undeformed. The dykes strike northeast, dip steeply to the southeast, and truncate the Grenvillian gneissosity indicating that they are a later feature.

The northeast trending dykes are most abundant and best exposed along the shore of Grand Lake, where they are locally only 10 meters apart. These are generally foliated parallel to sub-parallel to their contacts with the host. The most altered and deformed examples occur along road 185 due south of "Bear Ridge", and about 1 kilometer due east of "Steve's Pond".

The dykes contain roughly the same minerals throughout the area, but a change in texture is observed from northwest to southeast across the area.

II-6B Mafic dykes, Petrology

The major constituents of these dykes are plagioclase (forming about 45% of the rock), hornblende(~35%), and biotite (~15%). Epidote, sphene, chlorite, and iron oxides are common accessories(~5%), and quartz albite, calcite, and zircon occur locally.

In the northwestern part of the map area, the dykes are commonly altered, and the original nature of the minerals (igneous or metamorphic) is unknown. The plagioclase (An_{40-60}) in these dykes forms larger grains which are commonly polysynthetically twinned, and locally contain epidote inclusions and calcite grains at its boundaries as alteration products. Locally the plagioclase contains fine polygonal quartz and albite along cleavage planes.

Two types of biotite occur. The most common is pleochroic in shades of brown, has irregular shapes, is generally elongate, and defines a foliation. The less common type is pleochroic in shades of green and forms later decussate grains containing exsolved rutile needles along crystallographic planes(sagenitic biotite).

Hørnblende is generally idioblastic, containing altered cores rich in inclusions and fresher rims(plate -15). In places, the hornblende is rimmed by chlorite and iron oxides, and in others, contains exsolved quartz and plagioclase.

Sphene forms small prism shaped grains in mafic rich patches containing epidote, chlorite, and biotite, or anhedral masses around iron oxides. Quartz commonly forms inclusions in,or small grains around, plagioclase. Zircon occurs as inclusions in biotite where it has pleochroic haloes.

The altered plagioclase and hornblende probably form part of an early assemblage, the nature of which is unknown. The corroded appearance of these, and their alteration products imply a later recrystallization which probably resulted in the formation of the hornblende rims and foliated biotite. The polygonal albite and quartz are probably related to this event. Evidence of a later alteration occurs in the form of decussate sagenitic biotite and chlorite, and possibly the formation of the epidote minerals.

In the southeastern part of the map area, equilibrium textures are more common. Hornblende in these dykes defines a foliation and is of obvious metamorphic origin. It forms fresher, commonly idioblastic grains, locally containing plagioclase inclusions (plate -16). In places, an earlier altered hornblende containing numerous iron oxide inclusions occurs, probably representing an earlier assemblage of unknown nature.

Plagioclase (An_{40-60}) appears interstitial between hornblende, and is fresher than to the northwest. It may show polysynthetic twinning, but more commonly is turbid and contains epidote inclusions and calcite at its boundaries. Biotite is pleochroic in shades of brown and forms decussate grains which commonly have sagenitic textures. Quartz forms small polygonal grains near plagioclase, and chlorite is rare, occurring as an alteration product on hornblende or in mafic rich patches containing sphene, epidote, and iron oxide.

The foliated hornblende and interstitial plagioclase, here (southeast), form a metamorphic assemblage possibly related to the hornblende rims and foliated biotite to the northwest. If so, the earlier relict hornblende in the dykes to the southeast is probably equivalent to the hornblende cores in the dykes to the northwest. All dykes contain decussate sagenitic biotite and epidote minerals, possibly indicating a later metamorphic event of greenschist grade throughout the area.

II-6C Mafic dykes, Conclusion

All of the dykes are probably altered diabase dykes, and are probably genetically related. The differences occur in

Plate-15: Photomicrograph of a mafic dyke near "Steve's Pond"(northwest), showing a fresh amphibole rim around an earlier altered amphibole. The height of the photograph represents 0.46 millimeters. (M6-23-1)L

Plate-16: Photomicrograph of a mafic dyke in the southeast of the study area, showing fresh oriented hornblende grains. The height of the photograph represents 0.46 millimeters. (M8-13-1) the alteration of these by subsequent deformation and metamorphism. The first recognizable event is the alteration of the dykes to a middle to upper greenschist facies mineral assemblage in the northwest of the area(indicated by foliated biotite, hornblende rims, and polygonal quartz and albite), and an amphibolite facies mineral assemblage in the southeast of the area(indicated by foliated hornblende and interstitial plagioclase). A later partial alteration to greenschist facies mineral assemblages occurred throughout the area, indicated by decussate sagenitic biotite and epidote minerals.

The alteration of the dykes is of crucial importance in the interpretation of Paleozoic deformation and metamorphism for this area. The dykes are post Grenville and, therefore, record the Paleozoic events which overprint the already deformed Grenvillian basement units(Long Range Complex). At least two metamorphic events are recorded in the dykes of the map area. A first, produced amphibolite facies mineral assemblages in the southeast which decline to greenschist facies to the northwest. This was followed by a pervasive greenschist facies metamorphic event throughout the map area. The gradation in the earlier metamorphic event is consistent with the occurrence of greenschist facies mineral assemblages in the granitic gneisses which occur in the west and central part of the map area, compared to the amphibolite facies mineral assemblages present in the hornblende-plagioclase gneisses which occur in the eastern part of the area.

Similar dykes have been reported in crystalline rocks to the north of Grand Lake(Knapp, Kennedy and Martineau,1979) and in the Burlington Peninsula(Fleur de Lys Supergroup; deWitt, 1972). In all cases the dykes are interpreted as Late Precambrian to Early Paleozoic feeders to rift related volcanic flows. The same interpretation is favoured here, and the fact that no dykes are found in the Late Precambrian to Early Paleozoic Loon Pond metasediments may be fortuitous.

II-7 General geology, Conclusion

The rocks of the study area may be separated into the following groups: the Long Range Complex interpreted as Grenvillian basement, the Loon Pond metasediments interpreted as Late Precambrian to Early Paleozoic metamorphosed cover(east), the carbonate sequence interpreted as Early Paleozoic cover (west), the mafic dykes interpreted as Late Precambrian to Early Paleozoic in age, and the felsic intrusions interpreted as late to post orogenic Paleozoic intrusions.

The Long Range Complex shows evidence of a complex metamorphic history, locally involving relict granulites. These are probably features of Grenvillian metamorphism which have later been partially to totally retrogressed to greenschist (in the northwest) and amphibolite facies(in the southeast) mineral assemblages by Paleozoic metamorphism. This east to west zonation in Paleozoic metamorphism is, conveniently, recorded in the mafic dykes that cut the gneisses.

The cover units are all affected by the Paleozoic deformation, and show a variation in its intensity(the deformation) from the southeast to northwest. This is indicated by metamorphic mineral assemblages of up to amphibolite facies in the Loon

Pond metasediments in the east, compared to lower greenschist facies mineral assemblages to no recrystallization in the carbonate sequence rocks in the west.

Massive felsic intrusions containing no mafic dykes, may form the youngest of the map units in the study area. They contain localized shear zones which may be related to the faulting affecting this unit, and which form the last deformational event recorded in the area (the faulting).

Major faults in the area are the Grand Lake Thrust and the Cabot Fault. The Grand Lake Thrust juxtaposes granitic gneisses showing evidence of a complex structural and metamorphic history (locally up to granulite facies) in the east, with folded low grade (lower greenschist) rocks of the carbonate sequence in the west, implying major movement.

At the northeast end of the map area, the Cabot Fault, a major feature extending across Newfoundland from Port aux Basques to White Bay, separates the felsic crystalline rocks of the map area from mafic volcanics to the east.

Other faults in the area are the high angle block faults which separate the map units. These are of lesser importance, except for one northeast trending high angle fault separating the Long Range Complex from the eastern slice of the Loon Pond metasediments. This fault dips steeply at Grand Lake, but the fault could be a refolded major thrust like the Grand Lake Thrust. The fault juxtaposes totally different lithologies (felsic gneisses in the west from psammitic to semipelitic schists and carbonates in the east), but no major metamorphic contrast is observed across it.

The present configuration of the units, therefore, implies complex Paleozoic deformation of both cover and basement, followed by the thrusting of the deformed basement-cover block onto the carbonate sequence. The age of the granitic intrusions relative to the thrusting event is unknown, but the fact that no granitic bodies or dykes occur west of the Grand Lake Thrust, and that these are common to the east of it, implies that the intrusions are older than the thrusting.

III STRUCTURAL GEOLOGY

III-1 Introduction

Structures in the area vary from composite fabrics involving compositional segregation in the Long Range Complex, to folded schistosity in the Loon Pond metasediments, to open folds without penetrative cleavage in the carbonate sequence. Some plutonic rocks within the Long Range Complex are massive with a locally developed foliation along shear zones.

The area is dominated by a northeasterly oriented Paleozoic structural trend. Minor fold axis directions, and the composite fabrics in the Long Range Complex, however, indicate a complex deformational history, involving preserved Grenvillian structural elements.

Because of the varying complexity of structures for the different units, and the uncertainties of correlating structural elements, the units are divided into groupings which are described under separate headings. The groupings are as follows: the Long Range Complex(includes map units 1a, b,c,d, and e), the Loon Pond metasediments(includes map units 2, 2a, b,c,d, and e), the Grand Lake Brook Group(map unit 3), the carbonate rocks (map unit 4), and the intrusions (including map units 5a, b, and c, and the mafic dykes).

Faults generally form the boundaries between units, and are in most cases, the latest structural event. These are treated separately in a later section. A rough synthesis of the structures into a coherent deformational history follows.

III-2 Structures in the Long Range Complex

The earliest structure recognized in the Long Range Complex is its gneissic foliation. This foliation varies both in type and in orientation, and is probably not everywhere related. The gneissosity includes more than one type of texture. It varies from millimeter thick layers in mylonitic gneiss to centimeter thick layers in pinstriped gneisses to several centimeter thick layers in the banded gneisses. The fact that no mineral segregation is developed in the cover units, and that the gneissosity is overprinted by a later fabric developed in both basement and cover, indicates a Grenvillian age is likely for the gneissosity. Similar gneissic textures are also common in the Grenvillian Indian Head Complex to the west.

A second major type of foliation occurs in the gneisses. This is produced by the orientation of the mafic minerals. It is most commonly developed in the mafic rich layers of pin-striped granitic gneisses, and is sub-parallel to the gneissosity in these. In a few places, however, within the hornblende-plagioclase gneisses, the foliation produced by the orientation of small(about 1 millimeter) hornblende prisms is axial planar to minor folds in the gneissosity, indicating that it forms a fabric related to a later event folding the gneissosity, possibly Paleozoic in age(plate -17). This fabric is also developed in the Late Precambrian to Early Paleozoic mafic dykes, supporting this observation.

Lineations occur within the gneisses, and are most commonly developed on the south and west flanks of "Bear Ridge". The lineations are produced by the parallel orientation of rod-shaped quartz patches in mylonitic gneisses, to the parallel orientation of the long axis of hornblende prisms in granitic and mafic(altered diabase dykes) gneisses. The mylonitic gneisses may represent localized zones of high strain produced at the same time as the gneissosity, or less likely a later deformational event.

Minor folds are common within the gneisses(plate -11). They vary from simple folded gneissosity to refolded folds in the gneissosity. Larger scale folds(about 5 meters in amplitude) also occur. These were only recognized along the shore of Grand Lake, where they occur in both granitic and hornblende-plagioclase gneisses, but are best developed in the hornblende-plagioclase gneisses in the east of the map area. They(the folds) fold the Grenvillian gneissosity into tight upright folds with northeast trending sub-horizontal fold axes, and locally are associated with an axial planar fabric produced by the later Paleozoic foliation(oriented mafic minerals) described above.

Locally the folds appear truncated by mafic dykes at the hinge(plate -18), apparently indicating the folds predate the emplacement of the dykes. The dykes, however, also contain the axial planar fabric associated with the folds,indicating they are syn- or pre-folding. A likely explanation for this contradiction is that the folds are later and developed against the dykes. In some places the dykes are folded along with the gneissosity(where these had different orientations from the axial planes of the folds) supporting this inference. A similar occurrence has been documented in the Caledonides of Finnmark (Gayer, Powell and Rhodes,1979).

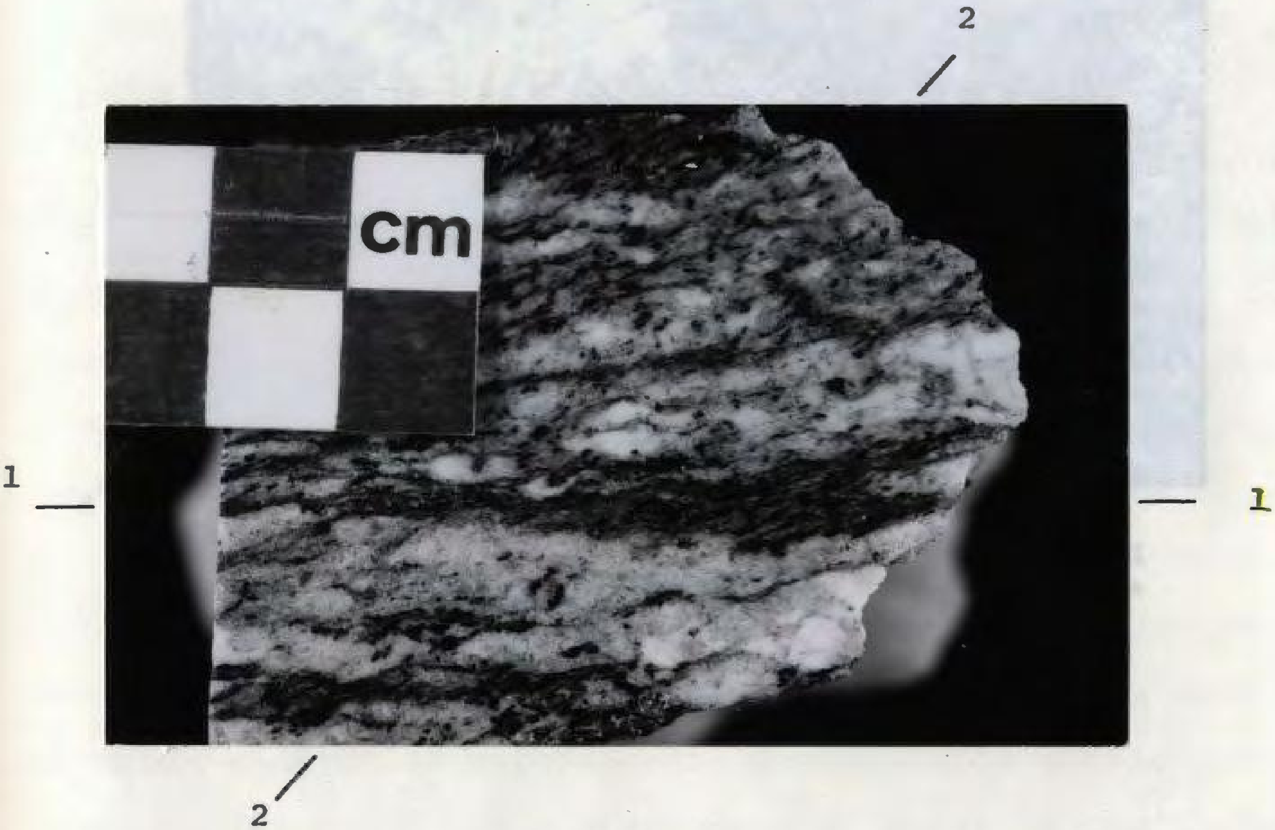
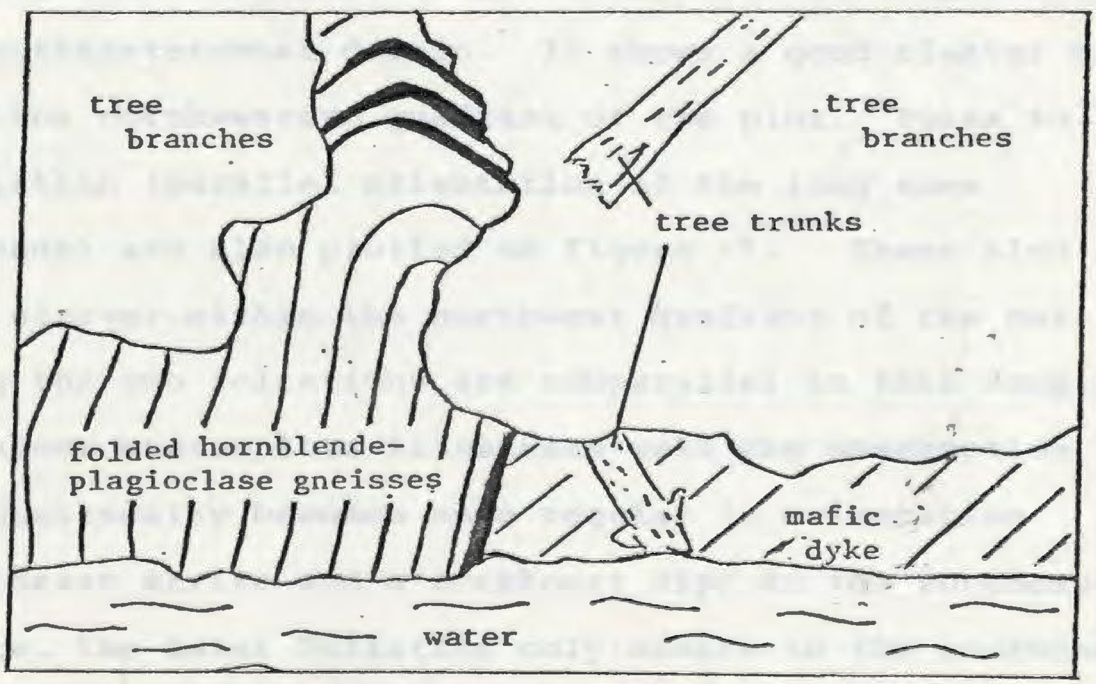


Plate-17: Hornblende-plagioclase gneiss sample showing two foliations(1-gneissosity,and 2-oriented mafic minerals). (M8-1-1)

Plate-18: Northeast trending fold in the banded hornblende-plagioclase gneisses, truncated by a mafic dyke at its hinge(see sketch below).



The gneissosity, as stated earlier, is variable in orientation. It shows, however, a change to a more consistent orientation to the southeast, possibly related to the Paleozoic folding described above which is best developed to the east. Figures 6 to 9 illustrate this observation.

Figure -6 is a sketch map of the study area in which the Long Range Complex has been subdivided into three domains from the northwest to the southeast. The subdivisions are chosen to coincide roughly with major faults. Figure -7 is a stereoplot of poles to the gneissosity on a Schmidt equal area net for gneisses occurring in the northwesternmost domain. It shows a mild clustering of points on the western side of the plot. Figure -8, however, is a stereoplot of poles to the gneissosity for the central domain. It shows a much stronger cluster of poles in the western side of the plot. Finally, figure -9 is a stereoplot of poles to the gneissosity for the southeasternmost domain. It shows a good cluster of points in the northwestern quadrant of the plot. Poles to the later foliation (parallel orientation of the long axes of hornblende) are also plotted on figure -9. These also fall in a cluster within the northwest quadrant of the net indicating the two foliations are subparallel in this domain.

The above stereoplots illustrate well the observation that the gneissosity becomes more regular in orientation (to a northeast strike and a southeast dip) to the southeast. Furthermore, the later foliation only occurs to the southeast, and has a similar orientation to the gneissosity in that

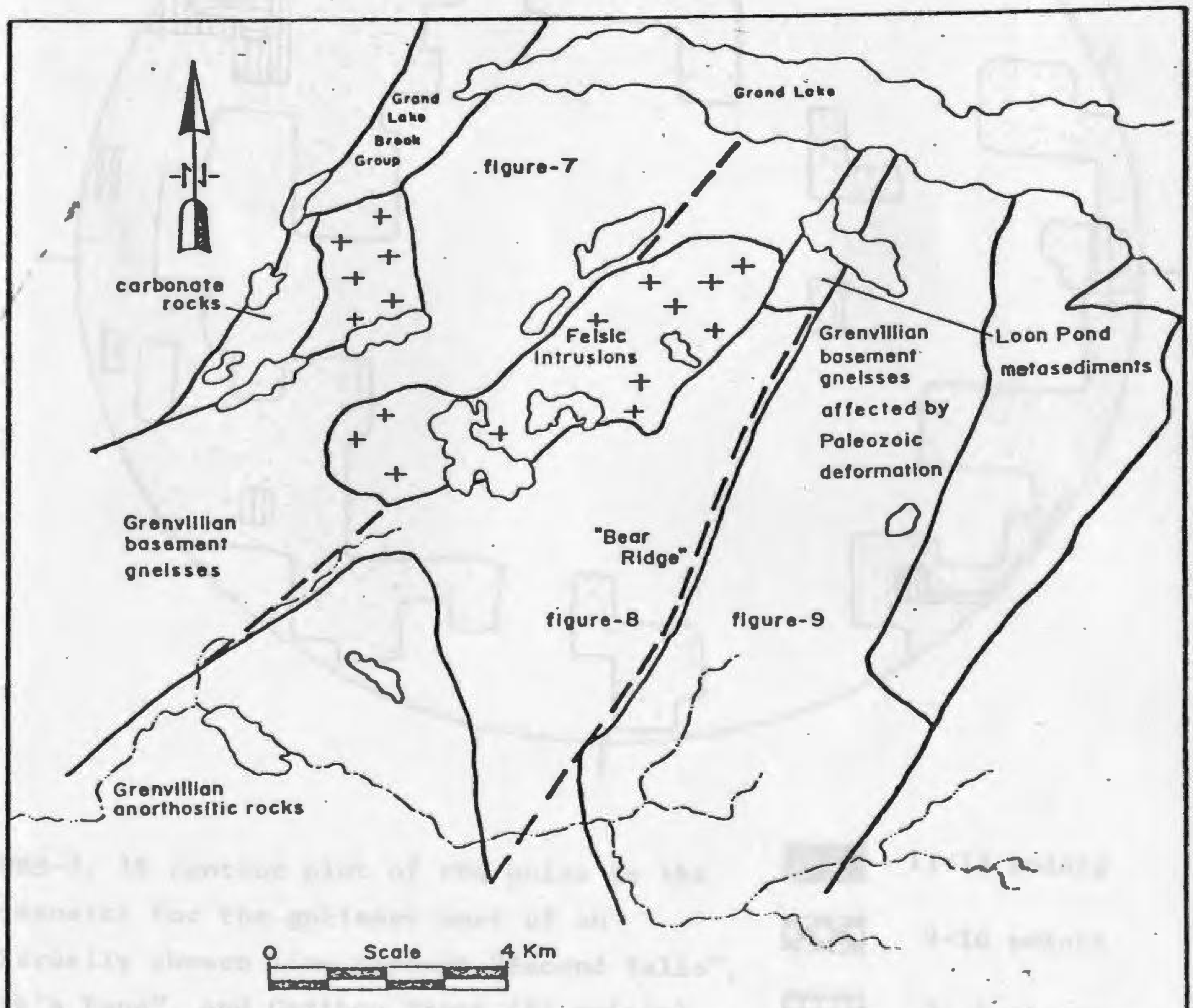


FIGURE-6. Sketch map of the study area showing the subdivisions for the stereoplot data.

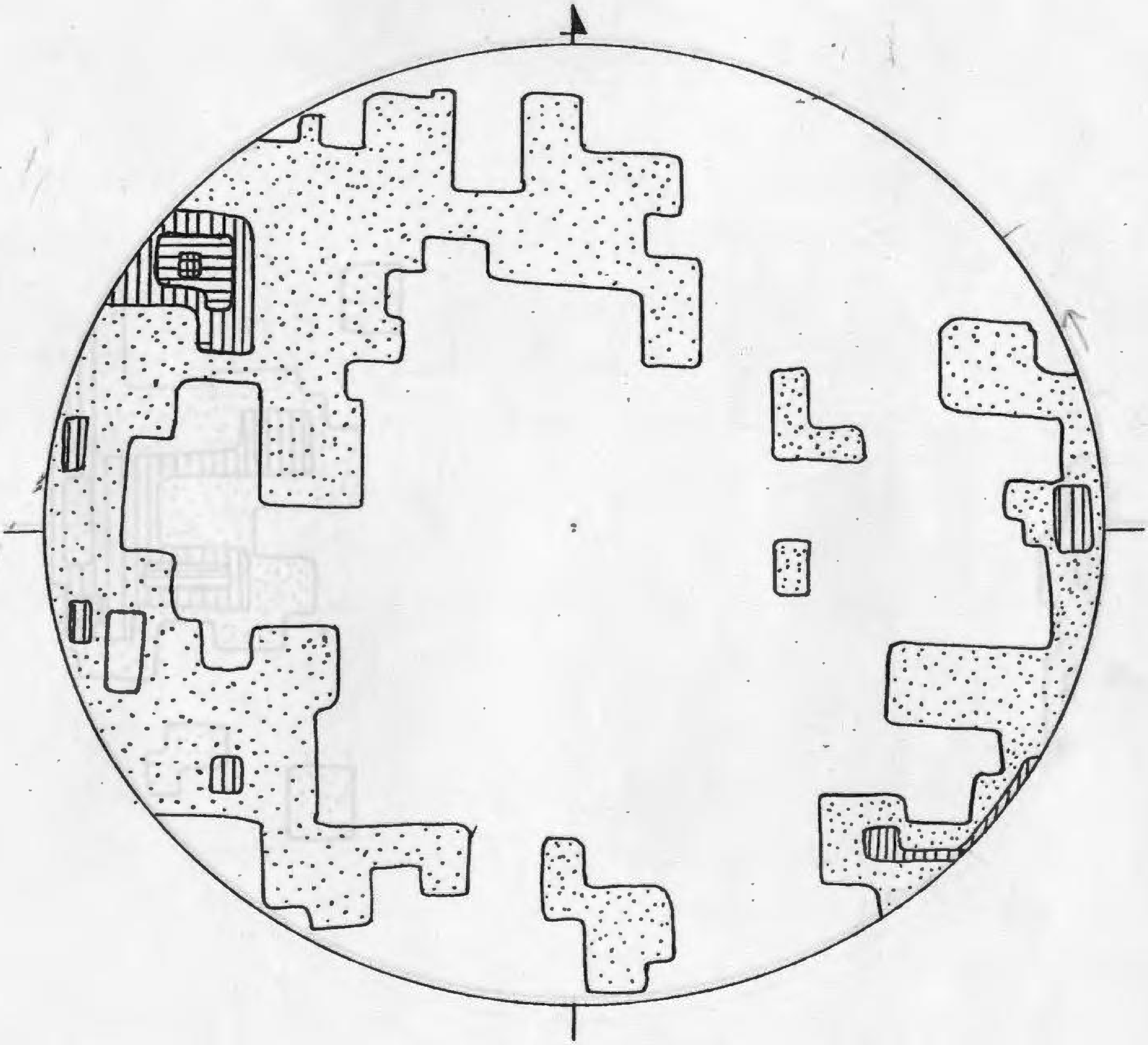
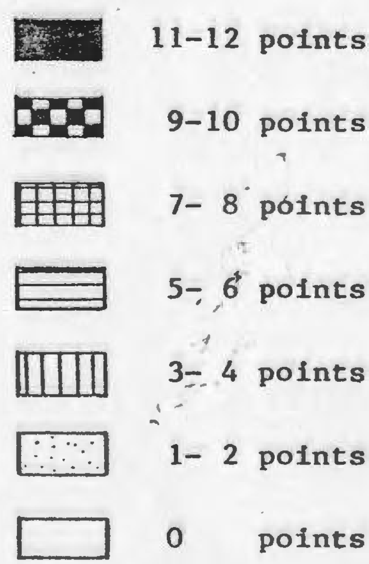


FIGURE-7. 1% contour plot of the poles to the gneissosity for the gneisses west of an arbitrarily chosen line through "Second Falls", "Tulk's Pond", and Caribou Brook.(83 points)



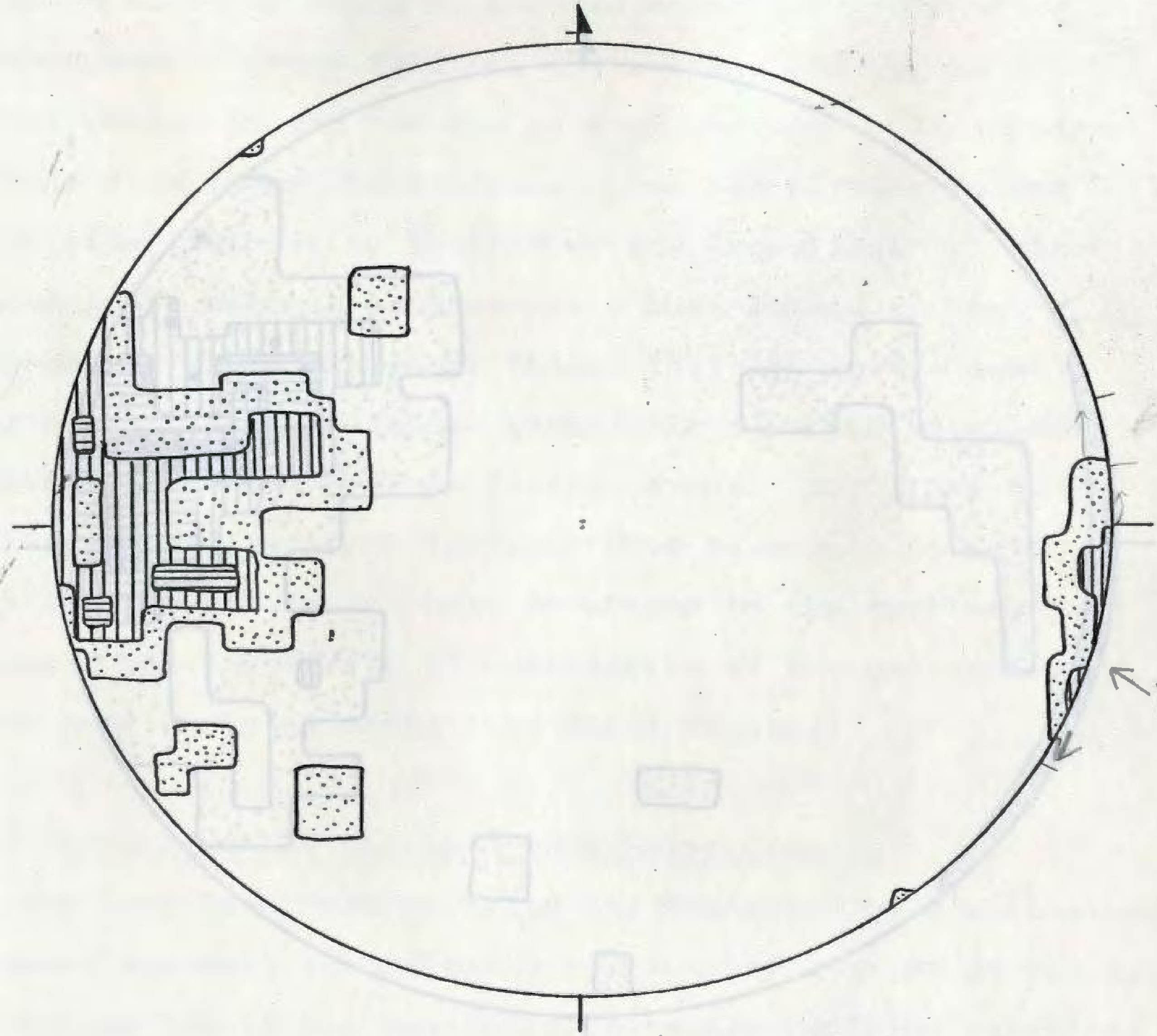
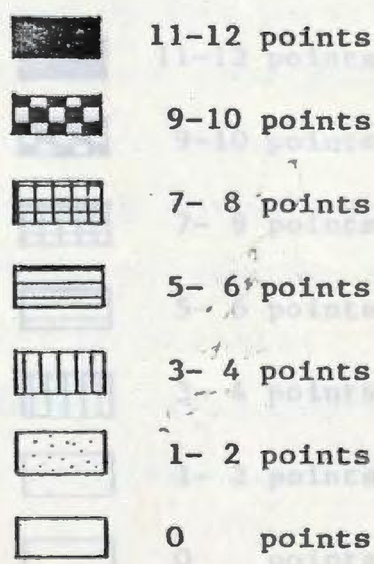


FIGURE-8. 1% contour plot of the poles to the gneissosity in the "Bear Ridge" area.(50 points)



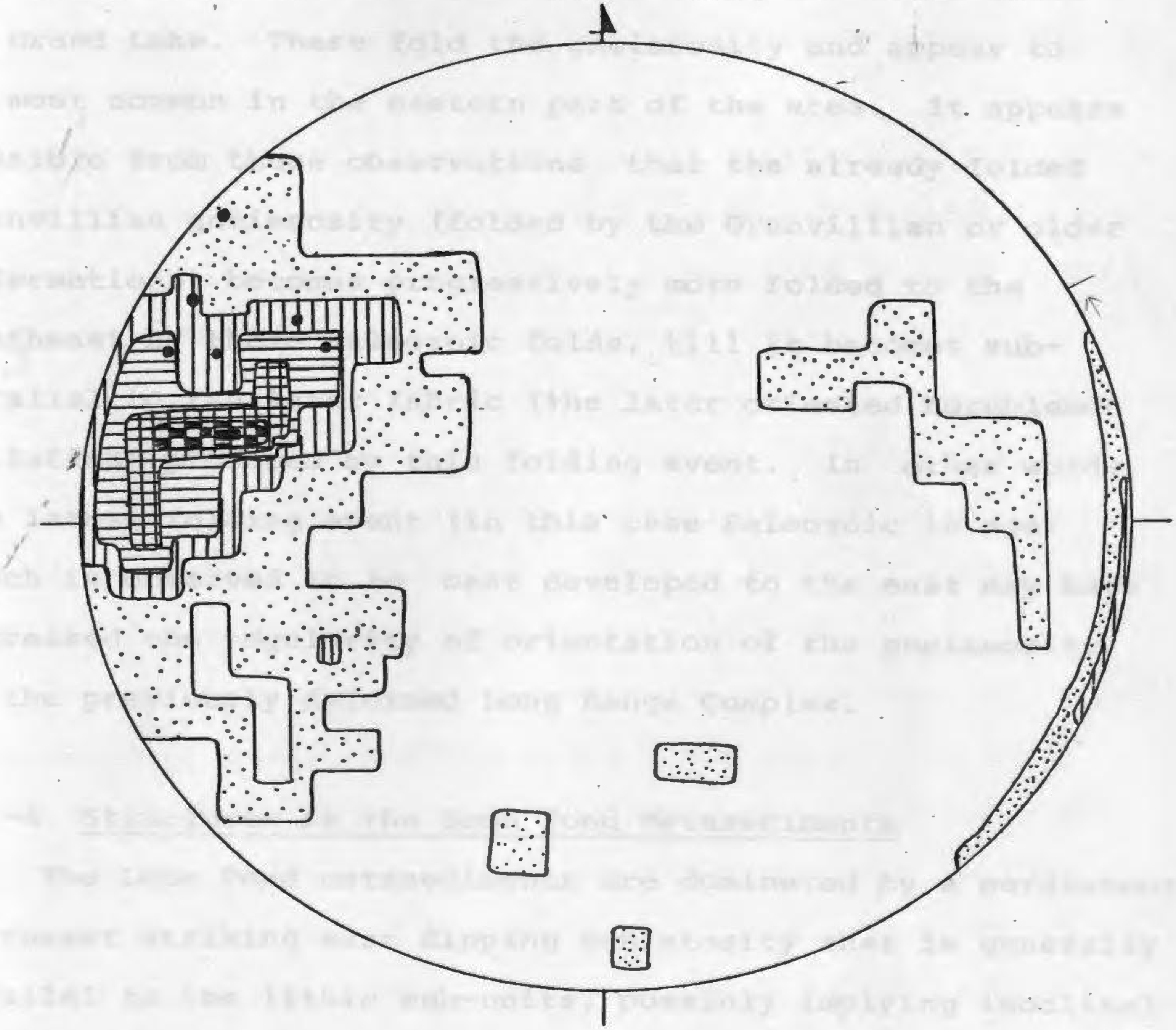


FIGURE-9. 1% contour plot of the poles to the gneissosity for the gneisses east of an arbitrarily chosen line through "Second Falls", "Beaver Pond", and the east flank of "Bear Ridge".(100 points)(• =poles to the later foliation) same area. As stated earlier, a set of Paleozoic,tight, northeast trending folds is exposed along the south shore of Grand Lake. These fold the gneissosity and appear to be most common in the eastern part of the area. It appears possible from these observations that the already folded Grenvillian gneissosity (folded by the Grenvillian or older deformations) becomes progressively more folded to the southeast by these Paleozoic folds, till it becomes sub-parallel to the later fabric (the later oriented hornblende foliation) produced by this folding event. In other words, the latest folding event (in this case Paleozoic in age) which is observed to be best developed to the east may have increased the regularity of orientation of the gneissosity in the previously deformed Long Range Complex.

III-4 <u>Structures in the Loon Pond Metasediments</u>

The Loon Pond metasediments are dominated by a persistent northeast striking east dipping schistosity that is generally parallel to the lithic sub-units, possibly implying isoclinal folding. This schistosity is produced mainly by the parallel orientation of micas and is associated with upper greenschist to lower amphibolite facies mineral assemblages. This Paleozoic fabric (since the protolith is roughly correlative with the Paleozoic Grand Lake Brook Group; Knapp, Kennedy and Martineau, 1979) is sub-parallel to parallel to the late similar grade (lower amphibolite facies) fabric developed in the adjacent part (east) of the Long Range Complex, and the two are possibly related. The fact that this later fabric in the basement gneisses is also developed in the intruding Late Precambrian to Early Paleozoic mafic dykes also supports this observation.

The fact that the schistosity and attitude of the lithic sub-units are sub-parallel along the shore of Grand Lake may indicate isoclinal folding forms the dominant feature within this unit. No fold closures were seen to prove this. However, the fact that Paleozoic folds occur within the adjacent Long Rang Gneisses would seem to support the inference that the Loon Pond metasediments are tightly folded, although it should be remembered that the units are in fault contact and that the fabrics are not necessarily related.

Minor folds are rare in this unit. These are restricted to a few kink bands observed along Grand Lake. The only large scale folds observed in the area are open folds with east trending fold axes, which bend the sub-units on the large scale (see map). The presence of these is inferred from the map pattern only. No penetrative foliation is associated with these folds, and it is possible that they were produced by drag along strike slip faults (E. Stander, pers. comm., 1979).

Figure -10 is a stereoplot of poles to schistosity for the Loon Pond metasediments. A marked cluster of poles occurs in the northwest quadrant of the plot. This cluster gives an average northeast strike and steep southeast dip for the schistosity. As stated above, this orientation is sub-parallel to that of the sub-units along the south shore of

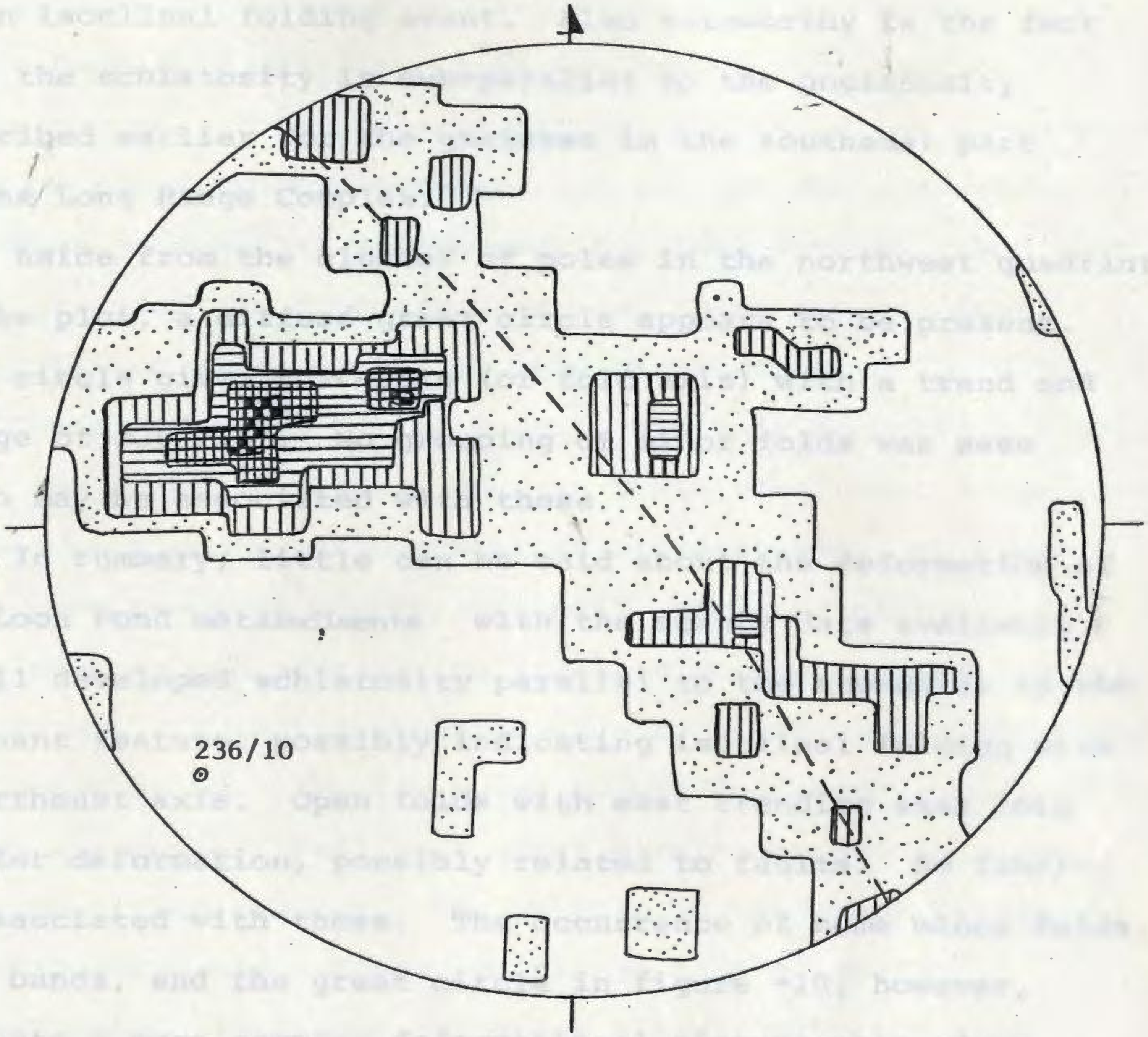
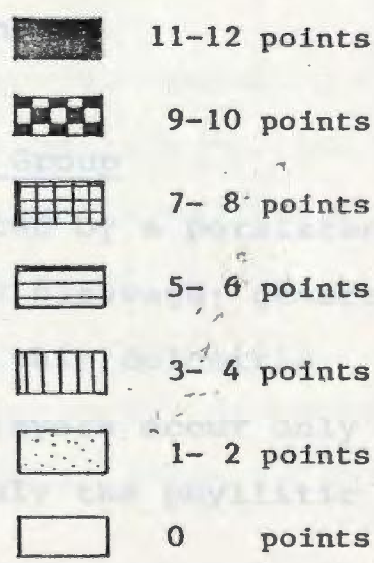


FIGURE-10. 1% contour plot of the poles to the schistosity for the Loon Pond metasediments. (136 points)(⊙=π-pole to the great circle)



Grand Lake, and may represent an axial planar fabric related to an isoclinal folding event. Also noteworthy is the fact that the schistosity is sub-parallel to the gneissosity described earlier for the gneisses in the southeast part of the Long Range Complex.

Aside from the cluster of poles in the northwest quadrant of the plot, a diffuse great circle appears to be present. This circle gives a π-pole (or fold axis) with a trend and plunge of $236^{\circ}/10^{\circ}$. No grouping of minor folds was seen which may be associated with these.

In summary, little can be said about the deformation of the Loon Pond metasediments with the scanty data available. A well developed schistosity parallel to the sub-units is the dominant feature, possibly indicating isoclinal folding with a northeast axis. Open folds with east trending axes form a later deformation, possibly related to faults. No fabric is associated with these. The occurrence of some minor folds, kink bands, and the great circle in figure -10, however, indicate a more complex deformational picture than given here, requiring detailed study of the unit.

III-4 Structures in the Grand Lake Brook Group

The Grand Lake Brook Group is dominated by a persistent northeast striking east dipping phyllitic cleavage; generally axial planar to tight minor folds bending thin dolomitic layers where these occur. The dolomitic layers occur only locally, and in general, the unit shows only the phyllitic cleavage.

A crenulation is commonly present on the cleavage possibly indicating more than one folding event. In one location, a poorly developed phyllitic cleavage occurs sub-parallel to the major one. This cleavage may be related to the crenulation found on the dominant cleavage, and the two features probably represent an event as widespread, but less intense, than that which produced the dominant cleavage. Both are now sub-parallel, and axial planar to, the minor folds.

The minor folds in the bedding are only recognized locally where the dolomitic layers occur. These form tight folds with 1 meter wavelengths and consistent orientations. No other folds were observed within this unit, however, although the two cleavages and crenulation indicate a more complex history.

Figure -11 is a stereoplot of structures within the Grand Lake Brook Group. The few poles to bedding shown (solid dots on the stereoplot) fall on a great circle representing the folds described earlier. The π-pole to the great circle (or fold axis) has a trend and plunge of 025° and 50° respectively. This axis coincides closely with the axes to the observed minor folds in the bedding.

The poorly developed phyllitic cleavage sub-parallel to the major cleavage, and associated crenulations on the major cleavage, indicate a more complex deformational history. The fact that the later cleavage is sub-parallel to the earlier one, and that the crenulations cluster around the minor fold axes on Figure -11, may indicate coaxial deformations. No refolded folds were seen, however, although folds in this

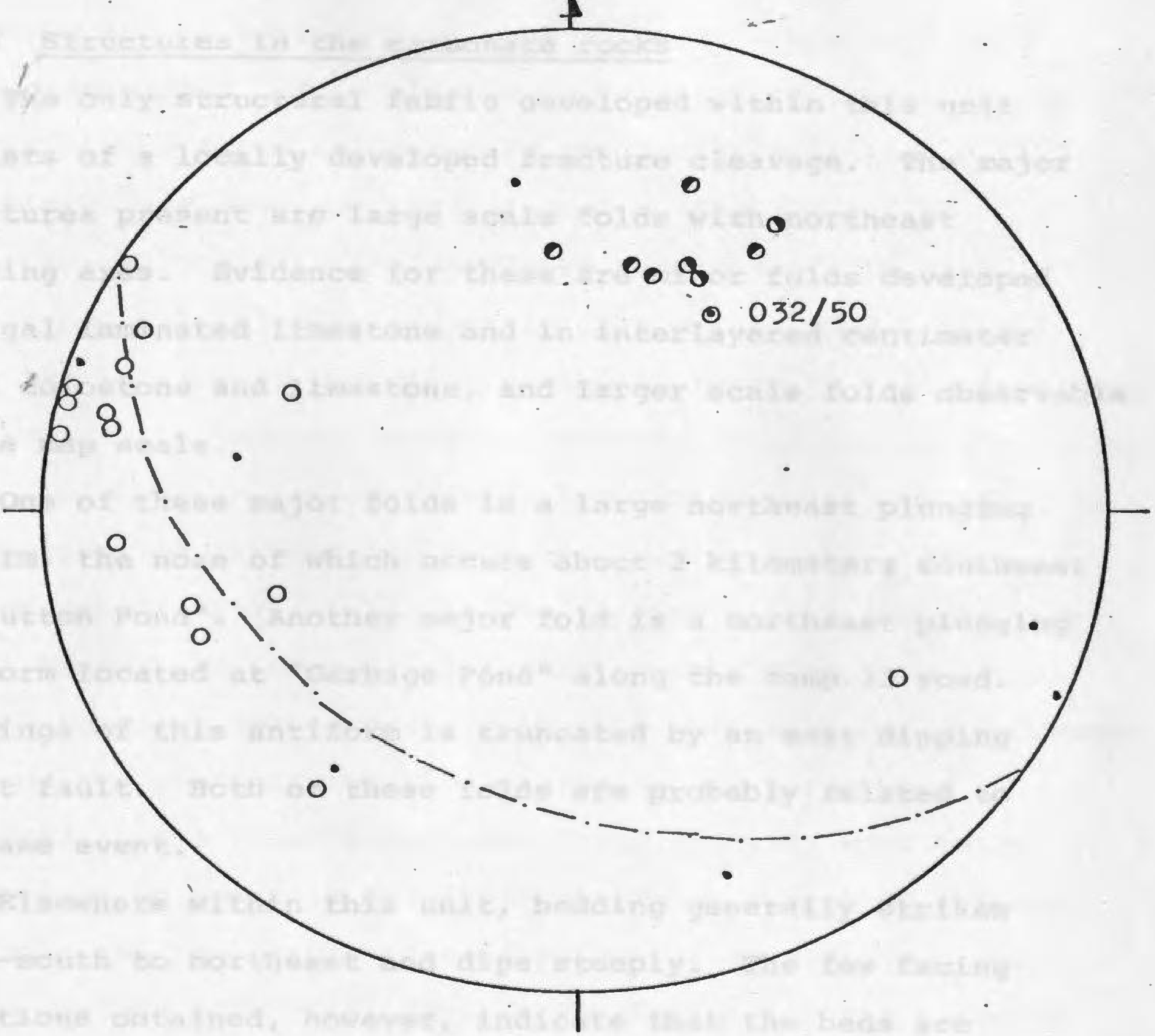


FIGURE-11 . Structural data for the Grand Lake Brook Group.

• poles to bedding

o poles to the phyllitic cleavage

⊘ crenulations(trend and plunge)

◔ minor fold axes(in bedding)

⊙ π-poles to the great circle

unit can only be seen where dolomitic layers occur, and these are rarely present.

III-5 Structures in the carbonate rocks

The only structural fabric developed within this unit consists of a locally developed fracture cleavage. The major structures present are large scale folds with northeast trending axes. Evidence for these are minor folds developed in algal laminated limestone and in interlayered centimeter thick dolostone and limestone, and larger scale folds observable on the map scale.

One of these major folds is a large northeast plunging synform, the nose of which occurs about 2 kilometers southwest of "Button Pond". Another major fold is a northeast plunging antiform located at "Garbage Pond" along the camp 33 road. The hinge of this antiform is truncated by an east dipping thrust fault. Both of these folds are probably related to the same event.

Elsewhere within this unit, bedding generally strikes north-south to northeast and dips steeply. The few facing directions obtained, however, indicate that the beds are tightly folded about north-south to northeast trending axes.

Farther west, along the cliff forming the westward limit of exposure in the map area, a large open synform has an east trending axis. This fold is probably related to a later event, since such an open structure would probably have been obscured by the tight north-south folding if it were related to an earlier event. The open folding could be related to the late, open, east trending folds in the Loon Pond metasediments.

Figure -12 is a stereoplot of structures within this unit. The poles to the bedding fall in a cluster on the west side of the stereoplot. This cluster may reflect the tight north-south trending folds indicated by the facing direction data.

Minor fold axes are also plotted on the stereoplot. These generally lie in the northeast quadrant of the plot, but are not well clustered. It is likely that these minor folds are related to the major northeast trending folds described earlier. It is unknown, however, whether these are related to the tight north-south trending folds indicating heterogeneous deformation, or represent a separate folding event. The lack of penetrative fabrics in the limestone make the deformational history of the unit difficult to determine.

In summary, the structures in this unit must be of Paleozoic age, and are probably roughly related to the structures developed in the Grand Lake Brook Group and Loon Pond metasediments. No specific correlations can be attempted between this unit and the Loon Pond metasediments, however, because of the sketchy structural data on the latter and the presence of the Grand Lake Thrust between them.

The folds observed in the adjacent Grand Lake Brook Group are probably related to the same deformational events as those in the carbonate rocks. The observed difference in scale of the folds may be due to the difference in competence of the two units. If this inference is true then one would

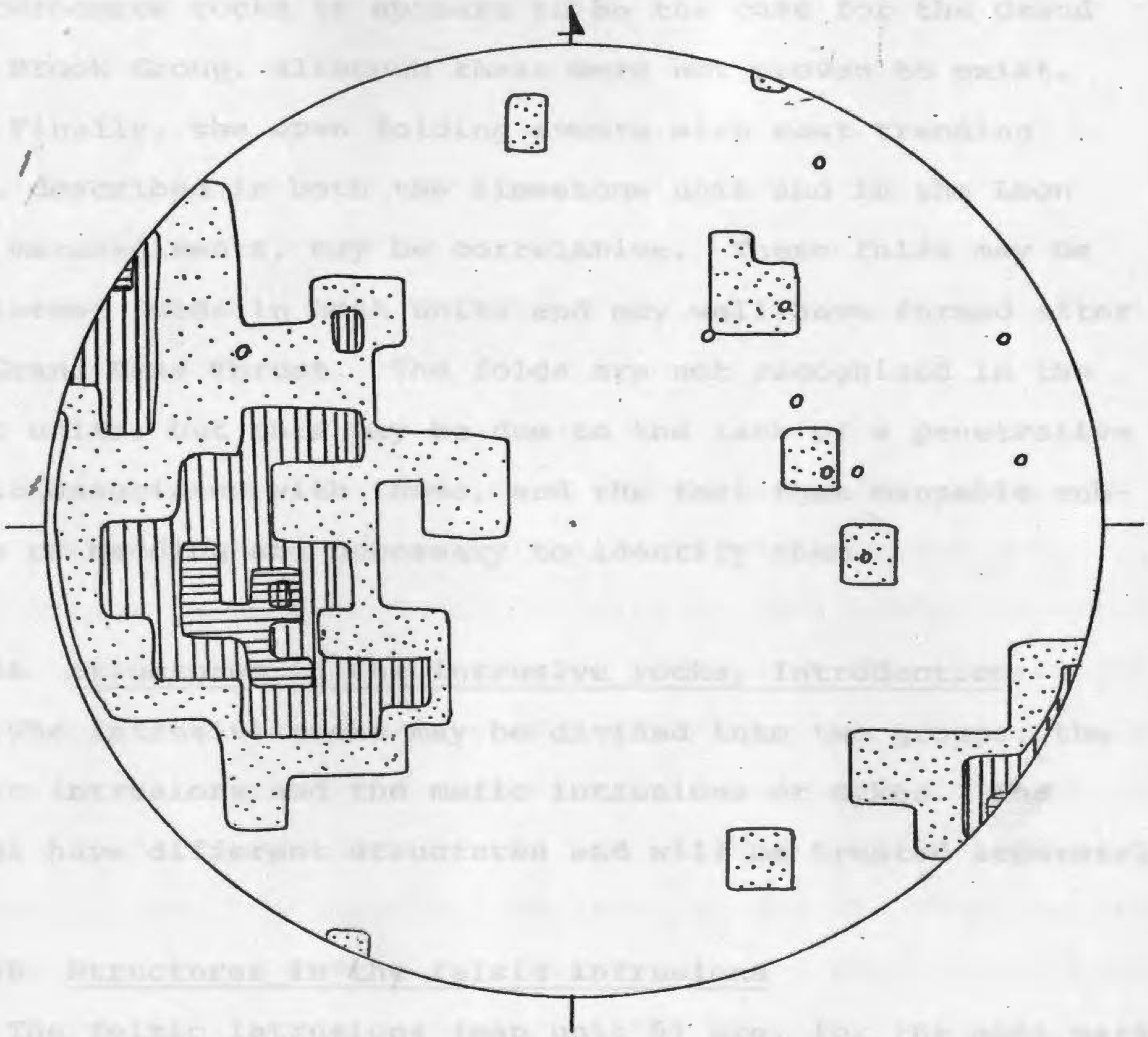


FIGURE-12. 1% contour plot of the poles to the bedding for the carbonate rocks. (81 points) (o = minor fold axes) expect two fold generations with roughly northeast trends in the carbonate rocks as appears to be the case for the Grand Lake Brook Group, although these were not proven to exist.

Finally, the open folding events with east trending axes, described in both the limestone unit and in the Loon Pond metasediments, may be correlative. These folds may be the latest folds in both units and may well have formed after the Grand Lake Thrust. The folds are not recognized in the other units, but this may be due to the lack of a penetrative fabric associated with these, and the fact that mappable sub-units or bedding are necessary to identify them.

III-6A <u>Structures in the intrusive rocks, Introduction</u>

The intrusive rocks may be divided into two groups, the felsic intrusions and the mafic intrusions or dykes. The groups have different structures and will be treated separately.

III-6B <u>Structures in the felsic intrusions</u>

The felsic intrusions (map unit 5) are, for the most part, massive except for localized foliations defined by the orientation of mafic patches. These form bands or are associated with deeply weathered rock (saprolite), and are interpreted as shear zones. The localized foliations occur in varying orientations from northeast to northwest, and may be related to one of the folding episodes, or more likely to the faulting.

III-6C Structures in the mafic intrusions

The mafic intrusions are probably altered diabase dykes. The nature of the foliations in these has been described earlier (foliated biotite in the northwest and foliated hornblende in the southeast) (see section II-6D). The dykes are best exposed along Grand Lake. Here, all are foliated subparallel to their trend, that is, striking northeast and dipping steeply to the southeast.

The dykes, for the most part, appear unfolded. Many are axial planar to, and truncate, the large folds in the gneissosity along Grand Lake described earlier (see plate -18; see section III-2), but some are folded along with the gneissosity. The folds are, here, interpreted as Paleozoic in age since they contain an axial planar foliation of similar grade (amphibolite grade) and orientation as do the Late Precambrian to Early Paleozoic dykes. A possible explanation for the above relationship is that the dykes predate the folds, and that those dykes which were roughly perpendicular to the principal stress orientation were not as intensely deformed as those in other orientations. A similar case of folds developing against dykes has been documented in the Caledonides of Finnmark (Gayer, Powell and Rhodes, 1979).

Mafic gneisses occur along road 185 near "Bear Ridge". These show a mineral lineation, and appear more deformed than those along Grand Lake. In this case, however, the lineation is also present in the granitic gneiss host. These may represent dykes which are older than those along Grand Lake, or more likely represent dykes of the same age in an area of larger finite strain.

III-7 Faulting

The Grand Lake Thrust which juxtaposes basement gneisses with rocks of the carbonate sequence, and high angle block faults separating basement and cover units, form the major faults in the area. Many of the faults are inferred from surface lineaments such as ridges or strings of oriented ponds and bogs, since the fault planes are rarely exposed. The lack of marker units within the fault blocks makes movement directions difficult to estimate. Nevertheless four groupings are observed and discussed separately.

Probably the earliest fault recognized in the area is the Grand Lake Thrust (see map). The fault is truncated at both ends by high angle northeast trending faults. The fault is nowhere exposed, but in a few places such as the south tip of "Button Pond", and between this Pond and "Boundary Pond", exposures of granitic gneisses and grey limestone may be seen as close as 30 meters apart. The fault has been interpreted as a thrust, in the north (Kennedy, 1978), and this interpretation seems reasonable for the map area as well. The metamorphic contrast from slightly recrystallized grey limestone (west) to greenschist facies mylonitic granitic gneisses (east) indicates a considerable displacement, typical of thrusting.

A later group of faults has north-northwest trends. One of these is exposed at the northeast tip of the Hare Hill granite (map unit 5a), where it dips vertically. The straight outline of these faults throughout the map area confirms a steep dip for these. Along road 185 near "Bear Ridge", and along the west flank of "Disappointment Hill", the faults appear sub-parallel to the mylonitic foliations of the host. If these textures are related to the faulting, the faults may be of similar age and origin to the Grand Lake Thrust. The straight trend of these faults, however, and the fact that they cut all map units including the carbonate sequence, indicates that they are probably unrelated to the mylonitic fabric near these, or represent in part reactivated older faults.

A third group of faults, which offsets the Grand Lake Thrust in the map area, trends to the northeast. These also have straight outlines indicating steep dips, and are exposed along Grand Lake where they have dips of 70 to 80 degrees to the east. The faults form the contacts between the rocks of the Long Range Complex and those of the Loon Pond metasediments. The "Goose Hill" granite breccia is a fault breccia produced by one of these faults.

Some of the sub-units within the Loon Pond metasediments have fault contacts which trend northeast. These faults, however, may be older and could represent bedding plane faults related to Paleozoic folding in these (described earlier).

The northeast faults are definitely younger than the Grand Lake Thrust since they offset it, and are probably responsible for the offset of the carbonate sequence in the southwest of the map area. If this is so, these faults contain a substantial right lateral strike-slip component of displacement.

Finally, a set of northwest and southwest trending faults occurs in the Loon Pond metasediments. These may be related to the folds with east trending fold axes as stated earlier (E. Stander, pers. comm., 1979). The faults were not recognized within the Long Range Complex, and so are probably cut by the northeast set of faults (which form the boundary with the gneisses), and, therefore, are older than these.

III-8 Structural synthesis

The faulting between rock units and the diffenent competence of these in response to stress makes a detailed correlation of structures between units, difficult. A general synthesis is attempted here, however, along with a possible evolving model explaining the generation of these structures.

The earliest structure occurring in the map area is the gneissosity developed in the Long Rang Complex. The variations in orientation and associated texture of the gneissosity, especially in the northwestern part of the complex where the basement is apparently least affected by (least remobilized) Paleozoic deformation (see section III-2), indicates a polyphase history of deformation is likely for these gneisses. This gneissosity is locally associated with relict granulite facies mineral assemblages (at "Disappointment Hill") not developed in the cover units which were involved in Paleozoic deformation only, and is most likely a Grenvillian feature. Most of the subsequent structures are related to the Late Precambrian to Early Paleozoic evolution of the area.

In the Long Range Complex, evidence of Paleozoic deformtion is found in the post Grenvillian mafic dykes (see section II-2A) which are folded in places, and which generally contain a foliation produced by an amphibolite facies mineral assemblage. These features are best developed in the southeast part of the complex, indicating stronger Paleozoic influence there. A late amphibolite facies mineral assemblage, defining a fabric which is axial planar to the folds in the gneissosity on Grand Lake, occurs in the gneisses and is interpreted as a Paleozoic feature. The presence of these folds may explain the observed southeastward increase in clustering of the poles to the gneissosity on the stereoplots (figures 7, 8 and 9) as reflecting increasing remobilization of the basement gneisses to the southeast by folding.

Little is known of the deformation of the Loon Pond metasediments. The dominant fabric is a schistosity sub-parallel to the northeast striking east dipping lithic sub-units, possibly related to isoclinal folding. Kink bands, crenulations, and minor fold axes indicate a more complex deformational history, however.

The orientation of the dominant schistosity, associated with upper greenschist to lower amphibolite facies mineral assemblages, parallels the late foliation with associated amphibolite facies mineral assemblages in the gneisses, possibly indicating that these fabrics are related. It should be remembered that the units are in fault contact, however, and perhaps a safer statement is that both are Paleozoic features. The northeast trending high angle faults between sub-units in the Loon Pond metasediments may be related to this folding event, and may represent bedding plane faults developed during the folding.

West of the Grand Lake Thrust, the Grand Lake Brook Group and carbonate rocks were also deformed by Paleozoic events. The units may show up to two, now coaxial (see section III-4), folding events. These have northeast trending axes, as is the case for the Paleozoic structures described above for the Long Range Complex and the Loon Pond metasediments. The structures in these units, however, are associated with lower grade assemblages. In the case of the Grand Lake Brook Group, the deformation produced minor folds with related lower greenschist grade phyllitic cleavage. In the limestones, large scale folds were produced with a locally developed fracture cleavage.

The contrast in metamorphism associated with these folding events across the Grand Lake Thrust, indicates that this feature is younger than the deformations. The relative age of the Grand Lake Thrust may further be bracketed by the fact that it is offset by the high angle block faults (see map), indicating that it is older than these. The fault may well be a late feature associated with the folding events described above.

The felsic intrusions show igneous textures with greenschist facies alteration, but no evidence of higher grade metamorphism. This appears to indicate that the bodies postdate the deformation. The massive nature of the bodies further supports this assumption.

Undeformed unaltered dykes, associated with these bodies, occur commonly within the host granitic gneisses, but no igneous phases are present on the west side of the Grand Lake Thrust despite the fact that the Hare Hill granite occurs as close as ½ kilometer from the fault. This appears to indicate that the felsic intrusions pre-date the Grand Lake Thrust.

The large scale open folds with east trending axes and no associated fabric, described in the Loon Pond metasediments (east) and in the carbonate rocks (west), form the latest folding event(s). The folds bend the schistosity in the Loon Pond metasediments, indicating that they are later features. The folds are probably related to minor faults within this unit which are truncated by the northeast trending faults, indicating that the folds are older than the northeast trending faults. The open folds with east trending axes in the carbonate rocks probably also form the latest event there (see section III-5), and may be related to those in the Loon Pond metasediments. If this is so, the folds may well post-date the Grand Lake Thrust since they occur on both sides. The lack of these folds in the other units, if they are indeed related and postdate the thrust, may be due to higher competency in the case of the crystalline rocks, or to the lack of traceable sub-units necessary to show the folding (since no related fabric occurs) in the case of the Grand Lake Brook Group. In any case, these folds are of minor importance only.

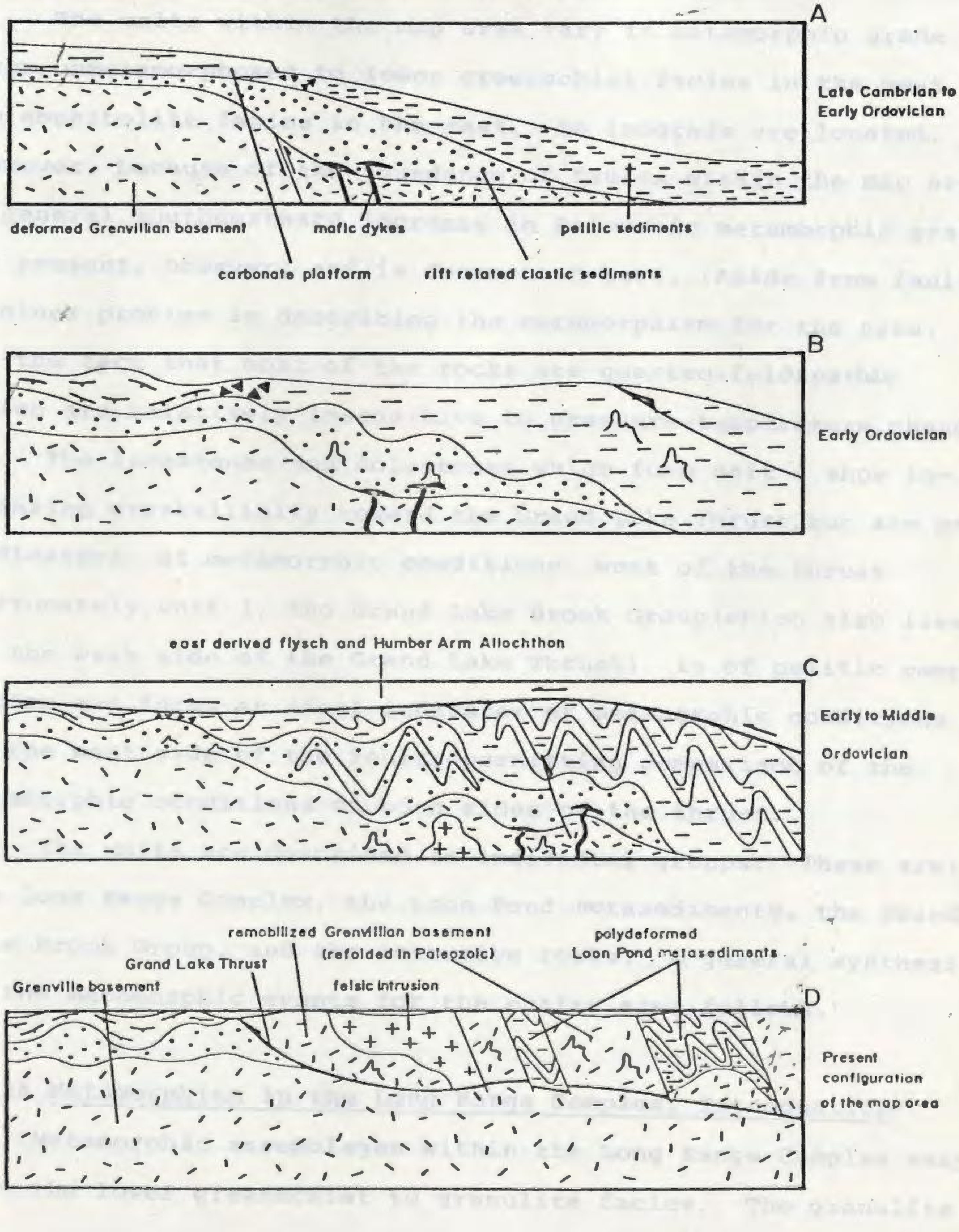
The latest deformational event of the area is the high angle block faulting since these faults cut all units and are unfolded. The relative ages of the north-northwest and north-east trending faults are a problem, however. All are unfolded and most do not appear offset where they cross. The steeper west flank of most ridges in the map area (described earlier) is probably caused by the high angle faulting.

The lithologies and deformation present within the study area can be related to the present model for the evolution of the ancient continental margin of North America (Williams, 1979). In terms of this model; the Long Range Complex may represent the ancient craton (last deformed during the Grenville event), the Loon Pond metasediments and mafic dykes may represent rift related clastic cover sediments and rift related dykes respectively, and the carbonate sequence may represent part of a carbonate platform which developed later along the rifted margin. An idealized cross-section of the ancient continental margin prior to its destruction is shown in figure -13A.

Most of the deformation in the cover units and in the eastern Long Range Complex may be attributed to the Paleozoic destruction of this continental margin. This deformational event is commonly referred to as the Taconic Orogeny, a polyphase event of Early to Middle Ordovician age (Williams, 1979). Figure -13B and C show progressive deformation of the margin during this event.

The area was further deformed by the Acadian Orogeny of Devonian age (William, 1979). In the study area, Taconic and Acadian structures are difficult to distinguish since no dated Late Ordovician or Devonian rocks occur. The felsic intrusions and the later Grand Lake Thrust may be late Taconic or Acadian features, indicating that much of the Paleozoic deformation which was described as earlier than the intrusions is Taconic in origin. Figure -13D is a schematic cross section of the study area showing the present configuration of the units after deformation.

FIGURE-13. Evolving model for the deformation of the ancient continental margin to it's present configuration, as seen in the map area.



IV METAMORPHIC GEOLOGY

IV-1 Introduction

The units within the map area vary in metamorphic grade from unmetamorphosed to lower greenschist facies in the west, to amphibolite facies in the east. No isograds are located, however, because of the abundance of faults within the map area. A general southeastward increase in Paleozoic metamorphic grade is present, however, and is documented here. Aside from faulting, another problem in describing the metamorphism for the area, is the fact that most of the rocks are quartzo-feldspathic which are relatively insensitive to pressure-temperature changes.

The limestones and dolostones which form unit 4 show increasing crystallinity toward the Grand Lake Thrust, but are poor indicators of metamorphic conditions west of the thrust. Fortunately, unit 3, the Grand Lake Brook Group (which also lies on the west side of the Grand Lake Thrust) is of pelitic composition and forms an ideal indicator of metamorphic conditions on the west side of the fault, permitting comparison of the metamorphic conditions on both sides of the thrust.

The units are described in individual groups. These are: the Long Range Complex, the Loon Pond metasediments, the Grand Lake Brook Group, and the intrusive rocks. A general synthesis of the metamorphic events for the entire area follows.

IV-2A Metamorphism in the Long Range Complex, Introduction

Metamorphic assemblages within the Long Range Complex vary from the lower greenschist to granulite facies. The granulite facies mineral assemblages occur locally as relict assemblages, now partially retrogressed by a later event producing greenschist facies mineral assemblages in the west, and amphibolite facies mineral assemblages in the east. Evidence of possibly another later retrogressive event is widespread.

The general variation in metamorphic assemblages, from greenschist facies mineral assemblages (retrogressed from higher grades) in the northwest, to amphibolite facies mineral assemblages (overprinting an older assemblage) in the southeast, has lead to the separation of the complex into two domains, the northwest and southeast domains. The boundary between these is an arbitrarily chosen roughly northeast trending line through "Bear Ridge" (see figure -14), coinciding roughly with the structural subdivisions and lithological change from granitic gneisses to hornblende-plagioclase gneisses.

IV-2B Northwest domain

The rocks of the northwest domain are dominantly of greenschist facies, but locally show evidence of retrogression from higher grade. Evidence for this earlier higher grade metamorphism is a commonly occurring relict texture generally consisting of an early mineral segregation where the micas which form the mafic rich bands are unoriented or oriented at an oblique angle to these mafic bands, indicating that they are (the micas, biotite and muscovite) probably alteration products developed after the mineral segregation. The feldspars, occurring (with quartz) in the felsic rich bands or as

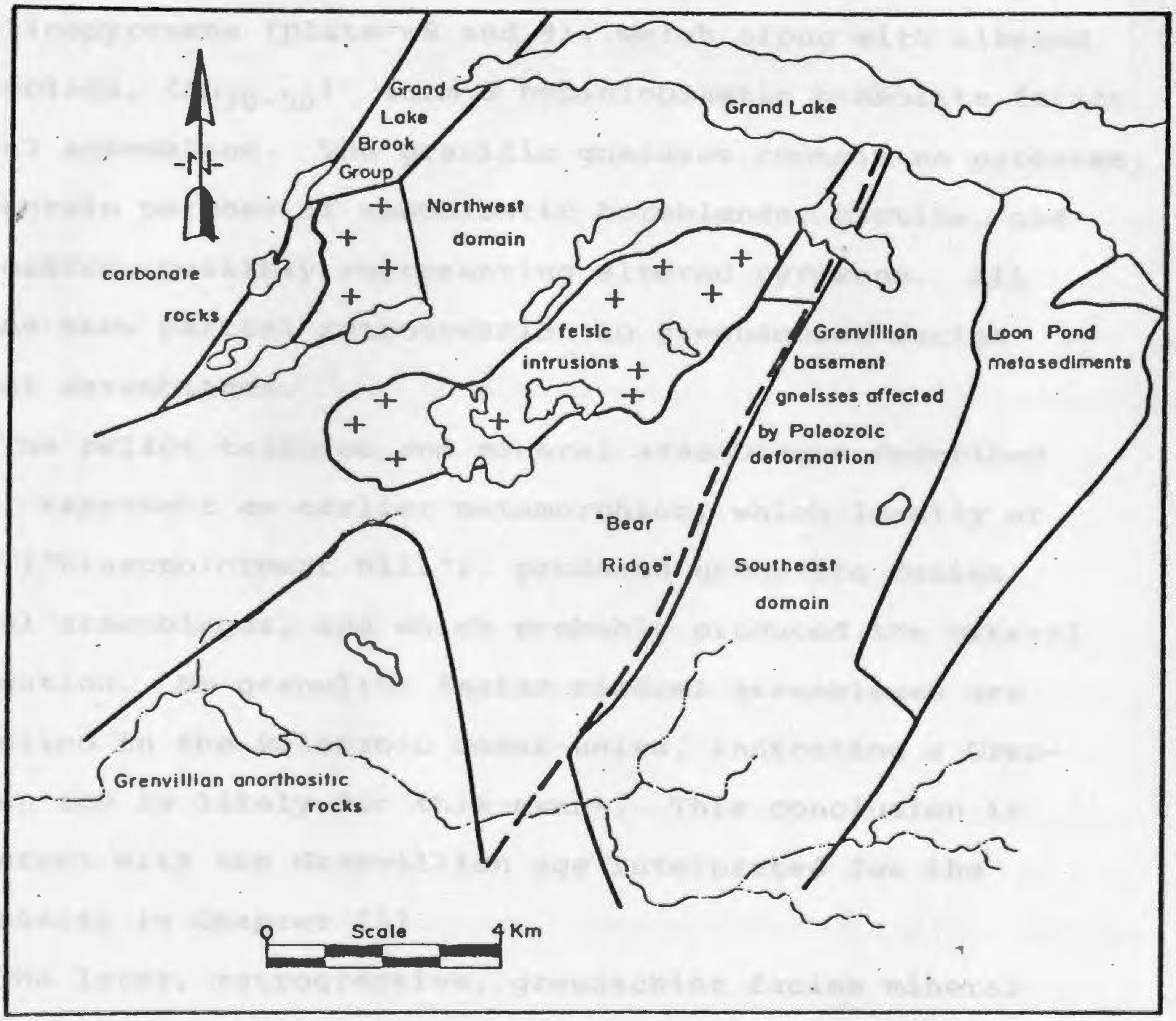


FIGURE-14. Sketch map of the study area showing the northwest and southeast domain of the Long Range Complex.

augen, locally show albite rims or alteration to sericite or epidote minerals.

Relict granulite facies mineral assemblages occur at "Disappointment Hill" in granoblastic gabbroic to granite gneisses, providing further evidence for an earlier metamorphic event. The gabbroic gneisses contain both orthopyroxene and clinopyroxene (plate 8 and 9), which along with altered plagioclase, (An_{30-50}) form a hypidioblastic granulite facies mineral assemblage. The granitic gneisses contain no pyroxene, but contain patches of xenoblastic hornblende, biotite, and iron oxides, possibly representing altered pyroxene. All samples show partial retrogression to greenschist facies mineral assemblages.

The relict textures and mineral assemblages described above represent an earlier metamorphism, which locally at least ("Disappointment Hill"), produced granulite facies mineral assemblages, and which probably produced the mineral segregation. No granulite facies mineral assemblages are recognized in the Paleozoic cover units, indicating a Grenvillian age is likely for this event. This conclusion is consistent with the Grenvillian age interpreted for the gneissosity in Chapter III.

The later, retrogressive, greenschist facies mineral assemblages in this domain, consist of epidote and/or clinozoisite, biotite, muscovite or sericite, and quartz. Albite, calcite, and garnet occur locally.

Epidote and clinozoisite commonly form inclusions in altered plagioclase (An_{30-50}) grains. Locally they occur as discrete small grains around plagioclase or in mafic rich patches. Biotite forms patches of small lath shaped grains. It is commonly pleochroic in shades of brown, more rarely green, and associated with irregular shaped grains of iron oxide. In most cases the biotite patches are elongate parallel to the gneissosity, although the individual biotite grains are commonly oriented at an oblique angle to it(gneissosity). Muscovite forms small inclusions in plagioclase, or may form discrete lath shaped grains within biotite patches where it commonly has the same orientation as biotite. The quartz forms small grains around larger relict quartz or plagioclase, and albite forms fresh rims or discrete grains around the relict plagioclase(An_{30-50}). Finally, calcite tends to form interstitial grains between altered plagioclase, and garnet forms small broken masses within biotite patches.

The middle greenschist facies mineral assemblages are widespread, and interpreted as later(possibly Paleozoic), partial to complete retrogression of the earlier Grenvillian metamorphism. The oriented biotite and muscovite grains which form part of the assemblage, indicate a dynamothermal event as was the case for the earlier assemblage. These oriented phases occur in mafic rich patches or layers probably representing totally retrogressed earlier mafic phases related to the earlier Grenvillian event. In the relict felsic layers, albite rims and epidote and muscovite inclusions formed in the earlier plagioclase. Discrete albite, calcite, quartz and epidote grains also formed around the relict quartz and feldspar.

The gneisses of the northwest domain show evidence of further partial retrogression from the biotite and garnet zone greenschist facies mineral assemblages described above, to a chlorite grade alteration. Evidence for this is the widespread occurrence of chlorite rims around biotite, and of chlorite patches. The green pleochroic biotite described above may be related to this event as well. No foliation is associated with these minerals, and they may represent a further stage in the same retrogression, or a separate event.

The calc-silicate unit (map unit 1c) and the north block of the anorthositic rock unit (map unit 1d) also show greenschist facies mineral assemblages. In the case of the calc-silicates, the assemblage observed is calcite, tremolite, and biotite. The tremolite and biotite may or may not define a foliation. The latest sub-biotite zone partial retrogression, described in the gneisses, may also be present in the calc-silicates as chlorite forming on tremolite grains.

In the case of the northern block of the anorthositic rock unit, the assemblage noted is epidote, clinozoisite, albite, calcite, and muscovite. Once again the latest partial retrogression may be present as chlorite on or next to the mafic phases.

IV-2C <u>Southeast domain</u>

The rocks of the southeast domain show dominantly amphibolite facies mineral assemblages with later partial retrogression to greenschist facies mineral assemblages. The amphibolite facies mineral assemblages form a fabric related to the Paleozoic folds described earlier, indicating that the metamorphism is Paleozoic in age. Similar grade mineral assemblages are developed in the Late Precambrian to Early Paleozoic mafic dykes, supporting this conclusion as well.

Evidence of an earlier relict Grenvillian event, here (southeast domain), is rare, probably because of the masking effect of the more intense Paleozoic metamorphism in this domain. Some evidence of an older relict assemblage, possibly of Grenvillian age, does occur locally, however, as altered plagioclase porphyroclasts and irregular shaped altered hornblende containing abundant needle-like iron oxide inclusions. No evidence of granulites were found in this domain.

The later (Paleozoic) amphibolite facies mineral assemblages consists of plagioclase (An_{30-40}), hornblende, quartz, and biotite. Garnet occurs locally. This metamorphic event may be related to the greenschist facies event described above for the northwest domain, indicating a northwestward decrease in intensity for this event. This correlation is supported by the east to west decrease in metamorphic grade of the assemblages developed in the mafic dykes described earlier.

The plagioclase and quartz form hypidioblastic grains. The plagioclase grains are commonly larger than the quartz grains, and in places, an augen texture with large plagioclase augen is developed. Hornblende is pleochroic in shades of green, and in most places oriented parallel to the foliation. It (hornblende) is commonly associated with grains of brown, pleochroic biotite, which have the same orientation as the hornblende. In some places, two hornblende generations occur. One of these, the latest, is fresh, idioblastic and defines a foliation, while the other has irregular grain outlines and contains what appear to be exsolved, very fine, iron oxide grains in the crystal cores (plate -13). This earlier altered hornblende is interpreted as evidence of an early, possibly Grenvillian, metamorphic event. The later foliated hornblende is related to the Paleozoic amphibolite facies metamorphic event. Garnet, where it occurs, forms idioblastic grains to fractured masses.

The later partial retrogression to greenschist facies mineral assemblages is developed in all samples observed. The assemblage produced by this metamorphism consists of epidote and/or clinozoisite, biotite, muscovite, and calcite.

Epidote, clinozoisite, and to a lesser extent muscovite, occur most commonly as inclusions in the hypidioblastic plagioclase grains. All may also occur, locally, as discrete grains, and in one location, the epidote is oriented parallel to a foliation defined by oriented biotite and muscovite lath shaped grains. Calcite occurs near plagioclase, and is most likely a product of the alteration of plagioclase. Finally, biotite forms brown, pleochroic grains. These are oriented such that they define a foliation, and in places, biotite rims hornblende as an alteration product.

The fact that some biotite rims hornblende may indicate that the greenschist facies mineral assemblage was indeed produced by a later metamorphism than that which produced the amphibolite facies assemblages. This metamorphism may be equivalent to the greenschist facies metamorphism occurring in the northwest domain, or more likely the event produced little retrogression in the northwest since the earlier assemblage there (possibly equivalent or older than the amphibolite facies mineral assemblages in the southeast) was already of greenschist facies. A new metamorphic event may, therefore, be represented here.

Finally (as in the case of the northwest domain) a late greenschist facies retrogression may be indicated by the formation of chlorite patches on some biotite and hornblende grains and the formation of 2 millimeter large, decussate biotite porphyroblasts.

IV-3 Metamorphism in the Loon Pond Metasediments

Most of the data on the metamorphism of this unit is based on observation of the section exposed on the south shore of Grand Lake. Consequently no detailed account can be given here.

The Loon Pond metasediments were metamorphosed to the upper greenschist to lower amphibolite facies. Evidence of a later partial retrogression of the mafic phases to chlorite is present, as is the case for the Long Range Complex.

Assemblages noted are: calcite, quartz, biotite, and muscovite for the calcarious sub-unit 2a in the west, and quartz, biotite, muscovite, garnet and an amphibole in the semi-pelitic to psammitic sub-unit 2d in the east. In the first case (in the west) all minerals are oriented such that they define a foliation. In the second case (in the east) biotite, muscovite, and the amphibole are oriented such that they define a foliation, but quartz and garnet have equant shapes and are porphyroclastic. Porphyroblastic garnets occur within similar rocks north of Grand Lake, but in this case are affected by a later crenulation cleavage which is associated with partial retrogression to form chlorite (D. Kennedy, pers. comm., 1979). The amphiboles in the study area are locally pseudomorphed by chlorite, supporting this observation as well.

Evidence of higher grade assemblages occurs along Grand Lake within sub-unit 2d, where a kyanite grade assemblage is developed (D. Knapp, pers comm., 1979) containing kyanite, garnet, biotite, muscovite, and albite. The biotite and muscovite define a foliation which is overprinted by biotite, kyanite, albite, and garnet porphyroblasts. Here again, the garnet grains contain chlorite alteration in their cores, indicating a later retrogression.

It appears, therefore, that the Loon Pond metasediments were affected by a prograde metamorphic event, producing both foliated micas and porphyroblastic garnet, kyanite, albite and biotite. This event may be, related to the amphibolite facies metamorphic event developed in the southeast domain of the Long Range Complex (described in section IV-2C).

Evidence of a later retrogression to the lower greenschist facies, associated with a deformation (crenulation cleavage), occurs as well. This may be equivalent to the greenschist facies metamorphic event occurring in the southeast domain in the Long Range Complex (see section IV-2C).

IV-4 Metamorphism in the Grand Lake Brook Group

The unit is, everywhere, composed of black phyllite with locally occurring thin calcareous layers. No porphyroblasts or relict higher grade minerals occur, and the unit unlike the Long Range Complex west of the thrust, was probably never subjected to higher grade than the chlorite zone of the greenschist metamorphic facies. This observation is substantiated by the adjacent limestones of map unit 4 which show only minor recrystallization to sparite, and in a few places marble beds. A drop in metamorphic grade is, therefore, indicated across the Grand Lake Thrust, from sub-biotite grade on the west side, in the Grand Lake Brook Group, to middle greenschist facies mineral assemblages within the granitic gneisses.

IV-5A Metamorphism in the Intrusive rocks, Introduction

As in the section on structure, the intrusive rocks are separated into felsic and mafic intrusions. The felsic intrusions are considered first.

IV-5B Felsic intrusions

The felsic intrusions, which include the Hare Hill and "Goose Hill" granites(map units 5a and 5b), the "Tulk's Pond" syenite(map unit 5c), and their related dykes, are generally massive with localized foliations related to shear zones. The textures are, in most cases, igneous, but show partial alteration to greenschist facies mineral assemblages.

The assemblages developed consists of muscovite, calcite, biotite, and epidote. Muscovite and biotite form randomly oriented lath shaped grains occurring in patches which also contain iron oxide, commonly rimmed by sphene. Epidote occurs as inclusions in feldspar grains which appear slightly fractured in places. Calcite occurs in the mafic rich patches where magmatic amphibole (hastingsite) is altered and rimmed by biotite. Quartz shows undulose extinction, and this along with the slightly fractured feldspar, indicates some straining (possibly triggering the alteration).

The alteration in the felsic intrusions could be late magmatic or equivalent to any greenschist facies metamorphic event which post-dates its emplacement, if any occurred. The absence of relict granulite facies assemblages and lack of penetrative deformational fabrics, however, seem to indicate the emplacement and subsequent alteration of these intrusions post-dates the Grenvillian granulite facies metamorphic event described earlier (see section IV-2A).

A later partial retrogression occurs, forming chlorite rims and patches on biotite. This retrogression may represent a further stage in the same retrogression or be correlative with a possible late retrogression developed within the Long Range Complex (see section IV-2B, C).

IV-5C <u>Mafic intrusions</u>

The mafic intrustions consist of the mafic dykes exhibiting a northwest to southeast variation in textures, described earlier (see section II-6B).

In the northwest, the dykes show disequilibrium altered textures, making it difficult to prove the nature (igneous or metamorphic) of the earliest assemblages consisting of altered plagioclase and hornblende. The plagioclase (An_{40-60}) grains generally have irregular shapes, contain epidote or clinozoisite inclusions, or may be sericitized at the grain cores. Albite rims or calcite filling interstices around plagioclase grains may be developed. The hornblende grains generally have irregular shapes and highly corroded cores. The shape of these grains makes it difficult to determine if these once defined a foliation. The grains, in most cases however, contain fresh hornblende rims definitely indicative of a later metamorphic recrystallization (plate -15).

Two generations of biotite occur. The earlier of these consists of brown, pleochroic grains which define a foliation, and are probably associated with the hornblende rims. These are altered to chlorite in places. The later generation consists of green, pleochroic, decussate biotite. These are commonly sagenitic (contain exsolved rutile needles).

These post Grenvillian dykes, therefore, contain evidence of possibly two metamorphic events of Paleozoic age. This involves the retrogression (late magmatic or metamorphic) of a plagioclase and hornblende assemblage, followed by a period of hornblende growth (fresh hornblende rims). The earlier (foliated) biotite generation, and the albite rims may be related to this metamorphic event. This was followed by partial retrogression producing decussate biotite and chlorite grains, and possibly epidote and clinozoisite inclusions in plagioclase(although these may have been produced during the event which altered the earliest assemblage).

In the southeast, the dykes contain the same primary assemblage as do those in the northwest. The plagioclase grains show the same general features as those described above, but two generations of hornblende are present. The earlier hornblende is corroded and is xenoblastic. These hornblende grains are equated with the rimmed hornblende in the northwest, although in this case, no fresh rims are developed. The later generation of hornblende consists of fresh idioblastic grains which define a foliation(plate -16). These are correlated with the hornblende rims and foliated biotite in the dykes to the northwest.

Biotite in the dykes to the southeast, consists of sagenitic, descussate, lath shaped grains which are pleochroic in shades of brown. Chlorite, here is developed on some hornblende grains as is the case in the dykes to the northwest. The biotite and chlorite may be correlative with the later biotite and chlorite in the dykes to the northwest.

It appears, therefore, that both northwest and southeast type dykes have a similar history. This involves the partial retrogression of the early assemblage of plagioclase and hornblende, followed by a metamorphic event producing foliated hornblende in the southeast and foliated biotite grains and hornblende rims in the northwest. The observed difference in phases from southeast to northwest indicates that this metamorphic event was more intense in the southeast.

The origin of the epidote, clinozoisite, calcite and sericite, associated with the plagioclase is unknown. They may have formed from the plagioclase during the alteration of the earliest assemblage (igneous or metamorphic), or during a later partial retrogression. However, since a similar grade assemblage occurs within the host hornblende-plagioclase gneisses in the southeast of the map area, where it is shown to post-date an amphibolite facies mineral assemblages (see section IV-2), it is likely that the greenschist facies mineral assemblage in the dykes, similarly, post-dates the latest hornblende generation in these (dykes).

These events were followed by a late partial retrogression which produced decussate sagenitic biotite and chlorite patches in both sets of dykes. This retrogression could be related to a possible late retrograde event noted in the Long Range Complex (see section IV-2B, C).

IV-6 Metamorphic synthesis

A possible metamorphic history for the study area and the relation of this to its structural history is given here. This data is summarized in figure -15, which gives possible ages and evidence for these metamorphic events.

The oldest metamorphic event recognized in the area is that which produced the relict augen texture and mineral segregation in the gneisses of the northwest domain (see section IV-2). Associated with this metamorphic event are the granulites at "Disappointment Hill", and possibly the oldest plagioclase-hornblende assemblage found in the southeast domain gneisses. This metamorphic event (M1) is probably a Grenvillian feature related to the development of the gneissosity in the gneisses

	Long Range Complex		Loon Pond Metasediments	mafic dykes		Grand Lake Brook Group	felsic intrusions
	Southeast domain	Northwest domain		in southeast of area	in northwest of area		
M4?(late M3) Paleozoic	1) chlorite patches 2) decussate biotite porphyroblasts	1) retrograde chlorite patches 2) green (pleochroic) biotite	1) chlorite alteration on garnet	1) chlorite patches 2) sagenitic decussate brown biotite	1) chlorite patches 2) sagenitic green decussate biotite		1) chlorite rims and patches on biotite?
M3(Acadian?) Paleozoic	1) epidote, calcite and clinozoisite on or around plagioclase 2) poorly foliated biotite muscovite and epidote in mafic patches		1) crenulation with associated chlorite grade alteration	1) sericite on plagioclase 2) epidote calcite and clinozoisite in and around plagioclase and in mafic rich patches	1) sericite on plagioclase 2) epidote and clinozoisite in plagioclase and in mafic rich patches		1) zoned quartz and fractured feldspar? 2) muscovite biotite epidote and calcite in patches around hastingsite?
M2(Taconic?) Paleozoic	1) foliated plagioclase quartz hornblende and biotite assemblage	1) epidote albite quartz calcite and clinozoisite on and around plagioclase 2) foliated biotite and muscovite in elongate patches	1) upper greenschist to lower amphibolite assemblages (depending on protolith) locally kyanite grade	1) foliated plagioclase and hornblende assemblage	1) hornblende rims on older hornblende 2) albite rims on plagioclase 3) foliated biotite	1) chlorite grade phyllitic cleavage	
M1(Grenvillian) Precambrian	1) relict plagioclase and hornblende (with iron oxide inclusions) assemblage	1) relict augen and mineral segregation textures 2) granulites at "Disappointment Hill"					

FIGURE-15. Metamorphic events recognized and the possible effects of these within the different units.

of the Long Range Complex, and is restricted to the basement gneisses.

Post-dating the Grenvillian (M1) event is a middle greenschist (west) to amphibolite facies (east) metamorphic event. Assemblages related to this metamorphic event (M2) may be developed in all units except those to the west of the Grand Lake Thrust, where a drop in metamorphic grade makes correlation difficult.

Within the mafic dykes, the event produced oriented hornblende and biotite grains in the southeast, and oriented biotite grains in the northwest, indicating that this metamorphic event decreases in intensity to the northwest (see section IV-5). The upper greenschist to lower amphibolite facies assemblages (locally up to hyanite grade) related to the dominant schistosity noted in the Loon Pond metasediments (see section IV-3) may be related to this event further supporting the postulated southeastward increase in intensity for this metamorphic event.

Within the southeast domain gneisses, the metamorphic event produced oriented hornblende grains and hypidioblastic garnet grains. These oriented hornblende grains occur parallel to the gneissosity (which strikes northeast and dips to the southeast) within this domain, and are probably related to the earliest Paleozoic folding event with northeast trending fold axes (described in section III-8).

Within the northwest domain gneisses, however, this metamorphic event is more difficult to recognize, since no amphibolite facies mineral assemblages are produced. It is possible that this metamorphic event decreases rapidly in intensity, and has produced the greenschist facies mineral assemblage noted here. Another possiblility is that the greenschist facies mineral assemblages here, represent a Grenvillian feature, and that the later Paleozoic event produced only minor effects on these gneisses. This is supported by the fact that the northeast striking foliation related to this metamorphic event in the southeast domain, is only mildly developed in the gneisses of the northwest domain.

The chlorite zone greenschist facies metamorphism in the Grand Lake Brook Group could in part be related to this event, since the group does contain Paleozoic folding with an associated phyllitic cleavage. This assumption is reasonable considering the postulated decrease in intensity of metamorphism, and the possible telescoping produced by the Grand Lake Thrust.

Yet another metamorphic event (M3) may be responsible for the partial retrogression of the amphibolite facies mineral assemblages to middle greenschist facies mineral assemblages. Evidence for this consists of muscovite, biotite, calcite, epidote and clinozoisite assemblages in the Long Range Complex units. The chlorite alteration associated with a crenulation cleavage described in the Loon Pond metasediments could also be related to this event. Evidence that the event is indeed retrograde is the fact that the biotite rims earlier hornblende grains, and that epidote minerals and calcite are developed in and around altered plagioclase grains in the southeast domain gneisses. In the northwest domain gneisses, the effects of this event are difficult to estimate since the gneisses may have already contained greenschist facies mineral assemblages (the M1 metamorphic assemblages may have been retrogressed by M2 or even earlier during Grenvillian times).

The assemblage produced by this retrograde metamorphic event rarely defines a foliation, except locally in the hornblende-plagioclase gneisses where biotite defines a foliation which is axial planar to the earlier folded gneissosity (see section IV-2). The folded gneissosity in these cases forms northeast trending minor folds, possibly related to the major (Paleozoic) northeast trending upright folds (described in section III-2).

Finally, the partial retrogression of the mafic phases of most units to chlorite, and the formation of decussate biotite grains and prophyroblasts, may be related and may represent the latest metamorphic event in the area (M4) (although it is possible that these are all features of a further retrogressive stage of the earlier event (M3)). No foliation is associated with this metamorphic event. The chlorite rims are recognized in all units except those to the west of the Grand Lake Thrust, which are never higher in grade than the chlorite zone of the greenschist facies. The decussate biotite occurs mainly in the southeastern part of the area, where it occurs in the hornblende-plagioclase gneisses as porphyroblasts, and in the mafic dykes, as hypidioblastic grains. In the northwestern part of the area, decussate biotite occurs as hypidioblastic grains within the mafic dykes only.

In conclusion, possibly four metamorphic events may be represented in the area. The earliest of these is restricted to the Long Range Complex and related to the development of the gneissosity in these rocks. This metamorphism locally attained granulite facies conditions and is most reasonably interpreted as a Grenvillian feature.

This earliest metamorphic event was followed by a Paleozoic, middle greenschist (in the northwest) to amphibolite facies (in the southeast) metamorphic event, forming a fabric related to Paleozoic folding with northeast trending axes (see section III-8). The intensity of metamorphism associated with this metamorphic event dies out to the northwest. This is consistent with the associated structures, which die out rapidly to the northwest within the basement gneisses; although related folds and foliations may be developed within the less competent cover units (map units 3 and 4) to the west, across the Grand Lake Thrust. The metamorphic grade associated with these structures here is of the lower greenschist facies, further supporting the postulated northwestward decrease in intensity for this metamorphic event.

Finally, possibly two Paleozoic retrogressions occurred, the earlier involving the development of middle greenschist facies assemblages locally defining a foliation, and the later involving lower greenschist facies alteration and locally decussate biotite. The effect of these events on the units west of the Grand Lake Thrust are unknown if any, since these units show chlorite zone mineralogy only (with no evidence of relict higher grade assemblages).

V COMPARISON OF THE GRENVILLIAN ROCKS OF THE MAP AREA TO AREAS OF SIMILAR GEOLOGIC SETTING

V-1 Introduction

Inliers, like the Long Range Complex of the map area, occur the entire length of the Appalachian system. In Newfoundland, other inliers are the Long Range Mountains of the Great Northern Peninsula, the Indian Head Complex, and the Steel Mountain anorthosite. To the south, other inliers are gneisses of the Green Mountains of Vermont, the Berkshire, Housatonic, New Milford and Hudson Highlands massifs of the northern United States, and the Blue Ridge massif of the southern United States. A slice of basement, imbricated within the internal domain of the Quebec Appalachians at Saint Malachie, may be included within this group(Vallieres, Hubert and Brooks,1978). Figure -16 shows the distribution of these along the Appalachians.

The above massifs are part of the Grenville Province of the Canadian Shield, exposed in horsts or anticlines within the Appalachians. Many of these contain similar tectonic features, implying a common origin. The map area is, here, compared to three of these massifs (the Indian Head, Reading Prong, and Berkshire massifs) in an attempt to substantiate the results obtained in this study as well as to speculate on the origin of some features in the map area by analogy with similar features to the south.

V-2A The Indian Head Complex, Introduction

The Indian Head Complex occurs to the west of the map area, near Stephenville(see figure -17). It forms a ridge composed

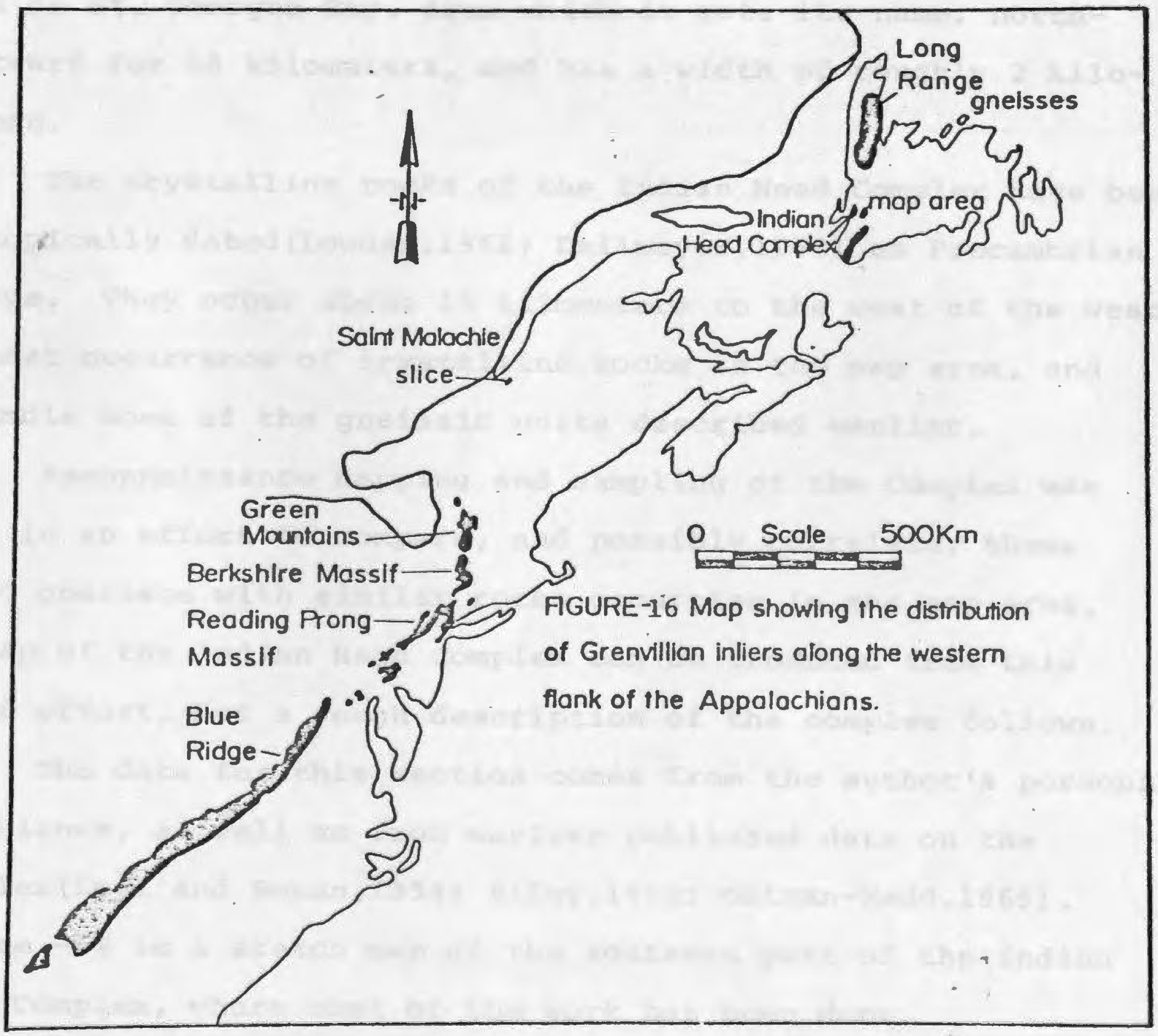


FIGURE-16 Map showing the distribution of Grenvillian inliers along the western flank of the Appalachians.

of Grenvillian crystalline rocks unconformably overlain by relatively undeformed and unmetamorphosed Early Paleozoic sedimentary rocks(indicating that the complex has sustained very little Paleozoic deformation), and unconsolidated recent sediments(glacial outwash). The ridge extends from Indian Head on St. Georges Bay, from which it gets its name, northeastward for 16 kilometers, and has a width of roughly 2 kilometers.

The crystalline rocks of the Indian Head Complex have been isotopically dated(Lowden,1961; Dallmeyer,1978) as Precambrian in age. They occur about 15 kilometers to the west of the westernmost occurrence of crystalline rocks in the map area, and resemble some of the gneissic units described earlier.

Reconnaissance mapping and sampling of the Complex was done in an effort to compare, and possibly correlate, these dated gneisses with similar rocks occurring in the map area. No map of the Indian Head Complex can be produced from this brief effort, but a rough description of the complex follows.

The data for this section comes from the author's personal experience, as well as from earlier published data on the complex(Heyl and Ronan,1954; Riley,1962; Colman-Sadd,1969). Figure -18 is a sketch map of the southern part of the Indian Head Complex, where most of the work has been done.

V-2B <u>General geology of the Indian Head Complex</u>

The contacts of the Indian Head Complex with the surrounding sediments are faulted or unconformable. To the north, the complex is flanked by rocks of the Kippens Formation which contains mainly sand-

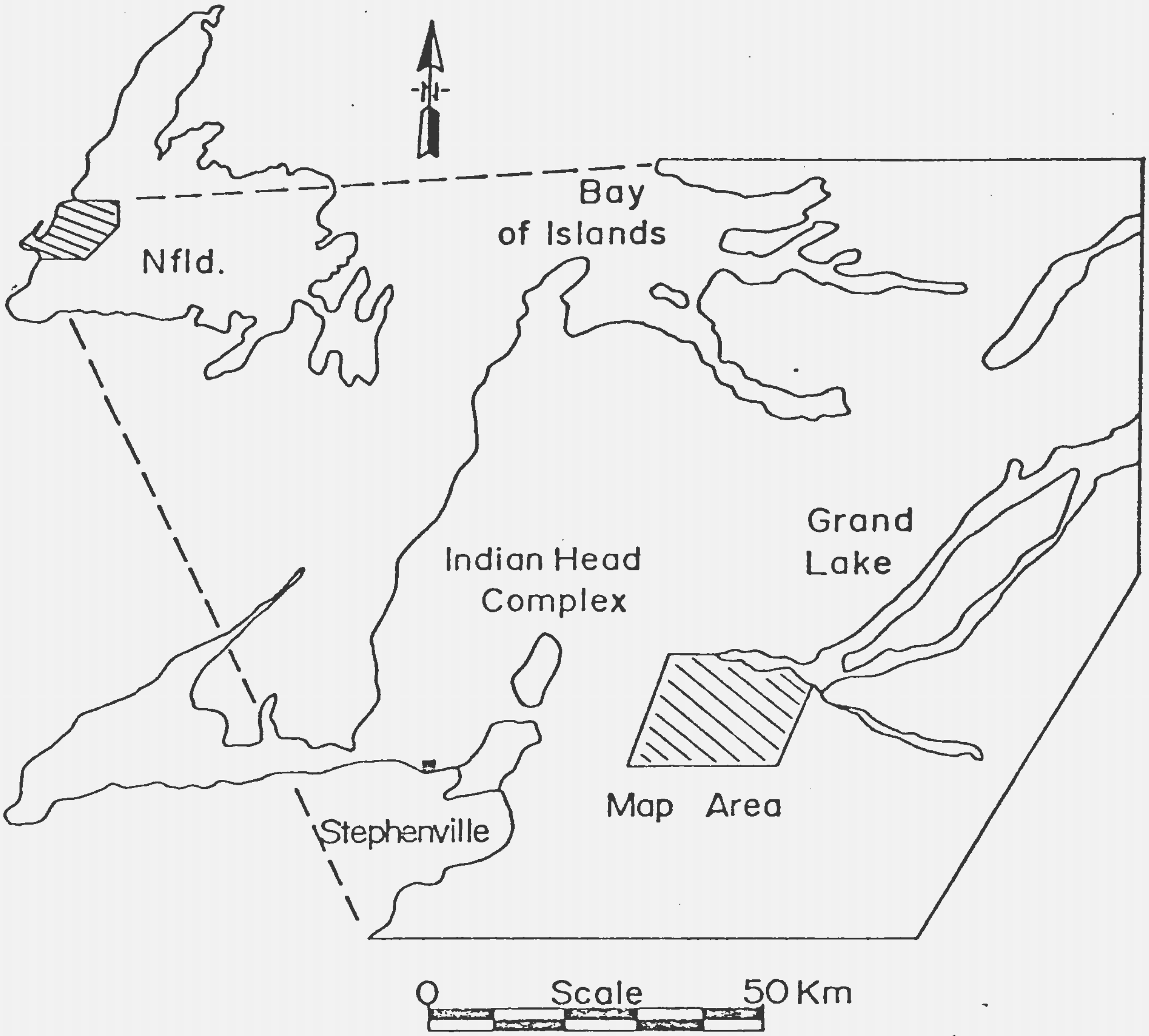


FIGURE - 17 Index map showing the location of the Indian Head Complex relative to the map area.

stone at the base, and shales interbedded with limestones containing Lower Cambrian fossils(Walthier,1949) toward the top. To the south, the complex is flanked by recent unconsolidated sediments, and around the edge of Rothesay Bay, by a narrow outcrop of the Carboniferous Codroy Group.

The complex has been mapped in detail in the south, where access is relatively easy and exposures are good. To the north, access is difficult and exposures occur only at the tops of ridges, therefore little is known of this part of the complex.

Rock types occurring within the complex are; gabbro, anorthosite, felsic gneisses, and granitic pegmatite, all of which are Grenvillian, and Late Precambrian to Early Paleozoic mafic dykes. The granitic pegmatites and mafic dykes were never seen by the author, but are described by previous workers (Heyl and Ronan,1954; Colman-Sadd,1969). The relationships between rock types are, for the most part, unknown.

The southern part of the Indian Head Complex is composed mainly of anorthosite rimmed by gabbro(see figure -18). The gabbro is intruded by anorthosite, pegmatite, and mafic dykes, and is probably older than the anorthosite which it rims. It has been interpreted as a marginal chill zone phase of the magma from which the anorthosite differentiated(Heyl and Ronan, 1954). The anorthosite forms cliffs at the tip of Indian Head. It is coarse grained(with plagioclase crystals up to 15 centimeters long) and has an ophitic texture, except at its boundaries where it is finer grained and altered.

The felsic gneisses occur commonly within the central and northern parts of the complex. Some of these gneisses

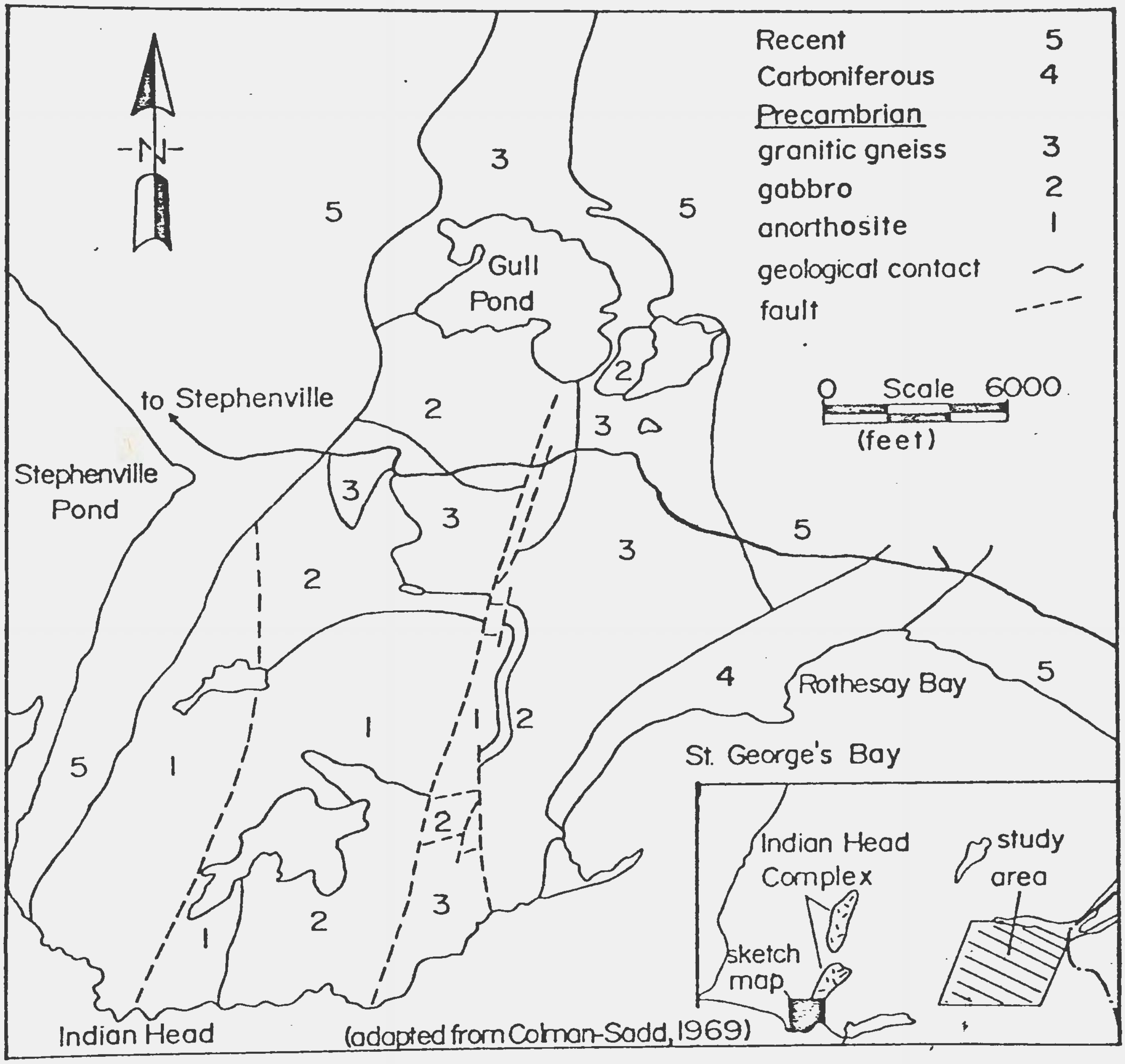


FIGURE-18 Sketch map of the southern Indian Head Complex.

contain the same mineralogy and textural variations as the granitic gneisses of the northwest domain of the map area (augened, pinstriped, banded, and locally massive or mildly foliated). Locally, these contain two foliations(1-gneissosity and 2-oriented mafics). The lack of recognizable metamorphism in the Paleozoic cover, here, implies polydeformation of these basement gneisses prior to the Paleozoic deformation described to the east in the map area.

The mafic dykes were not seen by the author, but have been reported by previous workers(Heyl and Ronan,1954; Colman-Sadd,1969). These are unfolded, contain plagioclase and pyroxene, and form an ophitic texture indicating that these are probably igneous phases. The dykes commonly show partial alteration of these phases to greenschist facies mineral assemblages.

IV-2C Indian Head Complex, Conclusion

The rocks of the Indian Head Complex are comparable to those of the Long Range Complex of the study area. On a large scale, both massifs consist of anorthositic rocks in the south (map unit 1d in the study area and the gabbro and anorthosite in the Indian Head Complex) and dominantly felsic gneisses in the north. Pegmatitic veins and felsic and mafic dykes are common to both.

The granitic gneisses of the Indian Head Complex and the northwest domain of the Long Range Complex have similar textures and mineralogy. These generally contain relict granulite facies mineral assemblages, now partially retrogressed, and textures varying from locally massive to augened to pinstriped(locally containing two foliations). The comparison, however, does not hold so well with the gneisses of the southeast domain which contain a dominant northeast striking fabric, and associated folds. These southeast domain gneisses are juxtaposed with polydeformed and metamorphosed cover sediments which also contain a northeast fabric, however, compared to the Indian Head gneisses which are unconformably overlain by gently folded relatively unmetamorphosed cover sediments. The differences between these gneisses is interpreted as reflecting differing degrees of overprinting by the Paleozoic deformations.

The mafic dykes in both massifs are confined to the basement lithologies, have northeast trends, and are probably related. In the Indian Head Complex, these dykes contain relict pyroxene and plagioclase forming an ophitic texture, now partially retrogressed to greenschist facies mineral assemblages. This indicates that these dykes post-date the Grenvillian metamorphism, and serve as convenient recorders of the Paleozoic deformation of the area(since they don't intrude the cover and therefore pre-date it).

The relict pyroxene and plagioclase(forming an ophitic texture) developed in the mafic dykes of the Indian Head Complex, implies that the early hornblende-plagioclase assemblage in those of the Long Range Complex is probably a metamorphic one, and that the deformational history given in chapter IV is an over simplified one. Furthermore, the Paleozoic greenschist facies event which caused alteration of the mafic dykes in the Indian Head Complex, probably does not account for all the retrograde assemblages developed in the other lithologies, and some of these are almost certainly of Grenvillian age. The same is certainly true for the Long Range Complex, and the retrograde assemblages noted in the northwest domain may represent any or all of the Grenvillian, and two Paleozoic greenschist facies retrogressions(indicated by the mafic dykes and cover units). In the southeast domain, however, the assemblages can be shown to be Paleozoic in age, since they form a northeast trending fabric(with related folds) developed in both the dykes and the cover units.

The major differences between the two massifs are the greater alteration of the mafic dykes in the study area(from partially altered igneous mineralogy in the Indian Head Complex to amphibolite facies mineral assemblages defining a fabric in the southeast of the study area), the lack of massive felsic intrusions in the Indian Head Complex, and the more intense folding and faulting present in the study area. All are interpreted as Paleozoic features.

It seems likely, therefore, that the Long Range Complex is correlative with the Indian Head Complex, and forms a Grenvillian basement inlier. The correlation, however, is best between the Indian Head gneisses and northwest domain gneisses (of the Long Range Complex), because of the increasing intensity of Paleozoic deformation to the southeast(which significantly overprinted the southeast domain gneisses). The increasing alteration of the mafic dykes, and increasing intensity of folding and metamorphism in the cover units, from the Indian Head Complex in the northwest to the southeast margin of the study area, supports this interpretation.

V-3 The Reading Prong massif

The Reading Prong massif forms a highland of Precambrian rocks in eastern Pennsylvania and southeastern New York(see figure -16). It is composed of gneisses which have been deformed, metamorphosed, and intruded by syntectonic granitic rocks during the Grenville orogenic event. Most of the massif was unaffected by Paleozoic metamorphism, except for the northeastern end, east of the Hudson River, where it has been affected by high grade Paleozoic metamorphism(Dallmeyer,1974).

The rocks of the northeastern end of the massif consist chiefly of biotite-quartz-feldspar paragneiss, amphibolite, and hornblende-quartz-feldspar orthogneiss, classified as representing hornblende granulite facies regional metamorphism. They form narrow structural blocks which are separated by a series of northeast trending high angle faults, and which are overlain by a Lower Cambrian quartzite unit that grades upward into Middle to Upper Cambrian to Lower Ordovician carbonate rocks. The Paleozoic retrograde alteration(garnet grade) of the prograde Grenvillian assemblages is widespread east of the Hudson River, and less intense to absent west of the river (Dallmeyer,1974). This observation is supported by the fact that the Cambrian-Ordovician section also shows no Paleozoic metamorphic effects west of the Hudson River.

The Reading Prong massif lies approximatly 1500 kilometers to the southwest of the study area, making detailed structural and/or metamorphic correlations meaningless. The two areas, however, do show noteworthy similarities on the large scale. Both areas contain Grenvillian basement gneisses which show evidence of up to granulite facies prograde metamorphic mineral assemblages. It appears that a large portion of the Reading Prong massif, however, is not as affected by Paleozoic retrograde metamorphism as is the Long Range Complex of the study area. This may be due to the greater area of the Reading Prong massif, or to differing intensities of the Paleozoic events.

The Paleozoic cover in both the Reading Prong and the study area contains quartzites and carbonates, indicating a Paleozoic tectonic history involving similar elements of the Early Paleozoic continental margin of North America. Furthermore, the east to west decrease in intensity of Paleozoic metamorphism, developed in both the Reading Prong massif and in the Long Range Complex of the study area, implies a similar style of deformation for both areas. The common occurrence of northeast trending high angle faults, in both areas, is yet another similarity.

V-4 Berkshire massif

The Berkshire massif forms a highland area in western Massachusetts and Connecticut(see figure -16), composed of biotite-hornblende-quartz paragneiss, granitic gneiss, calc-silicate rocks, and amphibolite, deformed during the Grenville orogenic event. The western end of the massif is composed of imbricate thrust slices of recumbently folded Precambrian gneisses and unconformable Lower Cambrian and Upper Precambrian metasedimentary cover(Dalton Formation and Cheshire Quartzite). These assemblages are thrust over Lower Cambrian to Upper and Middle Ordovician sedimentary rocks which were deformed prior to overthrusting(Ratcliffe,1969).

A blastomylonite fabric related to the thrusting, is developed in the Berkshire gneisses. This fabric is parallel to, and best developed near, the base of the thrust slices. The thrust fabric post-dates two folding events and a metamorphic event of Paleozoic age, but is cut by a granitic intrusion dated isotopically as Late Ordovician in age. This indicates a Taconic age for the thrusting(Ratcliffe and Harwood,1975). The thrusts were later folded, which produced a crenulation in the thrust related fabric. This may be an Acadian effect.

A similar history is reported at the north end of the Berkshire massif, where Taconic thrusts and associated recumbent folds are refolded. The Precambrian rocks, here, exhibit mineralogies and textures suggesting that they were metamorphosed to at least kyanite and probably sillimanite grade, before Paleozoic metamorphism(Norton,1975). These assemblages were later retrogressed by lower grade Paleozoic metamorphic events.

Once again, as is the case for the Reading Prong massif, large scale comparisons may be made between the study area and the Berkshire massif. The striking similarity here, is the Paleozoic thrusting of a slice assemblage of folded and faulted basement and cover rocks, westward, above deformed Paleozoic cover rocks. The major difference, however, is the association of a blastomylonite fabric with the thrusts in the Berkshire massif. Similar fabrics occur in the study area, but do not appear associated with thrusts, although these were not studied in detail. A mylonitic fabric is developed along the Grand Lake Thrust to the north of the study area near One Mile Pond, however (Kennedy,1978).

The Berkshire massif, like the Reading Prong massif and the study area, contains evidence of prograde Grenvillian metamorphism retrograded by Paleozoic metamorphic events. In this(Berkshire) case, the Grenvillian event produced kyanite and sillimanite grade assemblages which are retrograded by the later Paleozoic events, but the east to west decrease in Paleozoic metamorphic grade is not noted here.

Both areas(the Berkshire massif and the study area)contain Paleozoic granites intruding the Precambrian basement. In the Berkshires, the granite is post thrusting. In the study area, however, one of the granites(the Hare Hill granite) is near the Grand Lake Thrust but never cuts it, nor are any igneous rocks found west of this thrust, indicating the thrust is probably later than this intrusion.

The greater abundance of thrusts in the Berkshires may indicate that this massif is more allochthonous than the Reading Prong or the Long Range Complex of the study area. Alternatively, it is possible that the study area contains more thrusts than are recognized, and that these are folded or obscured by later events.

VI GENERAL SYNTHESIS AND CONCLUSION

VI-1 Introduction

A general synthesis giving the possible ages, significance, and deformational history for the different map units is given here. This is divided into two sections; the depositional phase, and the deformational phase(Paleozoic deformation). This is followed by a section relating the results of the study to the present model for the formation and subsequent destruction of the Early Paleozoic continental margin of North America.

VI-2 Depositional Phase

The oldest rocks of the map area are the gneisses and anorthositic rocks(map units 1a, b,c,d and e) of the Long Range Complex, which form a basement to the other units. The gneisses are correlated(section V-2C) with isotopically dated(Lowden, 1961; Dallmeyer,1978) Grenvillian gneisses of the Indian Head Complex; while the anorthositic rocks are interpreted as Precambrian because of their close association with the gneisses in both the Indian Head Complex and study area, and because most anorthosite occurrences are of Precambrian age(Foland and Muessig,1978).

The calc-silicates and quartzites along Grand Lake and on "Bear Ridge"(map unit 1c) are assumed to be Precambrian because they lie within the gneisses, and calc-silicates have been interpreted as such in similar geological settings to both north(Knapp, Kennedy and Martineau,1979) and south (Herd,1978). Calc-silicates and quartzites also occur within the Precambrian Grenville structural province of the Canadian

Shield, further supporting this assumption.

The Grenvillian Long Range Complex forms the basement to the other units, and as such contains structural and metamorphic features not developed in the later cover units. The isotopic ages obtained in the Indian Head gneisses(800-900 million years) almost certainly record the last major pre Paleozoic metamorphic and deformational event affecting this basement.

In the map area, the Grenvillian features have been obscured considerably by the later(Paleozoic) events. Some of these (Grenvillian features) are the gneissosity in the Long Range Complex, and the relict granulite facies mineral assemblages and textures in the granitic gneisses.

Following its Grenvillian deformation, the basement (both Indian Head Complex and Long Range Complex) was intruded by a group of near vertical, north to northeast trending mafic dykes. Those within the Indian Head Complex, however, are undeformed, and although they are altered, show relict igneous textures(Colman-Sadd,1969). This indicates that they are younger than the last Grenville deformation affecting the gneisses. In the map area, these dykes are deformed and metamorphosed. This indicates that these deformational events(in the dykes of the study area) must be post Grenville, and furthermore that they do not extend as far west as the Indian Head Complex. The deformations and metamorphic events registered in the dykes of the map area, are used in the next section in characterizing the Paleozoic deformation and its northwestward decline in intensity.

The Loon Pond metasediments(in the southeast) and Grand Lake Brook Group(in the northwest) were probably deposited as cover on the Grenvillian basement at roughly the same time, or slightly later than, the intrusion of the mafic dykes. The fact that no dykes are found in the cover of both the map area and the Indian Head Complex, indicates that these (dykes) are probably slightly older(Late Precambrian to Early Paleozoic) than the cover.

The protoliths of the Loon Pond metasediments are mainly psammitic to semipelitic, with rare calcareous layers. No stratigraphy is given in these because of the complex deformation; but the psammitic units probably represent sediments derived from erosion of the basement, while the more pelitic and calcareous units represent later marine deposition, once erosion of the local basement ended.

Similarly, the protolith of the Grand Lake Brook Group is mainly pelitic with minor calcareous beds, indicating that it may be broadly equivalent in age to the later semipelitic units of the Loon Pond metasediments.

To the west, near the Indian Head Complex, clastic and carbonate cover rocks unconformably overlying the basement gneisses are interpreted to be roughly of similar age to the cover units in the map area. These are the Kippens, March Point and Petit Jardin Formations, which have been palaeontologically dated as Cambrian(Riley, 1962).

The carbonate rocks of the map area lie conformably above the Grand Lake Brook Group(H. Williams, pers. comm.). These rocks are correlated with the St. George Group and Table Head

Formation to the west, and form part of an extensive carbonate bank extending the length of the Appalachians, from Newfoundland to Alabama(Rodgers,1968; Williams and Stevens,1974). The bank ranges in age from Early Cambrian to Middle Ordovician.

Possibly the latest rocks to form in the map area are the pink, medium to coarse grained, massive felsic intrusions (Hare Hill and "Goose Hill" granites, and "Tulk's Pond" syenite). These bodies are massive, show no evidence of relict high grade Grenvillian metamorphism, are discordant to the gneissosity of the host, and do not have any equivalents in the Indian Head Complex. No mafic dykes were observed in these.

VI-3 Deformational phase

The map area contains evidence of Paleozoic deformation, and its decrease in intensity toward the west. The overall northeast structural trend of the area is of Paleozoic age since it is best developed in such cover lithologies as the Ordovician limestones(map unit 4), the Cambrian Grand Lake Brook Group(map unit 3), and Late Precambrian to Early Paleozoic Loon Pond metasediments(map unit 2). It is poorly developed in the Grenvillian Long Range Complex, especially in the northwest domain gneisses.

The earliest recognized Paleozoic deformational event in the map area, varies in intensity from southeast to northwest across the area. In the Loon Pond metasediments the event may have produced the dominant schistosity(associated with up to kyanite grade assemblages in one sub-unit), and the bedding plane faults. Both of these features may reflect an isoclinal folding event.

The event is recognized in the Long Range Complex to the northwest, specially within the southeast domain, where it produced northeast trending folds in the gneissosity with an associated amphibolite facies axial planar fabric. The mafic dykes intruding this domain also contain a related, parallel, amphibolite facies fabric and truncate the folded gneissosity, indicating that it(gneissosity) is an earlier Grenvillian feature affected by the Paleozoic event.

In the northwest domain, the northeast trending folds are not so common as in the southeast domain, and may be locally associated with a lower grade, greenschist facies, fabric. This apparent northwestward decline in intensity of the deformational event is further substantiated by a drop in metamorphic grade of the fabric in the mafic dykes, from amphibolite facies in those of the southeast domain to greenschist facies in those of the northwest domain.

This deformational event is difficult to correlate across the Grand Lake Thrust because of the drop in metamorphic grade across this feature and its(the deformational event) northwestward decrease in intensity. The northeast trending folds in both the carbonate rocks and in the Grand Lake Brook Group(where they are associated with a chlorite zone greenschist facies phyllitic cleavage) are possibly related to this deformational event, indicating that the folding continues farther westward than its associated metamorphic fabric.

The fabric associated with this event is not recognized in the basement gneisses of the Indian Head Complex to the west(where the mafic dykes show relict igneous textures (ophitic) with only minor alteration), but may be related to the open folds in the cover, indicating that the event extends farther west in the cover.

A later, Paleozoic, deformational event is present in most units of the map area. In the Loon Pond metasediments, the crenulation cleavage(associated with retrograde greenschist facies metamorphism in correlative rocks north of Grand Lake(Kennedy, pers. comm., 1979) may be related to this event.

In the Long Range Complex gneisses of the southeast domain, this deformational event is associated with retrograde greenschist facies metamorphism, but no associated folds are recognized. Similar retrograde greenschist facies mineral assemblages occur within the northwest domain gneisses; but it is difficult to determine whether the assemblages are related to the earlier Paleozoic event (which may decrease in intensity to greenschist facies assemblages to the northwest), to a Grenvillian retrogression, or to this later event. The fact that retrograde greenschist facies mineral assemblages occur in the mafic dykes and possibly in the felsic intrusions(map unit 5) (which are massive and may postdate the earlier Paleozoic event) indicates that the later Paleozoic event did affect the host northwest domain gneisses.

Again, as is the case for the earlier Paleozoic event, this later deformational event is difficult to correlate across the Grand Lake Thrust. A reasonable assumption is that the event produced the lower greenschist facies crenulation to phyllitic cleavage in the Grand Lake Brook Group.

To the west, in the Indian Head Complex, the effects of this deformational event, if any, are not determined. The retrograde greenschist facies alteration which occurs here, may be Grenvillian, or associated with either of the Paleozoic events.

The exact age of the Grand Lake Thrust is unknown. However, it is most likely related to one of the Paleozoic deformational events described above. The contrast in metamorphic grade in the cover units on both sides of this fault, may indicate that the Grand Lake Thrust is a later feature, possibly representing a late compressive pulse.

A minor folding episode with east trending open folds may be present on both sides of the Grand Lake Thrust, indicating that it(the folding) is a later feature. These folds may be developed in the carbonate rocks in the west, as well as in the Loon Pond metasediments in the east. The folds have no associated fabric.

The last deformation in the map area formed the high angle block faults which cut all units, as well as the Grand Lake Thrust. These may be related to similar faults which cut Carboniferous sediments to the northeast, near Deer Lake (Webb,1969), but could also be older reactivated features. The Cabot Fault, which marks the eastern boundary of the map area, similarly, cuts Carboniferous rocks near Deer Lake, definitely indicating some Carboniferous movement did occur in the area.

VI-4 Model

The units and structures of the map area may be explained in terms of the present model for the construction and subsequent destruction of the Early Paleozoic continental margin of North America(see figure -13).

In terms of this model, the Grenvillian Long Range Complex forms part of the ancient craton which was rifted in the early stages of development of the ancient margin. Fragments of the ancient craton may be seen the entire length of the Appalachians(see figure -16). These occurrences are referred to as Grenvillian inliers. They are characterized by isotopic ages of about 800 to 1000 million years, and are part of the Grenville Province of the Canadian Shield, exposed in horsts or anticlines.

Possible correlatives to the Long Range Complex of the study area are the gneisses of the Great Northern Peninsula and Indian Head Complex in Newfoundland. Other Grenvillian inliers to the south are the Green Mountains of Vermont, the Berkshire, Housatonic, New Milford, and Hudson Highland massifs of the northern United States, and the Blue Ridge massif of the southern United States. A Grenville basement slice, imbricated within the internal domain of the Quebec Appalachians at Saint-Malachie, may also be included in this group(Vallieres, Hubert and Brooks,1978).

The Grenvillian basement was intruded by mafic dykes during the rifting stage which produced the Proto-Atlantic Ocean(Iapetus). These dykes are present in both the Long Range Complex of the study area and in the Indian Head Complex, where they crosscut the Grenvillian gneissosity, but are unknown within the Paleozoic cover lithologies. Similar dykes have also been reported in the Fleur de Lys Supergroup cover sequence of the Burlington Peninsula(deWitt,1972; Bursnall,1975; Bursnall and deWitt,1975), as well as in the Grenvillian gneisses of the Great Northern Peninsula(Clifford,1965,1969; Pringle, Miller and Warrell,1971; Strong and Williams,1972; Strong,1974). It is not known why the dykes are absent in the cover units of the map area. A likely explanation is that the cover sediments of the map area were deposited after the rift related intrusions were emplaced. The dykes are, therefore, Late Precambrian (post Grenville) to Early Paleozoic in age.

The Loon Pond metasediments(southeast) and Grand Lake Brook Group(northwest) were probably deposited as cover along the rifted basement margin, roughly at the same time(or slightly later) as the mafic dykes were emplaced(probably as feeders to rift related volcanism not represented in the map area).

The psammitic units in the Loon Pond metasediments probably represent the earlier sediments derived from local erosion of the rifted basement. The more pelitic layers of the Loon Pond metasediments are probably correlative to the dominantly pelitic Grand Lake Brook Group, and both are probably equivalent in age to the clastic to carbonate rocks of the Kippens, March Point and Petit Jardin Formations near the Indian Head Complex. These sediments probably represent later deposition when the margin was more fully developed, and the local source of coarse clastics was cut off by the development of a carbonate platform to the west. The association of calcareous beds with the semipelitic layers in the map area supports this.

Equivalent clastic cover lithologies along the length of the Appalachian system are; the Fleur de Lys Supergroup of the Burlington Peninsula of Newfoundland, the Rosaire and Caldwell Groups of Quebec, the Mendon Group and Pinnacle Formation of Vermont, and the Glenarm Series, Lynchburg Formation and Ocoee Group farther south. Parts of the clastic sequence also occur in the allochthonous terrains of the Humber zone of Newfoundland(Maiden Point and Summerside Formations).

The carbonate rocks are correlative to the St. George Group and Table Head Formation to the west, and form part of an extensive carbonate bank which follows closely the locus of Grenvillian inliers the length of the Appalachians, from Newfoundland to Alabama(Rodgers,1968; Williams and Steven,1974). This bank ranges in age from Early Cambrian to Middle Ordovician, and marks the final stage in the development of the margin.

The oldest deformation in the study area(Grenville) affected only the Long Range Complex rocks and is unrelated to the Late Precambrian to Early Paleozoic evolution of the ancient continental margin of North America. The later Paleozoic events, however, are probably related to the destruction of this margin.

It seems likely that the first event, which decreases in intensity from southeast to northwest, represents the Early to Middle Ordovician Taconic Orogeny(Rodgers,1971; Williams,1979). The southeast to northwest decrease in metamorphic grade of this deformational event may indicate that the locus of most intense deformation(the edge of the Grenville basement) was to the southeast. The rapid east to west decrease in intensity of folding in the Long Range Complex, relative to the cover which is tightly folded throughout the area, may indicate that the basement behaved competently relative to the cover, localizing the most intense deformation near its margin.

Farther west, the deformation produced by this event is weak or absent in the Indian Head Complex. Other features of the Taconic Orogeny near the map area are; the pre Middle Ordovician unconformity in the carbonate bank, the thick accumulations of east derived flysch, and the presence of the Bay of Islands Allochthon. These features may be slightly later than the deformation in the map area, since the map area is nearer to the basement edge where the deformation was most intense, and probably longest-lived. The structural and metamorphic history of the cover is more complex to the east, supporting this.

The Taconic Orogeny is interpreted by some (Williams, 1979) as marking the closure of the Iapetus Ocean.

The later Paleozoic event may be related to the Acadian Orogeny of Devonian age. Some Acadian features may be the faults which bring up the Indian Head Complex as a horst through the Paleozoic cover; and possibly the felsic intrusions and later Grand Lake Thrust in the map area, although these may also be Late Taconic features.

The Acadian Orogeny is interpreted by some workers as a late compression after the closure of the Iapetus Ocean (Williams, 1979), and by others as a final continental collision, and closure of the Iapetus Ocean (Bird and Dewey, 1970; McKerrow and Cocks, 1977).

VI-5 Conclusion

The study area is composed of a folded and faulted slice assemblage of Precambrian Grenville basement and Late Precambrian to Lower Paleozoic metasedimentary cover, thrust westward into juxtaposition with deformed platformal Paleozoic cover rocks during the Lower Paleozoic destruction of the Early Paleozoic continental margin of North America.

The Grenvillian basement rocks, here named the Long Range Complex, are composed of granitic gneisses, hornblende-plagioclase gneisses, calc-silicates and quartzites, foliated granite, and anorthositic rocks. The gneisses exhibit relict prograde granulite facies mineral assemblages and textures, now largely altered by retrograde Paleozoic metamorphic events and related deformations which are also recorded in Late Precambrian to Lower Paleozoic mafic dykes.

The cover rocks consist of the Loon Pond metasediments in the east, and the Grand Lake Brook Group and carbonate rocks in the west. These are affected by both prograde and retrograde Paleozoic metamorphic events(and related folds), which also produced the retrograde assemblages in the Grenville basement gneisses.

The earlier Paleozoic(Taconic?)deformation appears to increase in intensity to the southeast. Evidence for this is the northwestward decrease in Paleozoic folding and metamorphic grade in the Long Range Complex, and the overall decrease in tightness of Paleozoic folds in the cover units, from the study area westward to the Indian Head Complex area. Later Paleozoic folding and metamorphism(Acadian?) is also recorded in the area, but is less intense and difficult to characterize.

The Long Range Complex is intruded by Paleozoic felsic intrusions which predate the Grand Lake Thrust. This fault juxtaposes the Long Range Complex and Loon Pond metasediments (slice assemblage) against the previously deformed, platformal, Grand Lake Brook Group and carbonate rocks. Both intrusions and thrust fault may be late Taconic or Acadian features.

The latest deformational events in the map area, are east trending open folds of unknown age, and high angle block faulting, probably of Carboniferous age.

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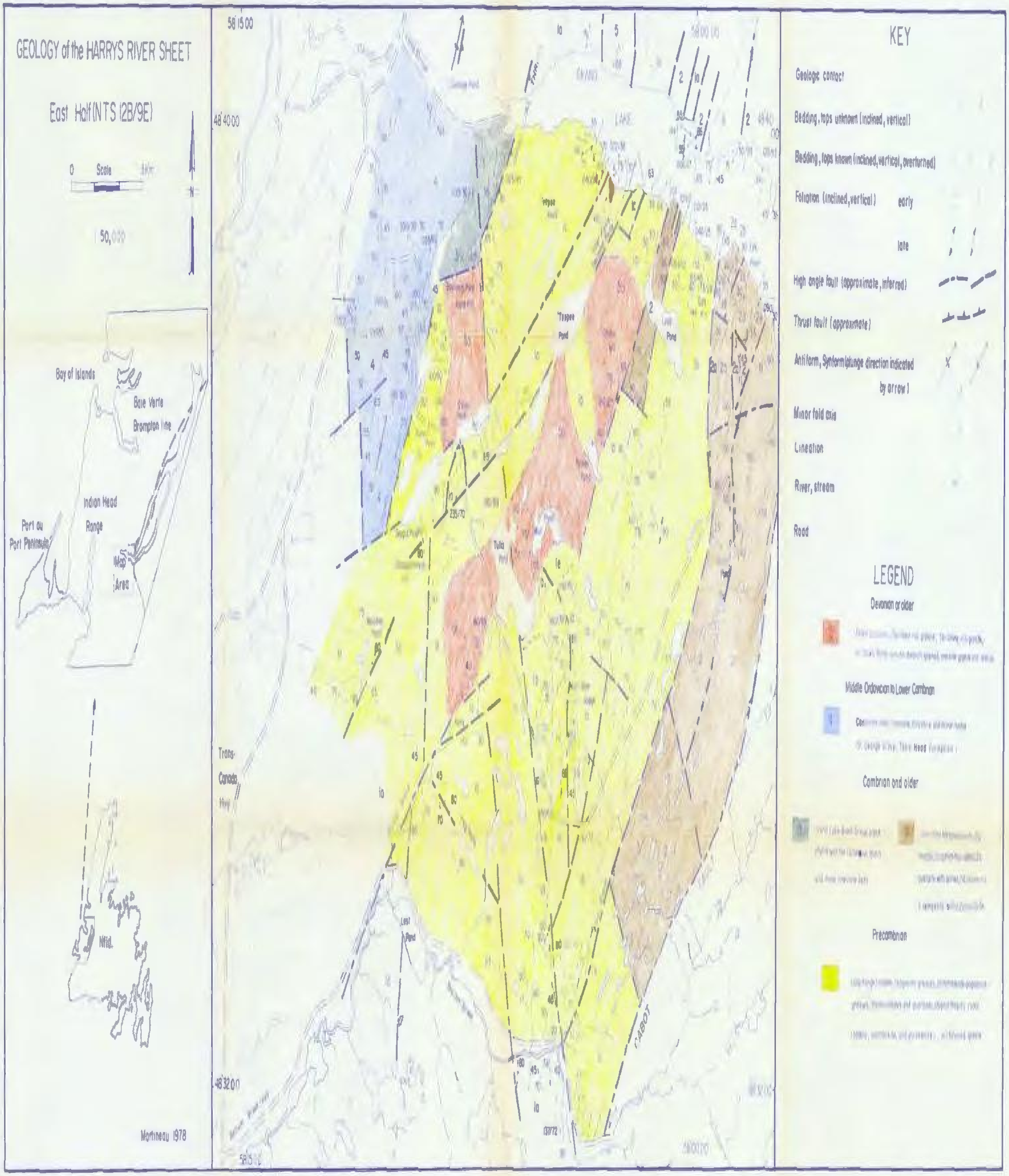

GEOLOGY of the HARRYS RIVER SHEET
East Half (N.T.S. 12B/9E)
0 Scale
1:50,000
Bay of Islands
Baie Verte Brompton line
Indian Head Range
Port au Port Peninsula
Map Area
Nfld.
Martineau 1978
KEY
Geologic contact
Bedding, tops unknown (inclined, vertical)
Bedding, tops known (inclined, vertical, overturned)
Foliation (inclined, vertical) early
late
High angle fault (approximate, inferred)
Thrust fault (approximate)
Antiform, Synform (plunge direction indicated by arrow)
Minor fold axis
Lineation
River, stream
Road
LEGEND
Devonian or older
Middle Ordovician to Lower Cambrian
Cambrian and older
Precambrian
Trans-Canada Hwy
Teapee Pond
Tulks Pond
Lost Pond
CABOT
LAKE

GEOLOGY of the HARRYS RIVER SHEET

East Half (N.T.S 12B/9E)

Scale

1:50,000