Current Research (2000) Newfoundland Department of Mines and Energy
Geological Survey, Report 2000-1, pages 251-277

GEOLOGICAL INVESTIGATIONS IN THE TYPE LOCALITY OF THE NAIN PLUTONIC SUITE (NTS 14C/12)

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ABSTRACT

The Nain area comprises a diverse assemblage of metamorphic and igneous rocks. The former are assumed to be part of the Archean Nain Province, whereas most of the latter are assumed to be part of the Nain Plutonic Suite (NPS) and thus a reflection of Mesoproterozoic anorogenic magmatism. However, some gneissose and plutonic rocks are of equivocal stratigraphic affinity. Some of the latter rocks are assigned a Paleoproterozoic age, but the former lack any features that could be employed to ascertain their probable age.

The Archean gneisses are mostly at granulite facies but an overprinting retrogression is locally obvious. They comprise a polyphase and multi-generation migmatite complex that varies from peridotite to enderbite in composition."Straight belts", in which the migmatitic structure is overprinted and reoriented into a regular, laminar layering, are developed adjacent to the largest NPS intrusion.

The NPS intrusions emplaced into the gneisses are overwhelmingly leuconoritic to anorthositic in composition, but troctolitic, ferrodioritic and monzonitic rocks are also present. The geometry of individual intrusions point to emplacement of the precursor magmas and/or crystal mushes within a variety of settings ranging from extraordinarily large, and perhaps diapiric, steep-walled plutons to moderately inclined and subhorizontal dykes. The differing textural and mineralogical aspects of the leuconoritic and anorthositic rocks across the survey area, coupled with intrusive contacts, permit local preliminary subdivisions into several different plutons, and clearly illustrate the regionally composite character of this group of rocks and the pulsing nature of the magmatism. Troctolite intrusions postdate and predate local anorthosite intrusions, and similarly represent repetitive magmatism. Field relations indicate that the largest ferrodioritic intrusions locally hybridized with proximal and coeval monzonitic magmas. There is a profusion of basic and felsic dykes throughout the survey area, but their local volumes are highly variable. Widespread chloritic alteration has affected many of the rocks in the Nain–First Rattle area, but its significance is unclear.

The geological history of the Nain area, as determined from the 1999 survey, is fraught with unanswered questions. Gneisses are quite probably Archean in age, but is the subsequent "straightening" a product of Mesoproterozoic deformation? Are there more Paleoproterozoic rocks in the Nain area than presently surmized? Are layered/gneissose mafic and ultramafic rocks near Nain Archean, Paleoproterozoic, or Mesoproterozoic? Is the chloritic alteration of some of the intrusions an indication that these are overprinted by a pre-NPS metamorphism, is it an NPS alteration, or is it a post-NPS phenomena? It is clear that those rocks of clearly Mesoproterozoic age likely represent some 50 million years of magmatism, and thus reflect nearly the whole chronological extent of the NPS as presently known.

Recent exploration for possible deposits of Ni–Cu sulphide minerals in the immediate area of Nain town has focused mainly on magnetite-rich ferrodioritic (gabbronoritic) dykes. The sulphide in these rocks is of primary magmatic origin, and is part of an oxide–sulphide liquid transported by the dykes.

INTRODUCTION

The area proximal to the town of Nain is the type locality for the Mesoproterozoic Nain Plutonic Suite (NPS; Ryan and Morse, 1985). All four families of igneous rocks that comprise the NPS – anorthositic, granitic, dioritic, and troctolitic – can be found there (*cf*. Ryan, 1990). Anorthositic rocks underlie and predominate in the immediate vicinity of the town, whereas the other components are best exhibited some distance from there. A Nain-based project was undertaken in the summer of 1999 to examine the coastal and inland geology of the Nain 1:50 000-NTS map area (14C/12). The objectives were to examine first-hand some of the various units that were portrayed on the compilation map of Ryan (1990), to further refine (if possible) the known pattern of the plutonic rocks, and to assess the local and regional stratigraphic setting of some of the recently discovered base-metal prospects.

The geology of the specific area proximal to Nain as portrayed on the compilation sheet referred to above was drawn from field work that had been done prior to the mid-1970s (*cf*. Wheeler, 1969; Wheeler *et al.,* 1984) and several detailed studies of specific parts of the sheet undertaken during the early phases of the 1971-1981 Nain Anorthosite Project. The quarter-century lapse of dedicated survey work in the Nain area invited a return to re-examine the local geology because significant advances had been made in understanding magmatic processes and mechanisms of intrusion since the original work was done. In addition, new data on the geology have emerged from exploration company activity in areas of potential base-metal concentrations, and these contributions have given insight into some of the otherwise little trodden parts of the NPS near Nain. It will become apparent to the reader that the survey was successful in attaining all the objectives to varying degrees, but that there are numerous unanswered questions remaining. Answers to some outstanding problems hinge on absolute geochronology, and this facet of investigation is currently being pursued.

PREVIOUS WORK

Previous geological mapping in the Nain area can be divided into three "phases": 1) that conducted as part of pioneering investigations of the whole Nain Plutonic Suite prior to 1970, 2) that conducted mainly for theses in the 1970s during the decade-long Nain Anorthosite Project, and (3) that conducted for base-metal exploration assessment in the mid 1990s.

The pioneering "Phase 1" studies of the Nain area were conducted virtually single handedly by E.P. Wheeler II. His topographical and geological surveys between 1926 and 1974 covered nearly all of the NPS at a regional scale (Wheeler, 1942, 1960, 1969, and unpublished manuscript maps). Wheeler's maps have, from the broad perspective under which the surveys were conducted, stood the test of time. However, he did not attempt to unravel the internal complexities of the anorthositic rocks, being content to subdivide them simply on the basis of weathering colour, setting up a pale, buff, and dark "facies", augmented in some cases with mineralogical traits (*cf*. Wheeler, 1960; Emslie *et al.*, 1972). New approaches by workers such as Berg (1974) and Wiebe (1976) brought other criteria into play within the NPS, and demonstrated that individual "facies" could locally encompass several different plutons.

"Phase 2" studies in the Nain area were focused examinations of some of the rocks in the immediate vicinity of Nain town and Nain Bay during the initial stages of the Nain Anorthosite Project (Morse, 1971-1983). Noteworthy among these were the theses-related mapping surveys of Rubins (1973) and Mulhern (1974) who conducted studies of the region straddling Nain Bay across Barth (Pardy's) Island. These theses were an outgrowth of work undertaken earlier and simultaneously by D. de Waard (*cf.* Rubins and de Waard, 1971; de Waard and Mulhern, 1973). During the same period Planansky (1971, 1973) conducted a survey of part of the western end of Paul (Paul's) Island, an area later examined by Wiebe (1990, 1992).

Exploration company interest in the igneous rocks of the Nain area prior to the mid-1990s was mainly restricted to the British Newfoundland Exploration Limited, which conducted broad-scale base-metal surveys in the 1950s and 1960s (*cf*. Grimley, 1955). It was not until the discovery of the Voisey's Bay Ni–Cu–Co deposit within troctolitic rocks about 35 km to the southwest of Nain, by Archean Resources Limited, in 1993 that the NPS was given intense scrutiny. Several blocks of claims were staked in the winter and spring of 1994-95 before much of the Nain region was declared by government as "Exempt Mineral Land" and thus ineligible for further claim staking. Among the geological units and areas that were staked and subjected to investigation were the Barth Island intrusion (Barth layered structure) at Nain Bay, the Newark Island intrusion on South Aulatsivik Island, anorthositic rocks adjacent to the town of Nain and south of Barth Island, anorthositic rocks at the west end of Paul Island, and anorthositic, dioritic and granitic rocks in the area of Sachem Bay. The recent exploration activity within the confines of the Nain map-area (*cf*. summaries in Kerr, 1998; Hinchey *et al.*, 1999) is considered as "Phase 3" of the study of Nain rocks.

GEOLOGICAL RESULTS

This section summarizes the salient aspects of the rocks examined during the 1999 field program, augmented by data

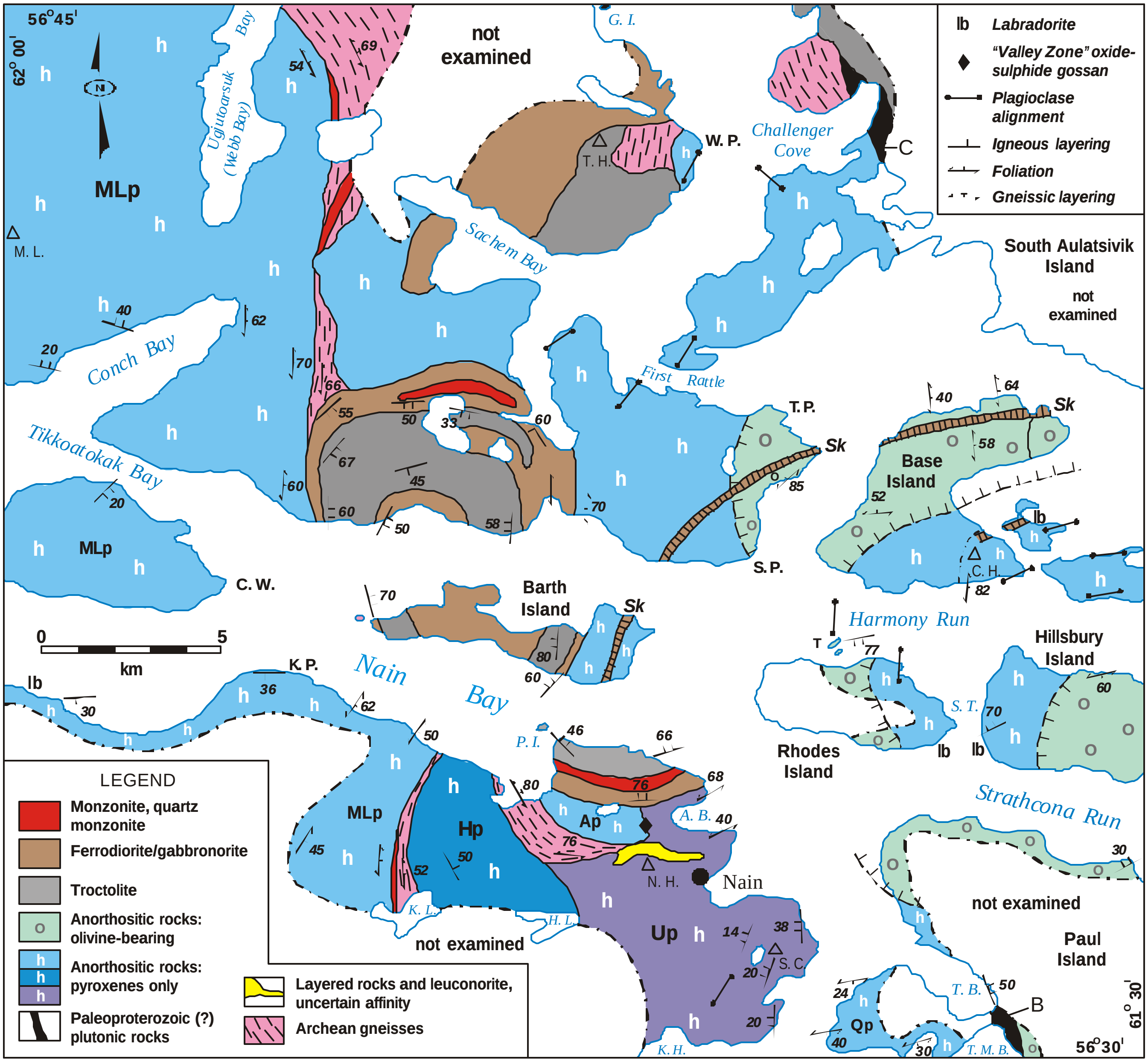

Figure 1. *Geological map of part of the Nain area (NTS map area 14C/12) arising from the coastal survey of 1999, augmented with inland geology derived from reconnaissance work and other sources. Key to abbreviations is as follows: Geographic names: A.B.=Akpiksai Bay, P.I.=Pikaluyak Islet, G.I.=George's Island, W.P.=Webb Point, S.T.=Shoal Tickle, H.L.=Hosenbein Lake, T.P.=Topsy Point, S.P.=Sandy Point, N.H.=Nain Hill, T=The Turnpikes, T.B.=Two Mile Bay, T.M.B.=Ten Mile Bay, K.H.=Kauk Harbour, C.W.=Cape Williams, K.P.=Kaiktusuak Point, S.C.=South Channel Cairn, T.H.=Tikkiraluk Hill, K.L.=Kangialuk Lake, C.H.=Camp Hill, M.L.=Mount Lister. Geological names: Ap=Akpiksai Bay pluton, Hp=Hosenbein Lake pluton, Up=Unity Bay pluton, C=Challenger Cove gabbronorite, B=The Bridges layered intrusion, Sk=Satorsoakulluk dyke, MLp=Mount Lister pluton, Qp=Quarry pluton.*

gathered from limited reconnaissance work in 1990, 1991, 1992 and 1994, as well as by relevant information compiled from other sources. The scale of the accompanying sketch map (Figure 1) allows only the major units to be illustrated; the figure incorporates some data compiled from other sources, and it also bears a degree of artistic licence because there is extrapolation of some contacts across areas that the writer has not visited. The regional picture illustrated on Figure 1 can be viewed as simply comprising Archean gneisses intruded by igneous rocks of the NPS. However, this simplicity camouflages alternative perspectives which can arise if specific features of the area are considered with-

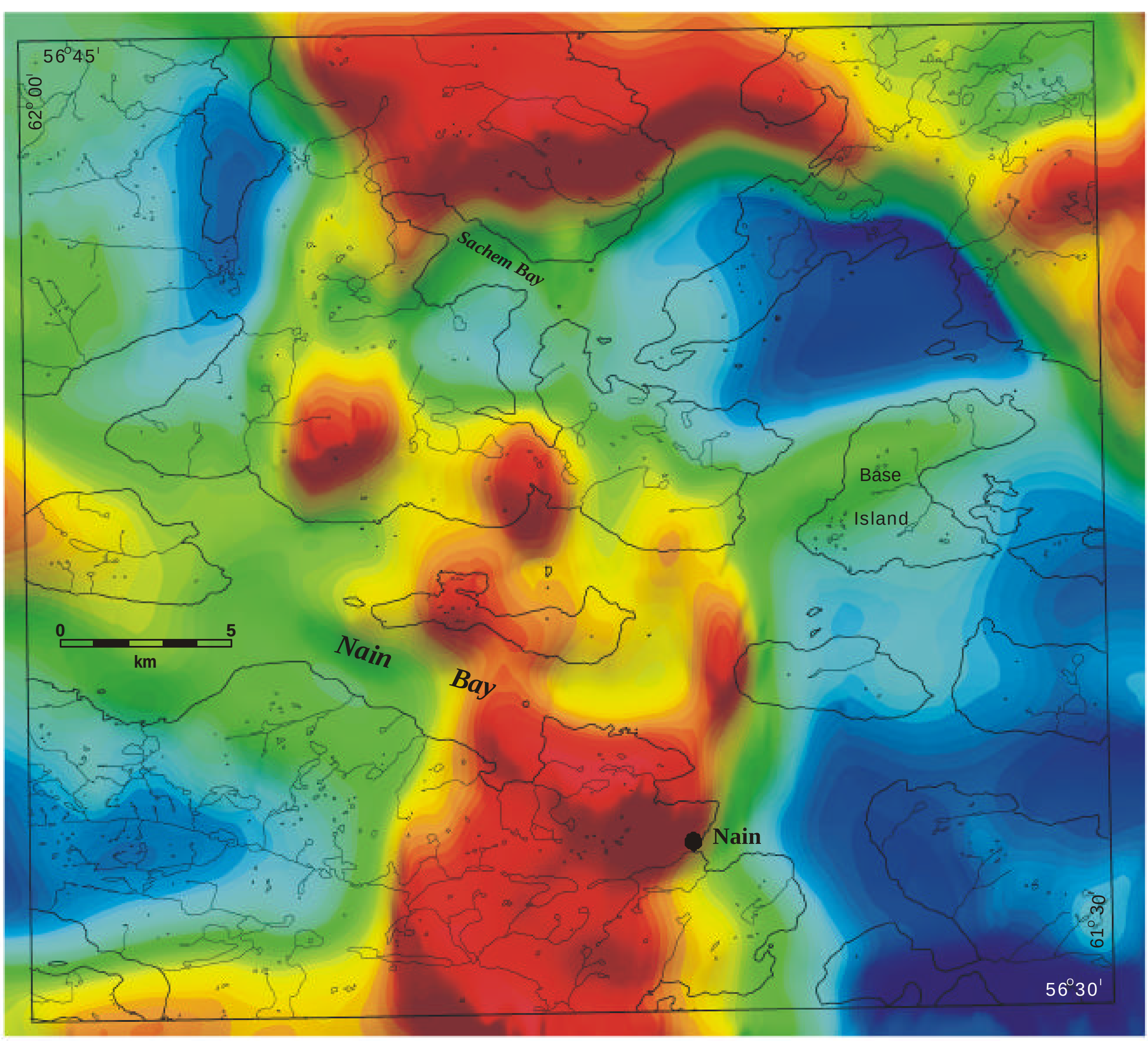

Figure 2a. *Shaded-relief map depicting aeromagnetic patterns for NTS map area 14C/12 derived from the Geological Survey of Canada database; highly magnetic rocks are indicated by shades of red, whereas low magnetic rocks are shown by blues. The north–south high of the gneisses and plutonic rocks in the central part of the area contrasts with the bordering lows over similar rocks. The green shaded area that bisects the low on the east side of the image is the expression of the Satosoakulluk ferrodiorite dyke. Image generated and supplied by G. Kilfoil. (*See *Figure 1 for geographic and geological names.)*

in the framework of the regional geological history (*see* later discussion). One of the interesting facets of the rocks of the Nain area is illustrated by the regional magnetic signatures of the rocks (Figure 2a) – a noticeable north–south magnetic "ridge" is formed by many of the plutonic rocks through the central part of the map area, yet lithologically similar rocks to the east and west are relatively "flat". High-magnetic versus low-magnetic patterns in the area south of Okak Bay can be used to reliably separate Paleoproterozoic intrusions from those of the NPS (Ryan *et al.*, 1998), but application of this criterion to the signatures here must be tempered with caution. It is clear from Figure 2b that even more meaningful local patterns are evident when the more detailed aeromagnetic surveys conducted by the exploration companies are "dropped into" the regional data.

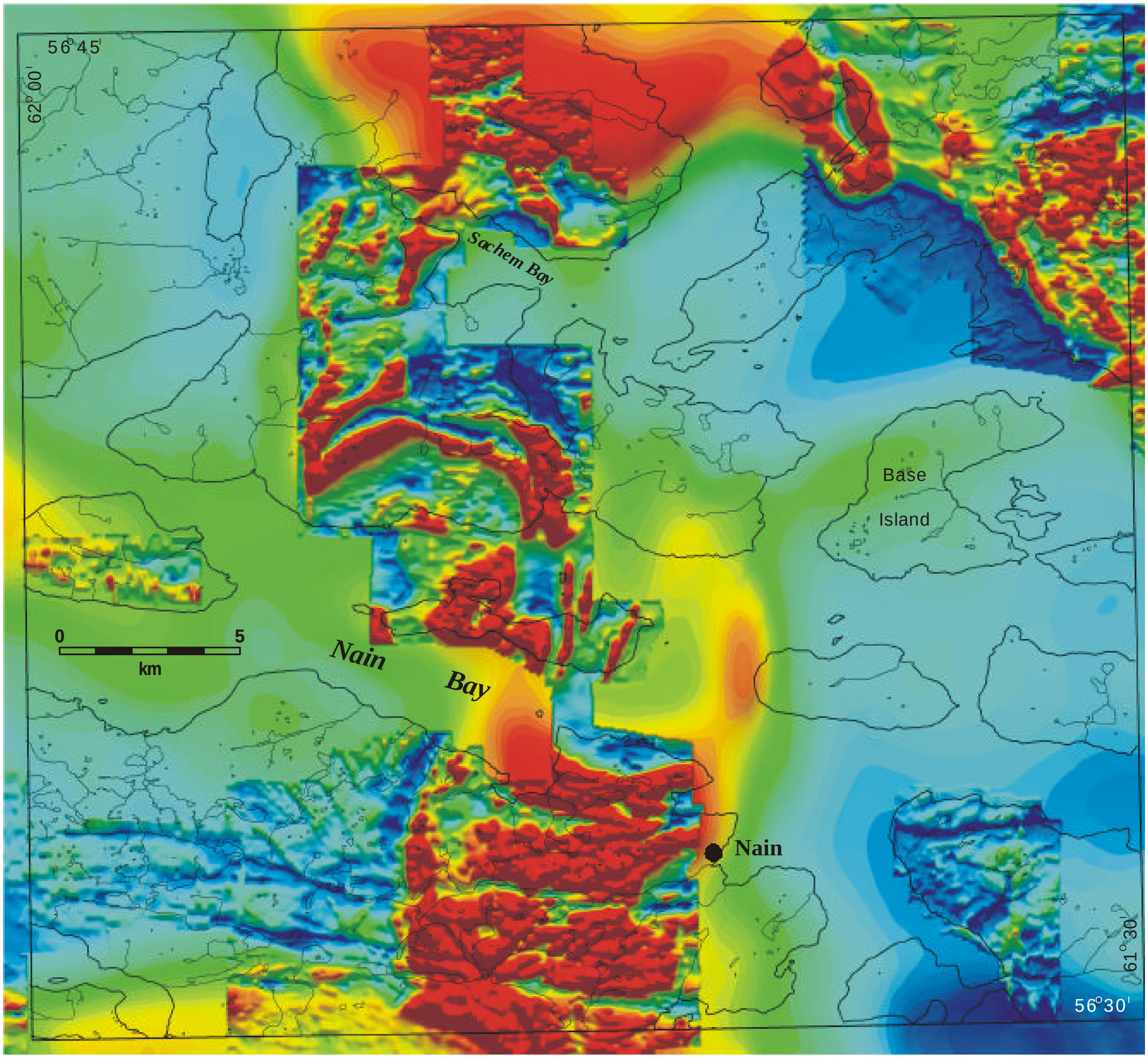

Figure 2b. *Shaded-relief map similar to 2a, but here having the detailed surveys of mining exploration companies superimposed on the regional data.. The contrast between the low magnetic pattern of the Mount Lister pluton and the high-magnetic pattern of gneisses and plutons to the east of it on the south side of Nain Bay is quite evident. Note also the expression of such rocks as the Archean gneisses and assumed Paleoproterozoic gabbro at Challenger Cove (contrast with The Bridges intrusion), the concentric ring structure of ferrodiorites crossing Nain Bay, the abrupt truncation of the northern ring pattern of ferrodiorite between Nain Bay and Sachem Bay, the abrupt truncation of this same high fingerprint along its western side, the trace of the Satosoakulluk dyke at the east end of Barth Island, and the trace of SE-oriented dykes in the Mount Lister pluton south of Nain Bay. (*See *Figure 1 for geographic and geological names.)*

GNEISSOSE ROCKS OF ASSUMED ARCHEAN AGE

Gneissic rocks assumed to belong to the Nain Province, and thus Archean in age, are exposed as narrow belts between the plutonic rocks through the central part of the area. Current mapping, along with the earlier work of Rubins (1971, 1973), indicate these gneisses stretch from Webb's Bay to the southern extent of the map area. They clearly constitute the country-rock envelope to the plutonic rocks, but the nature of the contact between the two varies. It is not everywhere possible to separate the gneisses from plutonic rocks based on their magnetic expressions, yet in some places the contrast is quite striking (compare Figures 1 and 2b).

The gneisses are predominantly granulite-facies migmatitic rocks, but they are locally retrogressed to amphibole- and chlorite-bearing types, and are particularly well exposed along the south shore of Webb's Bay, just north of the present survey area. Quartzofeldspathic gneisses derived from igneous precursors are the regionally most extensive type, within which are a myriad of mafic to ultramafic rocks, measuring from centimetres to hundreds of metres in maximum dimension; rare meta-leucogabbro and anorthosite are generally several metres in size. Locally, such as on the south shore of Webb's Bay and on the peninsula at the entrance to Challenger Cove, there are metre-scale mafic units containing plagioclase feldspar crysts (Plate 1); these units resemble dismembered porphyritic Saglek dykes, a distinctive component of crust of early Archean age in northern Labrador (*cf*. Bridgwater and Schiøtte, 1991). Some mafic gneisses are well-layered, probably derived from gabbroic intrusions or from volcanic rocks such as tuffs and attenuated pillowed lavas, and locally (e.g., south of Nain Bay) there are lighter coloured "spots" that appear to be decompression pseudomorphs of former garnets. Metasedimentary rocks were not noted as significant components of the gneisses that have been examined to date, but there are biotite-rich rocks among the migmatites on the Nain Bay shoreline south of Barth Island that have a blue cast suggestive of the presence of cordierite, and quartzite layers occur within the unit northeast of Conch Bay.

Plate 1. *Feldsparphyric mafic granulite layers, interpreted to be derived from porphyritic basic dykes, within migmatitic enderbitic gneiss. South shore of Webb Bay, just north of study area.*

Plate 2. *Ultramafic to mesocratic layering of The Bridges intrusion. North shore of Ten Mile Bay.*

PLUTONIC ROCKS OF POSSIBLE PALEOPROTEROZOIC AGE

There are two units of igneous rocks that are believed to predate the emplacement of the NPS. These are layered ultramafic to anorthositic rocks on the north side of Ten Mile Bay and massive to foliated gabbroic rocks exposed in the George's Island–Challenger Cove area.

Well-layered, easterly to southeasterly dipping rocks on the north and south sides of Ten Mile Bay, comprise centimetre- to metre-scale interlayered compositions ranging from ultramafic to anorthositic (Plate 2). Planansky (1971, 1973) examined these rocks in detail and named them The Bridges Layered Group, concluding they are a remnant of a previously larger olivine-bearing gabbroic to gabbronoritic intrusion preserved between two anorthositic intrusions (*see* section on Bridges lower contact relations). Ashwal *et al.* (1992) derived whole-rock Sm–Nd isotopic data from a series of rocks from The Bridges layered intrusion indicating a crystallization age of 1667 ± 75 Ma. If this is, indeed, the time of crystallization, then The Bridges layered intrusion is not part of the NPS, but rather is an example of late Paleoproterozoic magmatism that is otherwise unknown elsewhere in the Nain area (Ryan and Emslie, 1994).

The deformed gabbroic and gabbronoritic rocks at George's Island and Challenger Cove (Ryan, 1991) are surmized to be pre-NPS in age (Ryan, *in* Berg *et al.*, 1994; Ryan and Connelly, 1996; Connelly and Ryan, 1999). The major part of George's Island is composed of variably deformed and recrystallized medium-grained to coarse-grained gabbro. The original dark grey feldspars have locally recrystallized to fine-grained white aggregates, and hornblende has replaced the pyroxene. A similar gabbroic rock is also well preserved on the west side of Challenger Cove, where it contains orthopyroxene and prominent (primary?) black hornblende, but on the east side of the cove, near its contact with younger troctolite, it has been converted to a schistose rock of mafic granulite composition.

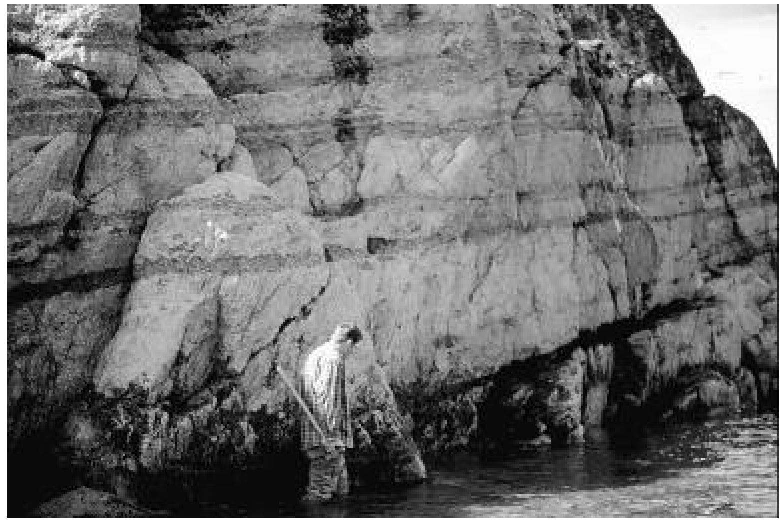

Plate 3. *Layering between anorthosite (pale) and subophitic leuconorite (dark) in the Mount Lister pluton. South shore of Tikkoatokak Bay.*

PLUTONIC ROCKS OF MESOPROTEROZOIC AGE–THE NAIN PLUTONIC SUITE

The Nain area is overwhelmingly dominated by rocks that have compositional linkages with the Mesoproterozoic NPS – namely, anorthositic, troctolitic, dioritic and granitic. At this time, it seems reasonable to assume that most are part of the NPS, but there is some uncertainty with the age designation for some of these rocks. This uncertainty will be discussed in greater detail in a later section.

Anorthositic Rocks

The majority of the plutonic rocks examined in the Nain area fall within this category. It is possible to make a major mineralogical field subdivision within this group between rocks that are (i) olivine-bearing and ones that are apparently (ii) olivine-free. Field relationships indicate that the two mineralogically distinct subdivisions can be further partitioned into separate intrusions, but the extent of these individual intrusions is nowhere totally defined. For convenience, the rocks are described below from west to east, the olivine-bearing types seemingly confined to the east.

Medium-grained to pegmatoidal (crystals of orthopyroxene and plagioclase locally in excess of a metre in maximum dimension), variably recrystallized, generally pale grey- to white-weathering, anorthosite and leuconorite occupy the western one-third of the survey area. These form the prominent bluffs around Nain Bay and Tikkoatokak Bay as well as being the rock type that forms the bald and imposing Mount Lister. This unit is here termed the Mount Lister pluton; its full extent is not known, but it is probably in excess of 35 km in a north–south direction. It has a low magnetic expression (Figure 2) because the opaque oxide is ilmenite; and this signature contrasts sharply with that of the magnetite-bearing gneissic and anorthositic rocks bordering it south of Nain Bay. Layering is locally well displayed (Plate 3), and attitudes measured between Nain Bay and Conch Bay indicate that the intrusion has a broad domal aspect. The unrecrystallized plagioclase within this intrusion is dark grey and locally exhibits a vivid deep blue schiller. The whole of the eastern margin of the Mount Lister pluton within the map area is a strongly foliated and more steeply dipping zone, up to 3 km in width, of pervasively recrystallized rock. South of Nain Bay, there is a very narrow (less than 50 m) outermost zone of layered and granular melanocratic basic rock.

At least three different intrusions are present in the region south of Nain Bay between the town of Nain and the east margin of the Mount Lister pluton. These intrusions differ from the Mount Lister pluton in having an abundance of magnetite, a fact quite strikingly demonstrated by the higher aeromagnetic pattern of the rocks proximal to Nain (Figure 2), but there is no sharp magnetic demarcation between these three intrusions. The largest, and possibly the oldest, of these intrusions underlies Nain itself, and is informally termed the Unity Bay pluton. It comprises massive clotted- to seriate-textured, variably chloritized/amphibolitized and epidotized, medium- to coarse-grained, leuconorite and anorthosite. South of Nain, this intrusion is generally undeformed although slightly recrystallized, and it locally exhibits a north-striking, gently west-dipping layering (Plate 4). West of the town an east-trending, north-dipping foliation and moderate amounts of recrystallization are locally quite noticeable, and north of the town, especially in the Akpiksai (Akhpikse) Bay area, the rock is generally pervasively recrystallized and deformed (*cf.* Hinchey *et al.*, 1999; Plate 5). The foliated northern part of the Unity Bay pluton is crosscut by a pluton of massive and undeformed leuconorite, within which, the (locally chloritized and amphibolitized) orthopyroxene has a more even distribution than in the rock it cuts (Plate 6). This intrusion is informally termed the Akpiksai Bay pluton because it outcrops west of that bay. Its full extent is unknown, but is tentatively extrapolated westward to encompass anorthositic rocks mapped by Rubins (1971) east of the large cove on the south shore of Nain Bay. The third intrusion identified west of Nain is one that is undeformed and locally internally layered, and is informally termed the Hosenbein Lake pluton because it was mapped north of Hosenbein Lake (Trousers Pond) and quite likely extends southward across the lake. Olivine gabbro, abutting the Archean gneisses, is interpreted to form the base of the pluton, although it could be unrelated to it. Eastward from the gabbro the rock is a clotted-textured, and locally well-layered, leuconorite that grades upward into seriate-textured leuconorite. The latter is locally choked with large inclusions of white anorthosite and leuconorite derived from the Unity Bay pluton (Plate 7); because of the varying percentages of older and younger rocks in outcrops where the two come in contact (i.e., it is a broad zone of breccia and dykes) a realistic junction between the Unity Bay pluton and the Hosenbein Lake pluton is difficult to portray at 1:50 000 map-scale. Other rocks south of Nain Bay (but not shown on Figure 1) that may be separate intrusions from those addressed in the foregoing include a northwest-trending, ill-defined, unit of friable, weakly foliated, granular to clotted-textured leuconorite abutting gneisses along the northeastern side of the Hosenbein Lake pluton, and a "dark facies" anorthosite south of Hosenbein Lake. The leuconorite is older than the Hosenbein Lake pluton, but its stratigraphic niche in the area is otherwise unknown. A "dark facies" olivine-bearing anorthosite has been described by Rubins (1971, 1973) from the area south of Hosenbein Lake, and its distribution as portrayed on Rubins' maps, combined with the aeromagnetic pattern of Figure 2b, can be used to argue that it is younger than the both the Hosenbein Lake pluton and the Mount Lister pluton.

Plate 4. *Gently inclined, west-dipping, layering between anorthosite and leuconorite in the Unity Bay pluton. Scale of feature provided by person near lower left corner of image. Below South Channel Cairn, Nain.*

Plate 5. *Pronounced foliation within layered anorthosite and leuconorite of the Unity Bay pluton. Note the narrow dyke of dark, granular "granulite" crossing the foliation. North shore of Akpiksai Bay.*

The central part of the survey area, north of Nain Bay, has not been systematically investigated. Reconnaissance work in 1992 on the highland east of Conch Bay (Ryan, 1993) revealed that a seriate-textured leuconorite transects gneisses as well as the foliated margin of the Mount Lister pluton, but no other subdivisions of the anorthositic rocks have been established. For the most part the coastal rocks, which remain undivided, are pale grey to white anorthosite and leuconorite, locally having single or aggregates of dark grey feldspar crysts (2 to 30 cm) and isolated fragments or segregations of orthopyroxene megacrysts (tens of centimetres in size). The pure anorthositic rocks are locally characterized by a net-texture of white lines somewhat similar to crazed pottery.

The eastern half of the Nain map area is underlain by anorthositic rocks that are orthopyroxene- and olivine-bearing, both minerals occurring either alone or together. These anorthositic rocks have low magnetic signatures, regardless of whether olivine or orthopyroxene is present; there is a faint hint of correlation between some geological and aeromagnetic patterns (compare Figures 1 and 2). The presence of olivine as a significant mineral in anorthositic rocks of the eastern half of the NPS has been previously pointed out by Xue and Morse (1993). The westernmost olivine-bearing rocks of this type occur in the Topsy Point–Sandy Point (Sioghakh) sector. Olivine-bearing anorthosite, leuconorite, and leucotroctolite also underlie parts of Base Island (Satorsoakulluk), Rhodes Island, Hillsbury Island (Kidlersoakh) (*cf*. Emslie, *in* Berg *et al.*, 1994), and Paul (Paul's) Island (*cf*. Wiebe, 1990). Relationships between olivine-bearing and olivine-free rocks are not consistent – in some areas, foliated and massive leucotroctolite occurs as rafts within leuconorite, and/or olivine-bearing rocks are intruded by olivine-free ones (e.g., Topsy Point, Base Island (Satorsoakulluk)), whereas in other areas there seems to be a gradational contact from olivine-only to olivine+ orthopyroxene-bearing to orthopyroxene-only rocks (e.g., northern Paul (Paul's) Island). The crystallization relationship between the coarsest olivine and orthopyroxene in all rocks is consistent: olivine has orthopyroxene haloes (Plate 8), or cores of olivine remain in orthopyroxene. Orthopyroxene-rimmed olivine mega-crysts were noted in some rocks where the intercumulus mineral is solely orthopyroxene. The following examples highlight some of the relationships between the olivine-free and olivine-bearing rocks in the eastern part of the survey area. Pale-grey, foliated (predominantly northerly striking, easterly dipping), olivine-bearing rocks (olivine anorthosite, leucotroctolite, and leuconorite) occupy the whole of the northwestern half of Base Island (Satorsoakulluk) (Plate 9), and are intruded by pegmatoidal, massive olivine-bearing anorthosite and leucotroctolite at the northeastern point of the island. The foliated olivine-bearing rock is intruded by a pale-grey, massive, medium-grained leuconorite pluton that occupies the central part of the island, a pluton that similarly intrudes a variably recrystallized and locally foliated leuconorite at the southeast tip of the island. Massive grey anorthosite and leuconorite intrude foliated olivine-bearing leuconorite along the north shore of Hillsbury Island (Kidlersoakh); the south shore of the island seems to be predominantly leucotroctolite (*cf*. Emslie, *in* Berg *et al.*, 1994). There appears to be a broad gradational contact, or somewhat haphazard distribution, between olivine-bearing and olivine-free rocks along parts of the shoreline of northern Paul (Paul's) Island, on several small islands in Harmony Run known as The Turnpikes, on the islands located in the bay on the east side Base Island (Satorsoakulluk), and to the south of Topsy Point. Rafts of olivine-bearing rock are clearly present in the anorthositic to leuconoritic rocks in all these areas, but the host to the rafts certainly has olivine. The geology of western Paul (Paul's) Island has been investigated only on the coast. It was noted earlier in this report that olivine occurs in rocks along the northern coast of the island, an observation at variance with the work of Wiebe (1990) and Ashwal *et al.* (1992) which portrays this area as "Northern Leuconorite" apparently lacking olivine. Pale grey to brownish-grey, foliated leuconorite, south of Two Mile Bay on Paul (Paul's) Island (the "pale facies anorthosite" of Planansky (1973) and the Lower Leu-

Plate 6. *Layered and foliated leuconorite and anorthosite as a raft enclosed by massive leuconorite of the Akpiksai Bay pluton. West of Akpiksai Bay.*

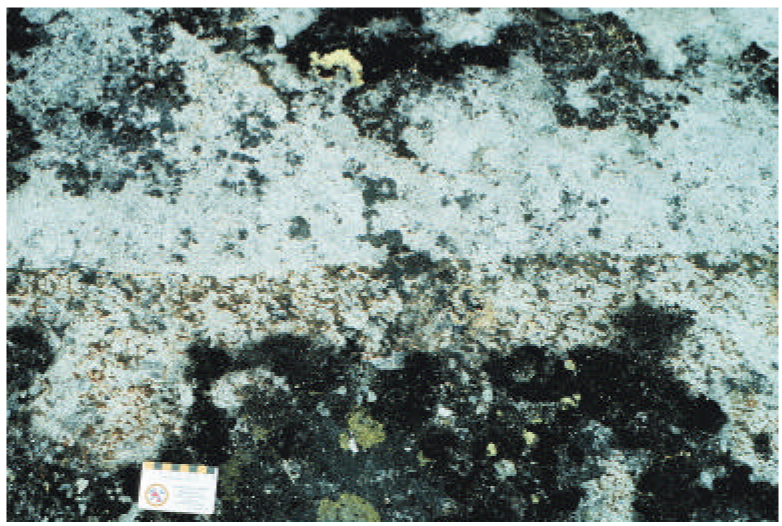

Plate 7. *Sharp, straight contact between an inclusion of white recrystallized anorthosite of the Unity Bay pluton (top) and the hosting leuconorite of the Hosenbein Lake pluton (bottom), within a broad zone of breccia that marks the contact between the two intrusions. North of Hosenbein Lake.*

conorite of Wiebe (1990)) has a consistent easterly strike and shallow- to moderate south-dipping fabric displayed by a preferred orientation to elongate clotted-texture; this orientation apparently changes to northeast trending and southeast dipping in equivalent rocks on the south side of the bay (Planansky, 1973; Wiebe, 1990). The foliated leuconorite is herein provisionally re-named the Quarry pluton because it is host to an active and an abandoned dimension-stone quarry along Ten Mile Bay; the name used herein also eliminates the stratigraphic connotations of the lithodemic name used by Wiebe (1990).

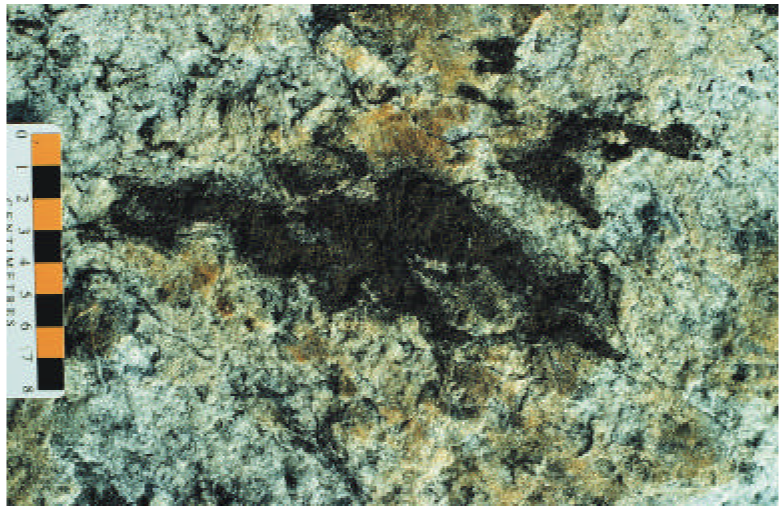

Plate 8. *Olivine, exhibiting a rind of orthopyroxene, within leucotroctolite. North shore of Base Island.*

Troctolitc Rocks

Olivine-bearing rocks (troctolite and olivine-bearing gabbro(norite)), which are distinct from those included within the anorthositic subdivision above, occur as significant units in only three areas examined, i) both shores of Nain Bay and the intervening Barth (Pardy's) Island, ii) the region between Webb Point and the entrance to Sachem Bay, and iii) east of Challenger Cove. The troctolitic rocks spanning Nain Bay across Barth Island were studied extensively in the 1970s (Rubins, 1971; de Waard and Mulhern, 1973; Mulhern, 1974; Levendosky, 1975; de Waard, 1976) as part of an examination of the "Barth layered structure" or "Barth Island structure". The foregoing unit names were coined by de Waard to indicate the fact that troctolitic, jotunitic (ferrodioritic), and adamellitic (monzonitic and quartz monzonitic) rocks in this area appeared to be all part of a single, oval, layered intrusion. The status of the "Barth layered structure" as a coeval and genetically related series of rocks is in need of re-evaluation, so the components that have been assigned to it in the past are described in this report as separate lithologic units, with reference to relationships between them, as appropriate.

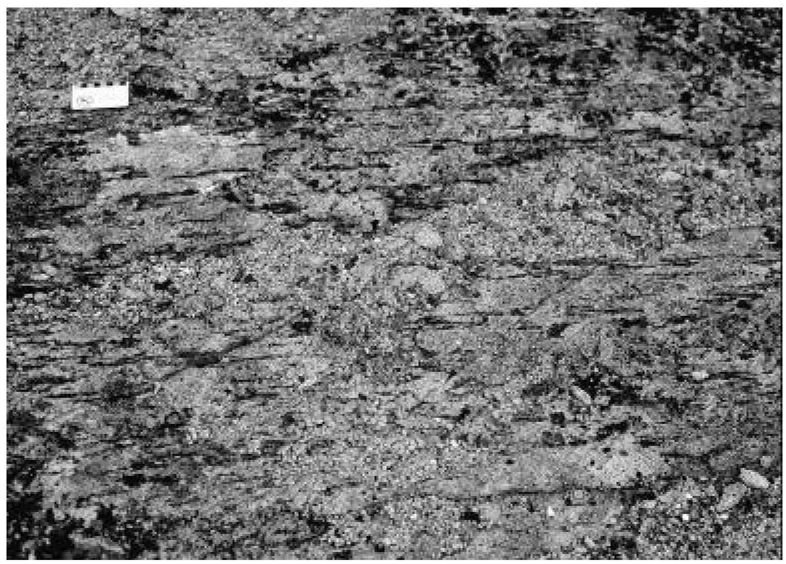

Plate 9. *Strongly foliated leucotroctolite. Eastern side of Base Island.*

Troctolitic rocks of the coastal Nain Bay area are fine to medium grained, grey–green to brown, and massive to very diffusely layered. The complete distribution of these as portrayed on Figure 1 is a combination of the results of this survey plus the earlier work of de Waard and his students as referenced earlier. The rocks inland and north of the bay were described by Rubins (1971), de Waard and Mulhern (1973) and Mulhern (1974) as being fine- to medium-grained, brown troctolite having a density-graded layering and prominent bronze-coloured biotite. Layering attitudes exhibited by the whole unit of troctolitic rocks indicate it forms a basinal structure, but whether it has the fanciful fluted shape envisaged by de Waard and Mulhern (1973) is questionable.

The true distribution of the troctolitic intrusion depicted sitting atop the gneisses north of Sachem Bay is not known. Fine- to medium-grained brown-weathering troctolite to olivine gabbronorite, apparently intruded by the dark grey leuconorite nearby (Plate 10) is well exposed on the north point entrance to Sachem Bay, and it was observed on one inland traverse in the vicinity of Tikkiraluk Hill. It is a grey green to dark brown rock similar to the Barth troctolites, and has poikilitic orthopyroxene and conspicuous biotite locally.

Troctolite east of Challenger Cove is a black, relatively coarse-grained rock in which both plagioclase and olivine vary from 1 to 10 cm in size. Pegmatitic patches containing black hornblende and needles of zircon(?) are locally present. This troctolite is part of the Port Manvers Run Intrusion (*cf.* Wiebe, 1992, p. 231).

Dioritic and Hybrid Rocks

Brown-weathering and locally friable, granular- to gabbroic-textured rocks of this subdivision are most abundant on Barth Island and to the north of Nain Bay, but limited work on the upland area to the north of Sachem Bay indicates that there may be a significant intrusion of such rocks there. A prominent northeast-trending dyke of diorite (the Satorsoakulluk dyke) can be traced from Barth Island to Base Island (Satorsoakulluk), and smaller dykes of such rocks occur on another island in the same area. Irregular subhorizontal sheets and subvertical dykes of magnetite-rich diorite occur in the general vicinity of Nain, and have been the focus of past exploration activity because they also carry sulphide mineralization.

Plate 10. *Diffusely layered reddish brown troctolite, invaded by dark-grey leuconorite. Nature of boundary between the two rock-types suggests the troctolite was not completely solidified at the time the leuconorite was emplaced. North shore of entrance to Sachem Bay.*

The dioritic rocks in the Nain Bay – Barth Island area that were investigated in the 1970s by de Waard and his students and at that time, were referred to as fine-grained norite, gabbro, and jotunite, based on the mineral assemblages, but Emslie (*in* Berg *et al.,* 1994) introduced "ferrodiorite" as an all-encompassing term based on their whole-rock and mineral geochemistry. The ferrodiorite on Barth Island occurs at two stratigraphic levels relative to the troctolite, *viz.,* above it and below it. This geometry exists on the north side of Nain Bay as well, but Mulhern's mapping implies there is also an interfingering relation with the troctolite between Nain Bay and Sachem Bay (*see* Figure 15 of de Waard and Mulhern, 1973; *see* Figure 3 of Mulhern, 1975). The ferrodiorite on the south shore of Nain Bay is texturally different from the two units examined on Barth Island. Rubins (1971) concluded the one proximal to Nain was an intrusion separate from those on Barth Island; Rubins and de Waard (1971) concluded that it was a "marginal facies of the anorthosite" to the south. All the ferrodioritic rocks have a very prominent high magnetic signature, and the crescentic outcrop pattern shown on the maps of Rubins (1971, 1973) and Mulhern (1974), as well as the narrow linear units and the central zone on Barth Island, are well matched by the aeromagnetic data (Figure 2b). A sharp east–west break in the aeromagnetic data along the north shore of Nain Bay is interpreted to correspond with a sinistral fault that offsets units across Nain Bay (de Waard, 1976). An abrupt break in the high magnetic pattern of the northern ring between Nain Bay and Sachem Bay (Figure 2b) suggests that the ferrodiorites here are truncated by the seriate leuconorite (*see* Figure 2a). The foregoing interpretation is not borne out by the mapping of Mulhern (1974) but has some support in that the writer visited one outcrop within Mulhern's "outer jotunite" zone on the west side of Sachem Bay and found it to be grey leuconorite. It is also compatible with the mapping of Rubins (1971) who portrayed the area north of the large C-shaped lake as being underlain by "pale facies anorthosite".

The lowermost, or marginal, ferrodiorite on Barth Island rests on gneisses on the islet to the west and on anorthosite at the east end of Barth Island itself. This ferrodiorite crystallized at ca. 1322 Ma (Hamilton *et al.,* 1994). On the westernmost shore of Barth Island, it is a well-layered rock in which the metre-scale layering is, in some cases, characterized by a finer grained lower section having a sharp base, grading upward through a more feldspar phyric (hybrid?) rock containing increasing-upward concentrations of oval to subhedral potassium(?) feldspar crysts, into what appears to be a monzonitic two-feldspar (+olivine+pyroxene?) crystal cumulate. Some layers have lobate and irregular bases against the feldspathic "cumulate" (Plate 11). Some layers crosscut other layers in a manner akin to erosional channels in sedimentary rocks. The ferrodiorite and associated hybrid rocks seem to grade up into monzonite and quartz monzonite, the latter having an intrusive contact against troctolite. At the eastern end of the island, fine-grained ferrodiorite, locally having streaky trains of (potassium?) feldspar, sits directly on grey leuconorite; the monzonitic rocks that occur above the ferrodiorite at the west end appear to be missing here, and there is an abrupt and indeterminate junction with the overlying troctolite. The ferrodiorite that overlies the troctolite is very poorly exposed through the centre of Barth Island. Where it was examined along the north coast it is overall coarser grained than the lower unit, lacks the layering, but has inhomogeneity in texture and contains finer grained ellipsoidal to amoeboid darker enclaves. Rocks assumed to be ferrodiorite on the south shore of Nain Bay differ from the rock on Barth Island by lacking the associated sharp and repetitive layering as well as the isolated to substantial accumulations of crystals of potassium(?) feldspar. Instead, it is a granular gabbronoritic or granulitic rock (Rubins, 1973) that has a diffuse and somewhat streaky layering of the mafic and felsic constituents, and has local aggregates and trains of grey subhedral to euhedral plagioclase (Plate 12).

Plate 11. *Ferrodiorite containing numerous crysts of potassium(?) feldspar (bottom) grading up into a coarse-grained monzonite (centre), the latter in sharp contact with massive fine-grained ferrodiorite having a lobate base (top). West shoreline of Barth Island.*

The distribution of the ferrodiorite north of Sachem Bay is probably not reliably portrayed on Figure 1 because it has not been sufficiently traversed. The pattern indicated on the figure is predicated on isolated outcrops north of Webb Point and on the north shore of Sachem Bay, as well as on a few inland exposures examined by helicopter reconnaissance in 1991 and on a short traverse in 1999. The detailed aeromagnetic pattern in this region is not helpful in distinguishing the probable extent of this intrusion because there is little distinction from abutting rocks (Figure 2b). The rocks north of Sachem Bay have many mesoscopic features in common with the ferrodiorites at the west end of Barth Island, including being brown and fine grained, locally layered, and having ovoid crysts of potassium(?) feldspar; monzonitic and quartz monzonitic rocks locally encountered within this unit are seemingly interlayered with the mafic rocks.

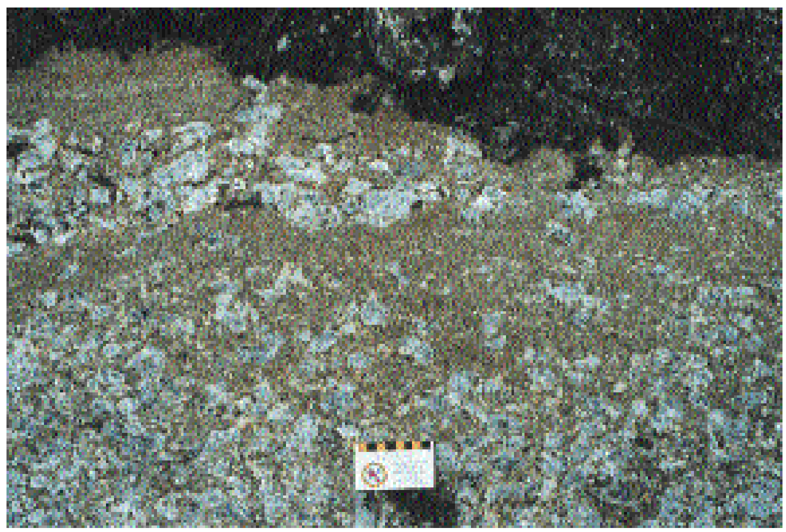

Plate 12. *Grey plagioclase feldspar forming a zone of connected and disaggregated grains within granular ferrodiorite. North of Akpiksai Bay.*

A large arcuate dyke of "gabbroic" rock was first identified between Barth Island and Base Island (Satorsoakulluk) by Wheeler (1942), and illustrated among the "minor intrusions" on his 1957 compilation map of the Nain area (Wheeler, 1960). This dyke was subsequently examined in some detail by de Waard and Hancock (1974) who indicated a gabbroic–granodioritic composition, and it was given the name Satorsoakulluk dyke on the compilation map of Ryan (1990). Emslie (*in* Berg *et al.*, 1994) briefly examined the dyke in the early 1990s and concluded that it is chemically, if not mineralogically, equivalent to the ferrodioritic rocks. Geochronological studies of the dyke indicate a crystallization age of ca. 1301 Ma (Hamilton *et al.*, 1994), significantly younger than the ferrodiorite of Barth Island. The previous work has shown that the dyke is exposed over a distance of approximately 20 km, can be up to 400 m wide but is locally a series of parallel narrower intrusions, and it appears to be a cone sheet or ring dyke that dips 50 to 65° south to southeast. De Waard and Hancock (*op. cit.*) reported that the rock is composed of plagioclase, approximately equal volumes of clino- and orthopyroxene, and interstitial quartz, potassium feldspar, hornblende and biotite, and accessory zircon, apatite and magnetite. They also recorded the locally poikilitic aspect of orthopyroxene, hornblende, quartz and potassium feldspar. The Satorsoakulluk dyke is (where examined during the 1999 survey) a variable rock; it is massive to layered, displays abrupt changes in grain size and texture over small areas, locally has poikilitic black hornblende, locally has isolated grains or clusters of potassium(?) feldspar crysts, has local accumulations of pillowed finer grained rock, and has a wide variety of inclusions. Some features not emphasized nor mentioned in previous literature are worthy of note because they reveal some interesting aspects of the dyke. For example, pillowed finer grained massive rock supported by a coarser grained phase – the whole containing blocks of layered oxide-rich dioritic rock and a diatreme-like breccia – is well exposed on the south shore of Barth Island (Plate 13). Additionally, the dyke intrudes foliated leucotroctolitic and olivine-bearing leuconoritic rocks along the north shore of Barth Island, but most of the rafts within the widest of the several parallel dykes here, comprise undeformed seriate-textured leuconorite that is different from local country rock. A dyke of ferrodiorite, similar in width and trend to the dyke, also forms the central part of the largest island in the bay, east of Base Island (Satorsoakulluk), and disappears under unconsolidated cover to the west. The location of the Satorsoakulluk dyke is splendidly displayed in the detailed aeromagnetic data for eastern Barth Island (Figure 2b), and it is even detectable in the regional data as a higher ridge trending across northern Base Island within an otherwise "anorthositic low" (Figure 2a).

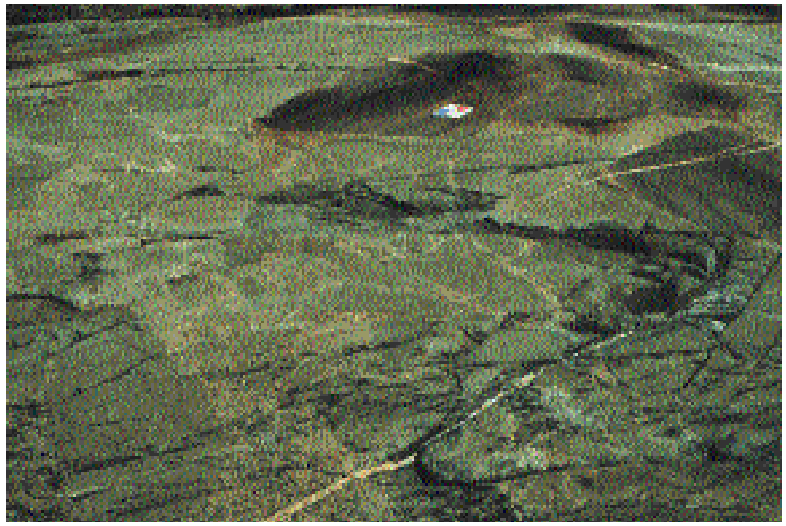

Plate 13. *Angular, rusty, layered and foliated, oxide-rich, dioritic blocks within the Satorsoakulluk dyke. The dyke here has a composite groundmass of coarse ferrodiorite having pillowed enclaves of finer grained "basaltic" rock. Note the encroachment of the pillowed component into the space between the two blocks at top right. South shore of Barth Island.*

An interconnected network of centimetre to tens-of-metre scale, chocolate-brown- to ochre-weathering, granular dykes is present in, and postdates deformation of, anorthositic rocks west and northwest of Akpiksai Bay. Generally, these are magnetite-rich dykes that are diffusely layered in places; they locally display a weak foliation parallel to strike, and have scattered, cream-coloured (pheno?)crysts of potassium(?) feldspar and grey xenocrysts of plagioclase. The dykes also contain local concentrations of sulphide minerals and were subjected to intensive investigation by NDT Ventures between 1995 and 1997 (*see* Economic Geology section). Kerr (1998), Hinchey *et al.* (1999) and Hinchey (1999) referred to these rocks as gabbronorite on the basis of modal composition, but they are considered to belong to the ferrodiorite "family" of the NPS because of their clearly iron-enriched character and their textural characteristics. Magnetite-rich, layered, ferrodiorite and pyroxenitic dykes, perhaps related to those west of Akpiksai Bay, also occur at several points along the ridge west of Nain (*cf.* Hinchey *et al.,* 1999), where they have intruded anorthosite and leuconorite of the Unity Bay pluton (Plate 14), as well as a layered series of mafic to ultramafic rocks of uncertain affinity. These dykes were also investigated for base-metal sulphide potential by NDT Ventures.

Granitoid Rocks

This subdivision of the NPS is the least voluminous of the rocks examined during the 1999 season. These rocks fall into four geological and geographic niches: foliated fayalite monzonite peripheral to the Mount Lister pluton, foliated monzonite to quartz monzonite within the "Barth layered structure", foliated monzonite to quartz monzonite north of Sachem Bay (not shown on Figure 1), and layered monzonite west of Sachem Bay

Foliated to gneissic, fayalite-bearing granitoid rocks were first recognized as external to the deformed and recrystallized anorthositic to leuconoritic margin of the Mount Lister pluton along the shoreline of Webb's Bay by the writer in 1990 (Ryan, 1991; Ryan, *in* Berg *et al.,* 1994), and were traced northward and southward across the bay in 1992 (Ryan, 1993). These foliated rocks are apparently discontinuous units, but are interpreted to be remnants of a previously more continuous sheath peripheral to, and intimately associated with, the Mount Lister pluton, and display the same deformation as the adjacent pluton. This type of monzonitic rock has now been identified along the Mount Lister margin south of Nain Bay, here too abutting Archean gneisses. Generally, these are pale-brown- to pink-weathering, fine-grained, granular rocks that are clearly green on freshly broken surfaces. However, the deformation does not mask that they were originally coarser grained rocks locally, having perthitic feldspars up to a couple of centimetres in length.

Plate 14. *Rusty, oxide- and sulphide-bearing meladiorite to pyroxenite forming a ramifying network cutting white anorthosite of the Unity Bay pluton. West of Nain.*

Granitoid rocks occur on both sides of Nain Bay, along the west shore of Barth Island, and along the southwest shore of Pikaluyak, within the confines of the so-called Barth layered structure. The setting of these was examined as part of the investigations undertaken by de Waard and his students in the early 1970s. The granitoid rocks at the west end of Barth Island (*cf*. de Waard, 1976) are, as alluded to in the previous section, an intimate part of the layered ferrodioritic succession there, generally as coarse-grained rocks having a gradational contact with, and covering, the tops of ferrodiorite layers. The uppermost, and most extensive, granitoid unit of this area is a buff-weathering, seemingly fayalite-bearing, coarse-grained monzonite that is in abrupt contact with a ferrodiorite; the nature of this contact and the relative age of the two rocks are not established. This monzonite passes upward into a brownish-orange- to white-weathering even-grained to porphyritic quartz monzonite locally having oval quartz and plagioclase-mantled potassium feldspars, which is intrusive into, and contains amphibolitized angular fragments of, the troctolite to the east.

The crescentic monzonitic to quartz monzonitic unit on the south shore of Nain Bay is one of the most extensive within the "Barth layered structure". It is a buff-, grey-, pink- and white-weathering rock containing irregular to oval quartz, from which Rubins (1973) has documented olivine, clinopyroxene, and orthopyroxene as the main mafic minerals. The contact with the underlying fine-grained granular gabbronorite (ferrodiorite?) has not been seen, but Rubins (1973) interpreted the monzonitic rock (adamellite) to be younger. The contact between the layered, foliated monzonite and the overlying troctolite is exposed at its eastern end and on the southwest coast of Pikaluyak. There is a veneer (a few centimetres to a few metres thick) of ferrodiorite atop the monzonite and locally mingled with it, separating the main monzonite unit from troctolite at both locations; this ferrodiorite, as well as the monzonite, penetrates the overlying troctolite at both locations. Elliptical and elongate, mafic enclaves having crysts of feldspar (xenocrystic from the host?) within monzonite on the south side of Nain Bay are aligned parallel with the foliation within it; there is a jagged interface between some of the enclaves and the coarse crystal network of the host (Plate 15). No troctolitic fragments are present in the distal younger rocks at either locality.

Pyroxene- and hornblende-bearing monzonite and quartz monzonite, having ovoid feldspars and aggregates of "drop" quartz were observed in a couple of locations during a single traverse in the highland area west of Webb Point. There, like on Barth Island, these rocks are in mingled and apparently gradational contact with adjacent ferrodioritic rocks, and hybrid mixtures of the two are locally developed.

A body of diffusely layered, fine-grained olivine–clinopyroxene monzonitic to quartz monzonitic rock, locally displaying a mingled component of fine-grained ferrodiorite, was partly outlined west of Sachem Bay in 1992 (Ryan, 1993). The layering dips moderately to the east. The intrusion has been emplaced into mylonitic gneisses bordering the eastern side of the Mount Lister pluton, and the map pattern indicates that it "unconformably" overlies the foliated margin of the Mount Lister pluton but is intruded by seriate-textured leuconorite at its southern end. The full extent of this composite body has not been delineated, but it could be a southward extension of the mingled ferrodioritic and monzonitic rocks north of the Sachem Bay.

LAYERED TO GNEISSOSE AND PLUTONIC ROCKS OF INDETERMINATE AGE AND PARENTAGE

This subdivision of the rocks encompasses some of the rocks that Wheeler (unpublished maps) referred to as "granulites of uncertain origin" (*cf*. Wheeler *et al.,* 1984). The subdivision within this report similarly denotes one in which the rocks are of equivocal relative stratigraphic position because some components have similarities to the Archean gneisses, yet others have similarities to the Mesoproterozoic anorthositic intrusions. The three most outstanding units of this type are dominated by mafic and ultramafic rocks, and are located west of Webb's Point, at the west end of an islet west of Barth Island, and south of Akpiksai Bay. The first two of these belts are too small to illustrate on Figure 1.

The first unit was examined in only two outcrops along the eastern edge of the gneiss unit shown on Figure 1, where it comprises well-layered, but not significantly migmatized, mafic and ultramafic rock. The former are dark green to black rocks having fine-grained grey anorthositic layers, and white spots seen in mafic enclaves within the Archean gneisses elsewhere in the area and attributed to "ghost garnets". There is field evidence to suggest that these mafic rocks are part of the Archean gneisses because they are veined by granitic sheets similar to the quartzofeldspathic gneisses nearby. The dark brown, olivine- and brown-hornblende-bearing, layered melanocratic mafic to ultramafic rocks are, however, devoid of these granitic sheets, but are intruded by white anorthositic veins. Rocks of this overall character are also present along the southern edge of the Hettasch intrusion north of Webb's Bay (Ryan, 1993).

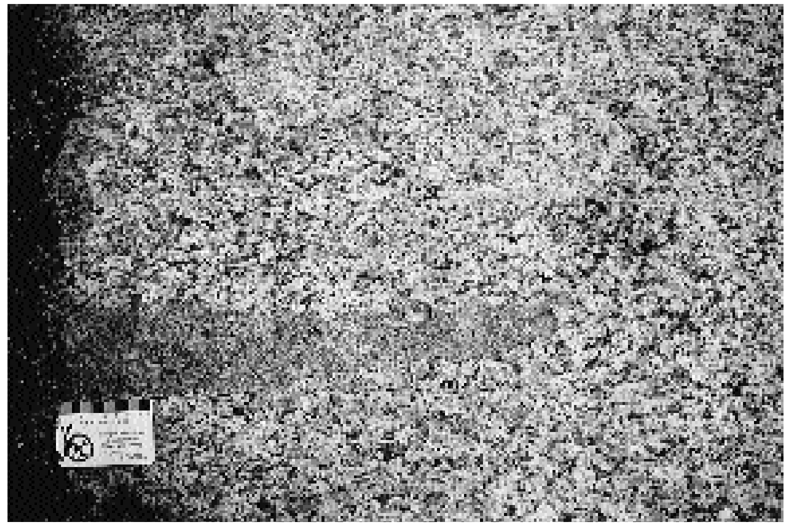

Plate 15. *Elongate mafic enclave within quartz monzonite. Note the irregular contact of the enclave against the enclosing rock, and feldspar crysts, like those of the monzonite, within the enclave. North of Akpiksai Bay.*

The second unit is a diverse series of layered anorthositic to ultramafic rocks that is well exposed at the west end and along the northern coast of the small islet near the western end of Barth Island. The main unit is a rusty-weathering, layered and foliated, friable rock that is mainly gabbronoritic in composition. Locally, it displays well-preserved subophitic texture and has numerous dark-grey plagioclase crysts, and, like the first unit at Webb's Point, the more melanocratic rocks contain olivine and brown hornblende. Associated with these layered gabbronoritic compositions are streaky foliated leucogabbronoritic rocks having L>S fabrics, as well as isolated dark-grey plagioclase crysts and dark-brown orthopyroxene megacrysts. The gabbronoritic and leucogabbronoritic sequence is bounded to the east and west by a leucocratic pale buff rock resembling an anorthosite, within which are numerous fragments of mafic and ultramafic rock and white anorthosite; the pale buff rock is seen in thin section to contain significant quartz and is thus tonalitic in composition, and therefore could be interpreted as a less deformed example of the plutonic precursor to the regional quartzofeldspathic gneiss sequence.

The third and largest of the units grouped within this map subdivision is the one that trends east–west near Nain, exposed on the ridge above the town and west of Akpiksai Bay (Barbour and Dearin, 1996). The continuity of the belt from east to west has not been traced, and there is enough deviation between strike to suggest that they may be two separate, but similar, sequences. For illustrative purposes the rocks are shown on Figure 1 as a single sequence. Unlike the first two units just discussed, the unit near Nain is enclosed by anorthositic rocks, yet has within it rocks that are of anorthositic composition. The Nain unit, as outlined here, comprises mafic, ultramafic and mesocratic rocks interlayered on the centimetre to meter scale (Plate 16), as well as massive leuconoritic rocks of unequivocal plutonic origin (*see below*). There is a lack of migmatitic structure in these rocks compared to the proximal granulite-facies gneisses, but a few, foliated, blue-quartz-bearing granitic sheets have been observed west of Akpiksai Bay. The layered part of the succession appears to define a coherent sequence, which on the ridge above Nain has pale grey, foliated and folded leuconoritic to anorthositic gneiss and mesocratic gneiss at its base, overlain by a layered sequence of interlayered mafic and ultramafic rocks. Mesocratic gneisses structurally overlain by mafic and ultramafic rocks are also present west of Akpiksai Bay, but here there appears to be an overlying layered anorthositic unit as well. The sequence west of Akpiksai Bay is in modified (sheared) intrusive contact against foliated leuconorite of the Unity Bay pluton on its southern side, but is discordantly intruded by a massive leuconorite of the Akpiksai Bay pluton on its northern side. Both areas of layered rocks contain white granular anorthosite that occurs as layer-discordant and layer-parallel centimetre-scale dykes within the mafic–ultramafic rocks; these dykes are folded by the isoclinal folds that affect the layering of their host. In addition to the folded granular anorthositic dykes, there are sharp-walled and straight leuconoritic dykes that postdate the deformation.

Massive to weakly foliated to gneissose, mauve–grey to brown–grey leuconorite, anorthosite, and associated granular to weakly layered gabbronoritic rocks seem to intrude and split the well-layered sequence on the ridge above Nain. At the easternmost flank of the ridge, the layered and granular rocks of this leuconoritic–anorthositic unit contain sills of epidote-spotted and chloritized white leuconorite; rafts of the granular rock occur in the sills. These relationships, along with the 1:50 000-scale map pattern of this leuconoritic–anorthositic unit leads to the suggestion that it, like the well layered "granulites", is enclosed by, and also older than, the foliated to recrystallized white leuconorite of the Unity Bay pluton.

Plate 16. *Layered and foliated mesocratic (gabbronoritic) to leucocratic (anorthositic) rocks of uncertain affinity. These are intruded by the Unity Bay pluton. Ridge above Nain town.*

MINOR INTRUSIONS OF SEVERAL GENERATIONS

The major units previously addressed are crosscut by a myriad of minor intrusions (basic, dioritic and granitic dykes); they are not illustrated on Figure 1. The intrusions are clearly of more than one generation, but intersections are so rare that generalized statements regarding their relative ages are not warranted, and the absolute times of emplacement are impossible to ascertain. All of these intrusions display differing characteristics and volumes within the region, and the following examples provide some indication of this. As a general comment (and probably a reflection of the differing degrees of examination of various parts of the area, rather than a real pattern) there appears to be a greater abundance of these type of intrusions in the anorthositic rocks near Nain than in similar rocks on the distal mainland and islands.

There are several types of basic dykes within the gneissic septum that separates the Mount Lister pluton from the Hosenbein Lake pluton south of Nain Bay. The field character of these dykes implies that they may all be "granulites", but contemporaneity of intrusion cannot be demonstrated. It is clear from the observed structural relationships that some of these dykes adjacent to the Mount Lister pluton postdate the development of the gneissic layering but predate the development of a subsequent structural overprint ("straightening") on their hosts. Other, foliated and/or gabbroic textured dykes in the gneisses distal from the high-strain zones may be the same age, but no dyke has been traced from the low-strain areas into the overprinted zones. Some of the dykes contain crysts of dark-grey to black plagioclase, a feature suggestive of a connection with NPS magmatism. No such dykes penetrate the proximal anorthositic rocks, so if they are of NPS age they would appear to be older than, or emanate from, the adjacent plutons.

A layered, ferrodiorite dyke, approximately 100 m in width and steeply inclined to the northeast, trends northwest across gneisses in the cove south of Pikaluyak. It is dark green to dark brown, plainly olivine-bearing, and locally has a rusty patina because of its high content of opaque oxide and lesser sulphides. This intrusion was first outlined by Rubins (1971, 1973), who noted its apparent limited extent as a coastal unit that could not be reliably traced inland. The present survey has outlined another, narrower, granular brown ferrodiorite dyke, which may be related to the layered one, on the west side of the cove. Rubins (1973) identified the rock types within the layered dyke, based on the modal composition of 10 samples from different layers across it, as gabbro, olivine gabbro, troctolite, and peridotite. This intrusion is clearly different from the Satorsoakalluk dyke, which apparently lacks olivine, but it could be related to the ferrodiorites of Barth Island.

The Unity Bay pluton is intruded by several types of basic dykes. Most prominent are dykes that are straight-walled and vary from a few centimetres to several tens of metres in width. Individual dykes vary in trend from north–south to east–west, and they are steeply dipping to vertical, but intersections between them are rare. Many of these dykes have clearly undergone a secondary chlorite/actinolite alteration, but no associated deformational fabric has been recognized. Narrow ones are uniformly fine grained, but may be locally porphyritic. They appear to be normal diabases, but some have granular textures and appear to be gabbronoritic. Coarser grained dykes display a well-developed gabbroic texture, and one such dyke outcropping on the north shoreline of Kauk Harbour and at the entrance to Ten Mile Bay has a peripheral zone in which a wispy layering is normal to the dyke walls. On the ridge above the town of Nain there is a northwest-trending brown-weathering porphyritic gabbro having a profusion of plagioclase phenocrysts, which crosscuts a north-trending finer grained green to black diabase (*cf*. Emslie, *in* Berg *et al*., 1994); the porphyritic dyke can be traced over 4 km along strike into the cove south of Pikaluyak Islet. The Unity Bay pluton is also intruded by centimetre-scale, granular, sinuous, southeasterly to easterly trending, "granulite" dykes which, unlike the diabasic and gabbroic dykes, have cuspate–lobate contacts with their host and they are variably foliated (Plate 17). One thick dyke of granular mafic rock within foliated leuconorite on the north point of Akpiksai Bay postdates the foliation of the host, but is itself lineated. All these "granulite" dykes are probably older than the straight-walled gabbroic and diabasic dykes, but no intersections between the two types have been seen.

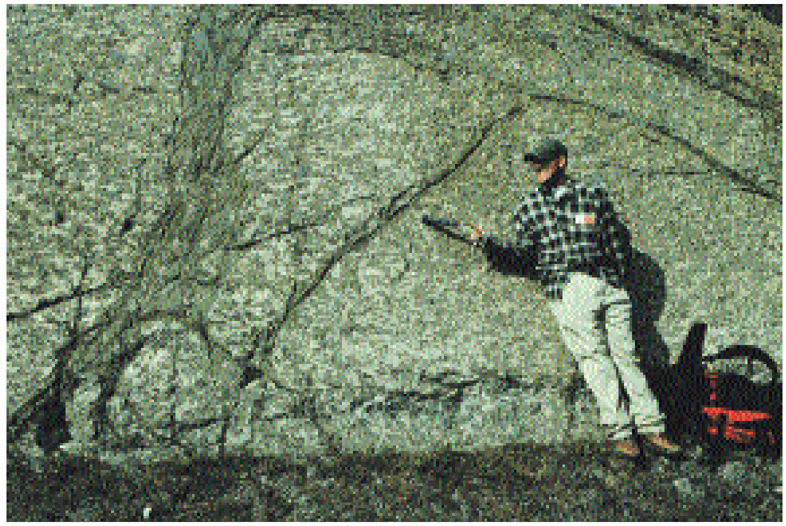

Plate 17. *Irregular and bifurcating, fine-grained, "granulite" dykes intruded into weakly foliated mottled and clotted-textured leuconorite of the Unity Bay pluton. West of Nain town.*

Granular and foliated, dark-grey to black,"granulite" dykes, similar to those within the Unity Bay pluton, are also found within the Mount Lister pluton, but they are generally larger and have a shallow dip; examples can be seen on the steep mountain wall at the foot of Ugjutoarsuk (Webb's Bay) and above Kaitusuak Point. A steeply dipping southeast-trending "biotite–granulite" dyke, foliated subparallel to its trend, crosscuts the foliated margin of the Mount Lister pluton south of Nain Bay. In addition to these dykes, the Mount Lister pluton is invaded by i) rare mingled mafic–felsic dykes that are foliated, (ii) brown, southeast-trending foliated "dioritic" dykes, (iii) massive southeast-trending (fayalite-bearing?) monzonitic dykes, and (iv) coarse-grained to pegmatoidal, straight-walled, olivine-bearing "leucodiorite" dykes having zircon crystals up to 2 cm in length (Plate 18). One massive 8- to 12-m-wide monzonitic dyke can be traced along strike for over 5 km. Some of the previously mentioned southeast-trending dykes can be detected in the aeromagnetic map (Figure 2b). None of these dykes have been seen in contact so their relative ages are unknown, but it is assumed that the massive monzonite and "leucodiorite" dykes are younger than the others. One east–west-trending, 30-m-wide gabbro dyke is exposed on the peninsula separating Nain and Tikkoatokak bays, northwest of Cape Williams; this dyke is comparable to the one cutting the Unity Bay pluton at Kauk Harbour in having a marginal, wall-normal, spongy and discontinuous layering.

Plate 18. *Parallel and interconnected dykes of pegmatoidal, olivine-bearing "leucodiorite" emplaced by brittle fracture into white anorthosite of the Mount Lister pluton. South shore of Nain Bay.*

Granitic dykes are widely distributed in the Unity Bay pluton, and have a diversity of orientations – north, northeast, east, southeast; no intersections between any such dykes were seen. The dykes are white to pink, and vary from aplite to pegmatite, the latter locally displaying graphic quartz-feldspar intergrowths. Biotite is the predominant mafic mineral, hornblende is rare, and pyroxenes are apparently absent; magnetite is a locally conspicuous mineral. Granitic dykes are far fewer in the Hosenbein Lake pluton than they are in the Unity Bay pluton, and only the northeast-trending set of the Unity Bay pluton appears to be present within the younger intrusion. The latter observation suggests that the granitic dykes within the Unity Bay pluton, with the exception of northeast-trending ones, predate emplacement of the Hosenbein Lake pluton. Two composite granitic dykes were noted in the survey area. One is a subhorizontal, 6- to 8-m-thick felsic intrusion crosscutting the Satorsoakulluk dyke on the northeast shore of Barth Island.

The felsic rock here comprises alternating 20 cm to 1.5 m layers of pink, magnetite-bearing granitic pegmatite and grey, aplitic, granodiorite or tonalite. The base of each aplitic layer has a cuspate–lobate form whereas the top of each is sharp and planar. The other dyke of this type is a 2-m-thick one that is similarly shallowly inclined but less distinctly layered, emplaced into recrystallized anorthosite of the Mount Lister pluton on the north side of Nain Bay west of Cape Williams.

A couple of other minor intrusions are worthy of mention because they are unusual. A single, north-trending, undeformed, composite, mafic–felsic dyke intrudes ferrodiorite at the entrance to the cove on the north side of Nain Bay opposite Barth Island. This dyke is 1.5 m wide, and has a sharp demarcation between a black, fine-grained, basaltic component and a coarser, light-grey granitic component. Globular basaltic enclaves are locally suspended in the granitic part of the dyke, and the compositional variant of the dyke that abuts the walls changes along strike. These relations imply that a mafic magma entered a fracture already occupied by felsic magma, in part pushing aside some of the resident felsic magma and in part breaking up within it. The second unusual minor intrusion is an agmatite zone developed where a younger granitic intrusion, of unknown extent, has been emplaced within foliated fayalite of the Mount Lister margin at the north arm of Kangilluk Lake. Here the "post-tectonic" granite has numerous angular blocks of gneiss but is apparently devoid of local fragments. The host is in sharp contact with the older granitic rock and varies from aplitic to pegmatitic.

STRUCTURE AND METAMORPHISM – PROBLEMS THAT THEY HIGHLIGHT

This section addresses several aspects of the structural and metamorphic character of the rocks. These are presented to give the reader some notion of the lithological variation of the rocks apparent in the field and to serve as a basis for statements of the petrological/structural problems that some of them pose.

MIGMATITIC AND MYLONITIC GNEISSES

The gneisses that are preserved between the plutons are assumed to be Archean. There is a hint, from the possible Sagkek dyke-like remnants, that some of these gneisses are early Archean. The migmatization and granulite-facies metamorphism, by comparison with other parts of the northern Nain Province, could have been imposed at 2.8-2.7 Ga (*cf*. Bridgwater and Schiøtte, 1991) or it could be a manifestation of thermotectonism associated with the ca. 2.5 Ga overprint identified within gneisses of the archipelago 30 km to the east (*cf*. Connelly and Ryan, 1996). Alternatively, the high-grade metamorphism could be a pyroxene–hornfels contact metamorphic overprint from the nearby plutons. A feature that could be used as an argument to negate the latter possibility is that the granulite-facies minerals define the foliation in the rocks; orthopyroxene, as a foliation-forming mineral implies that the metamorphism, migmatization and deformation were simultaneous and thus of regional, rather than local (contact) extent. A general laminar, straight layering characterizes the granulite-facies gneisses within 15 to 100 m of the eastern contact of the Mount Lister pluton on both sides of Nain Bay. This layering is slightly mylonitic in character, basic dykes are deformed and strongly attenuated within it, and it is parallel to the contact with the anorthositic pluton. It is reasonable to conclude, based on the degree of deformation in the adjacent anorthositic rock, that the foliations in the Mount Lister pluton and the wall-rock gneisses are coeval, and that the "straightening" imposed on the migmatites is a consequence of deformation associated with the forceful (diapiric?) emplacement of the pluton. Field aspects of the foliated rocks on each side of the contact indicate that the deformation in both units was imposed under granulite-facies conditions because orthopyroxene is stable in both. A down-dip lineation locally present in the gneisses south of Nain Bay may also be related to intrusion of the Mount Lister pluton. However, it cannot be ruled out that the foliated margin of the pluton fortuitously follows a pre-existing straight belt. This belt may have developed either in the Archean (*cf*. Connelly and Ryan, 1996) or it may have been impressed upon Archean gneisses during the Paleoproterozoic continental collision that formed the Torngat Orogen to the north (*cf*. Van Kranendonk, 1996).

LAYERING IN PLUTONS

Layering attitude in igneous rocks is an important feature that can be used as a criterion to subdivide large amorphous areas of such rock into separate intrusions (*cf*. Emslie, 1980, p. 29, 30) and it allows some indication of local, and perhaps regional, geometry of the intrusions. Layering can also give clues to the processes in magmas, be it the frozen product of the gravitational accumulation of primocrysts or the expression of current activity. Layering in the rocks of the Nain area is locally well developed, varies from centimetre- to metre-scale, and has been used for the aforementioned purposes, but its absence from vast tracts of anorthositic rocks has proven to be a frustrating impediment to deciphering these rocks' internal architecture. There is no evidence to suggest that any of the layering in the rocks has been overturned since its formation, so its inclination can be used to ascertain real stratigraphic changes within individual intrusions. The following examples serve to illustrate its use in the current map area.

Diffuse layering between anorthosite and leuconorite is a feature of the Mount Lister pluton that is readily seen in coastal exposures and on the cliffs along Nain Bay and Tikkoataoak. Bay. This layering is a function of a pure plagioclase cumulate alternating with one in which orthopyroxene has filled intercumulus spaces. The changing attitudes of the cumulate layering between Conch Bay and the south side of Nain Bay implies that the Mount Lister (anorthositic) pluton has an antiformal or domal shape, dipping gently to the north at Conch Bay, to the southeast at Cape Williams peninsula (Akkuliakhattakh), and south at Nain Bay (*see also,* Morse and Wheeler, 1974). A feature noted in one cliff section on the south side of Tikkoatakak Bay is that the layering is lensoid when seen normal to dip but continuous when viewed normal to strike; the layering thus has the form of a "mega-lineation", but the origin of this structure (whether primary or secondary) is unclear. The layering along the whole eastern side of the pluton is overprinted by a penetrative "tectonic" foliation.

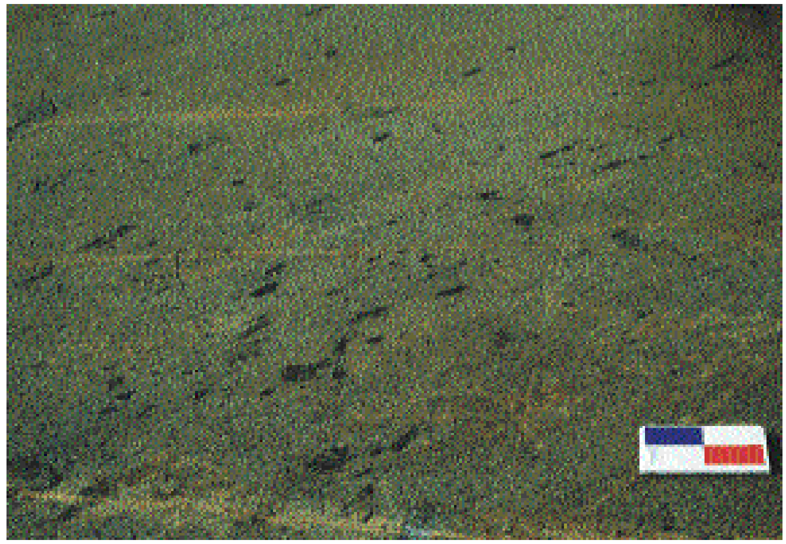

Plate 19. *Preferred alignment of dark-grey plagioclase crysts within a pale-grey leuconoritic host. Lack of a three-dimensional view of such features prevents reliable inferences regarding the significance of this alignment (see text). Islet in Sachem Bay.*

The Unity Bay pluton has a well-developed layering of anorthosite and leuconorite southeast of Nain, especially evident in the Mount Sophie–South Channel Cairn area. The layering has an undulating, but overall north-trending strike, and is inclined gently to the west. The layered rocks pass upward into massive, nonlayered, clotted- to seriate-textured leuconorite and anorthosite. This strike of the layering in the pluton is normal to that of the foliation in the Quarry leuconorite (*see below*), and from the map pattern of the two units it could be advocated that the Unity Bay pluton is layered in its basal sections where it sits upon the (older?) Quarry leuconorite.

The Hosenbein Lake pluton rests against Archean gneisses in the west, is layered in its central part, and has numerous angular fragments of older anorthosite and leuconorite at its contact with the Unity Bay pluton. Its apparent northwest–southeast orientation, coupled with moderately northeast-dipping layering, implies that it is an inclined sheet that passively punctured an older contact between Archean gneiss and the Unity Bay pluton, the floor being an olivine gabbro and the upper levels being a megabreccia formed by accumulation of blocks spalled from a roof formed by the pluton.

The three aforementioned anorthositic to leuconoritic plutons (Mount Lister, Unity Bay and Hosenbein Lake) display the best layered structure observed during the survey. The eastern anorthositic rocks, unfortunately, generally lack a coherent and consistent widely developed planar structure that would allow some inkling of their shapes and subdivision. However, these rocks do display primary preferred orientation of anhedral to euhedral darker plagioclase crysts (Plate 19) and, less commonly, trains of orthopyroxene. Three-dimensional views of such features are difficult on many smooth and ice-scoured coastal outcrops, so whether these orientations represent an inclined planar feature or a current alignment on a depositional surface is unclear. There is some uniformity to the trend of such structures – e.g., leuconorite to anorthosite between Webb Point and First Rattle has a northeasterly orientation of the long axes of plagioclase crysts – but it has not been possible to unequivocally define the extent of individual intrusions based on this characteristic.

Layering in the ferrodioritic intrusions is well developed, both in the plutons and the dykes. This feature is especially apparent in the lowermost unit on Barth Island, but less-so in the unit that overlies the troctolite. Layering in the lowest unit on Barth Island is quite striking and is, as noted above, clearly of primary derivation. Individual layers locally exhibit ascending gradational changes from massive mafic rock having a lobate or pillowed base, through a zone containing sparse perthitic feldspar crysts, to a zone where the feldspars are abundant, into an overlying zone of coarser grained monzonite of apparent cumulate origin (*cf.* Plate 11). The repetitive layering and its internal characteristics are interpreted to reflect successive injections of mafic magma into a chamber or conduit containing crystal-rich silicic magma, the variations from massive rock to feldspar phyric rock to massive monzonitic rock being an indication of upward hybridization and eventual feldspar accumulation atop the mafic influx prior to arrival of the next mafic injection. A sharp-bordered to wispy magmatic layering is also present locally in the Satorsoakulluk dyke (de Waard and Hancock, 1974), probably reflecting the flow of magma during dyke emplacement. It is apparent from outcrops examined during the 1999 survey that the Satorsoakulluk dyke is locally a composite body (Plate 13), and the mingling and variable mixing of successive pulses of magma in conduits such as this dyke could easily contribute to flow layering. Layering of different types is evident in parts of the network of ferrodiorite dykes in the Nain–Akpiksai Bay area; steeply inclined dykes west of Akpiksai Bay have diffuse layering defined by variations in the ratio of mafic to felsic minerals, whereas dykes on Nain Hill have layering that, in part, reflects the amount of magnetite present. Massive magnetite layers in the latter setting may be an indication that the silicate magma that produced these dykes transported an iron oxide liquid with it.

Plate 20. *Multiphase hybrid rock of overall ferrodioritic composition in which some of the components display a well-developed planar alignment of subhedral to euhedral (potassium?) feldspar crystals. West shore of Barth Island.*

FOLIATIONS IN PLUTONS

Many of the igneous rocks of the area are foliated, i.e., they exhibit a preferred planar orientation of mineral constituents. Rarely, this foliation can be attributed to magmatic processes *sensu stricto*, but in most cases, it reflects imposition of strain upon a crystalline mass outside the realm of the magma. Foliations of the magmatic type are those such as laminated tablets of plagioclase feldspar in anorthosite (reflecting a current alignment or settling attitude) or the trains of feldspar aggregates in ferrodiorite (reflecting the disaggregation of crystal accumulations as a result of flow). Foliations of the post-crystallization type seem to be of two different origins (late-magmatic/early solidification compaction of a crystal cumulate pile and totally post-solidification) which may be interrelated or superimposed in some cases. The degree to which the rocks of the map area exhibit the post-crystallization type of foliation is not easily gleaned from existing literature, but it was certainly recognized by others (*cf*. Rubins, 1971; Planansky, 1973; Wiebe, 1992). Some examples of magmatic and post-crystallization fabrics are presented below.

A primary magmatic foliation is well displayed by some of the feldspar phyric rocks of the layered ferrodiorite unit at the west end of Barth Island. There, fine-grained and texturally diverse layers having current-aligned trains of feldspar crysts (Plate 20) are an intimate part of a sequence of hybridized rocks interpreted to be products of repetitive influx of basic magma into a chamber containing silicic magma. The feldspar crystals in the trains appear to have been scavenged from outside the immediate area of the layered succession and were preferably oriented by the flow regime in the host prior to final crystallization. Therefore, the foliation in these rocks is a function of primary flow processes during deposition, and its presence does not indicate, as advocated by de Waard (1976), that the rocks were subjected to syn-emplacement deformation. Similarly, the schlieren and trains of plagioclase crysts in gabbronorite north of Akpiksai Bay can be explained as due to the disaggregation and dispersal of an anorthositic cumulate (*cf.* Plate 12)

The first subset of the post-crystallization foliation is one in which the fabric of anorthositic rocks is defined by elongate irregular lenses of orthopyroxene within a feldspathic groundmass. These appear to be derived from the deformation of "clotted-textured" leuconorite and do not show any indication of profound recrystallization associated with the foliation. One of the best examples of this type of structure can be seen in the Quarry leuconorite, where streaks of orthopyroxene are distributed within a groundmass of anhedral 1 to 5 cm feldspar exhibiting labradorescence. The impression gleaned from these rocks is that the foliation is a "compaction texture", and that the original tabular plagioclase has been modified by a load-induced and grain-boundary-migration (solution/precipitation) process imposed upon the cumulate pile prior to final consolidation (*cf.* Meurer and Boudreau, 1998). The anhedral plagioclase, although in overall aspect very similar to that seen in foliated and recrystallized rocks of the Mount Lister pluton, differs from the latter setting in as much as the grains are larger and the crystal modification in the Quarry leuconorite has not destroyed the original labradorite schiller of the igneous feldspar, thus making the leuconorite an attractive dimension stone.

Granitic rocks also locally display features that are compatible with a post-crystallization, but pre-full-consolidation, origin. The monzonitic rock on the south side of Nain Bay, has elongate mafic enclaves, assumed to be derived from captured mafic liquid (transported globules or remnants of basic dykes), that have cuspate borders from which "flames" penetrate into the surrounding coarse feldspathic rock (Plate 15). The elongation of these enclaves, coupled with a diffuse foliation and preferred orientation of the feldspars, imply that the morphology of the enclaves is a result of deformation that took place when the mafic fraction and its surroundings were still soft.

Post-crystallization and post-solidification penetrative foliations are well developed along the eastern side of the Mount Lister pluton, identified initially by Rubins (1971). There, strongly deformed and recrystallized rocks define an easterly dipping "marginal foliated zone" that is 3 km wide. The leuconoritic rocks display the most obvious fabrics because orthopyroxene defines it; the aspect of the pyroxene varies from kinked and marginally recrystallized elongate, presumably high-alumina, megacrysts to granular "pyroxenite" lenses and/or granular pyroxene+plagioclase lenses derived from totally recrystallized larger grains. Anorthositic rocks in this zone are generally finer grained, granular rocks that locally contain abundant fractured remnants of larger (and darker grey) plagioclase still displaying original labradorite schiller; anorthosite rarely exhibits a distinct fabric because it is an annealed, monomineralic, rock. The apparent restriction of the foliated rocks to the perimeter of the Mount Lister pluton, along with the refoliation of the abutting gneisses, implies that the development of this "marginal foliated zone", like that surrounding the Egersund-Ogna intrusion in Norway (*cf.* Duchesne and Michot, *in* Maijer and Padget, 1987, p. 56), is directly related to "tectonic" process along the interface during emplacement of the pluton to this crustal level. The deformation was imposed upon already layered and cumulate-textured rocks, as indicated by the preservation of compositional layering and relict subophitic textures in lower strain zones, and it occurred at high temperature as indicated by the orthopyroxene fabric and the pervasive annealing.

The zone of foliated rock at Akpiksai Bay suggests that the Unity Bay pluton was, like the Mount Lister pluton, at its edges bordered by "marginal foliated zone". It is possible the preserved deformed rock is a small remnant of a once larger zone, that zone and the country-rock envelope having been largely excised by the emplacement of younger intrusions such as the ferrodiorite and troctolite to the north and the massive leuconorite to the west. Further support for an original "tectonic" junction having characterized the Unity Bay pluton in this area comes from the "layered rocks of uncertain affinity" that trend east–west in the Nain Hill area. These rocks, interpreted to be intra-pluton screens rather than part of the envelope of older rock, all have structurally modified contacts against abutting deformed leuconorite and anorthosite; internal structural contacts imply that external contacts were similar.

Foliated anorthositic rocks having the deformational and recrystallization fabrics of the marginal zone of the Mount Lister pluton were also noted just west of Camp Hill at the southeastern end of Base Island. Here, the foliated rocks are only about 200 m wide, and are intruded by massive leuconorite. The absence of gneisses nearby makes it difficult to argue for proximity to a contact with such country-rock, but the intrusion of other plutons in this area may have completely eliminated any such rocks.

SECONDARY ALTERATION OF ANORTHOSITIC ROCKS

There is widespread, altough not evenly developed, secondary chlorite and/or actinolitic amphibole replacement of pyroxene in many of the anorthositic rocks through the central part of the study area between Kauk Harbour and Sachem Bay, and eastward from Base Island. Locally, bright green epidote clots are a conspicuous feature of the anorthosite and leuconorite rocks. The alteration is also present, although less apparent, in the basic dykes that intrude these rocks, and in the gneisses that abut them. Alteration of this type was a criterion used to identify Paleoproterozoic anorthositic rocks as separate from the NPS south of Okak (Ryan *et al.,* 1997; Ryan *et al.,* 1998), but as a single characteristic, it has to be used with caution for such an interpretation of the rocks around Nain. Here, the alteration seems to postdate many of the rocks that can fairly confidently be assigned to the NPS, including the Mount Lister pluton and anorthosites through the First Rattle area. Kerr (1998) concluded that the alteration predated intrusion of the ferrodiorite dykes north of Akpiksai Bay. However, Hinchey (1999) has documented alteration of the pyroxenitc dykes west of Nain, and Wheeler (1933) noted that the porphyritic "Nain Hill" diabase, which cuts the dioritic dykes, is also altered, so a post-diorite overprint is probable. However, the actual cause of this greenschist-facies alteration is not apparent.

"UNCONFORMITY"? AT THE BRIDGES LOWER CONTACT

The map pattern derived from the limited work on the north side of Ten Mile Bay indicates a discordancy in trend between the foliation in the Quarry leuconorite and the layering in The Bridges intrusion. This abrupt change, from an easterly striking and southerly dipping deformational fabric in the leuconorite to a northerly striking and easterly dipping compositional layering in The Bridges, is of the type that could represent an "unconformity" between the layered rocks and the foliated rocks.

Planansky (1971) was the first to undertake a systematic examination of this area, and he initially offered several possible alternatives to account for the "contradictory and baffling transgressive to transitional contacts" between the various rock units that he found there. Subsequent work led him to conclude, as is suggested by the map pattern from the present study, that the "pale facies" anorthosite (the Quarry leuconorite of the present study) to the west of the "Layered Group" (i.e., The Bridges intrusion) formed the floor to the layered rocks, and that "dark facies" (olivine-bearing) anorthosite to the east intruded both (Planansky, 1973). Wiebe (*in* Berg *et al.*, 1994) offered an alternative interpretation, concluding that the The Bridges layered rocks are the oldest unit and that the leuconorite to the west (termed by him the Lower Leuconorite) was diapirically emplaced into the layered rocks; he agreed with Planansky (1973) that the olivine-bearing rocks to the east (Leucotroctolite) intruded both. This interpretation differs from that offered at one point in an earlier paper (Wiebe, 1990, p. 6) that stated The Bridges "has an abrupt lower depositional contact with the underlying" leuconoritic rocks. Thus, there is some question as to the nature of the stratigraphic relationship between The Bridges and the leuconorite, but if the former was deposited on the latter then it has profound implications for the local, and regional, stratigraphy. This is because it indicates that the Quarry leuconorite, rather than being an NPS intrusion, is older than 1667 ± 75 Ma, the age of crystallization that Ashwal *et al.* (1992) derived for The Bridges, and is, thus, Paleoproterozoic in age as well.

ECONOMIC GEOLOGY

The Nain area has been extensively explored for base-metal sulphide mineralization between 1995 and 1997 in the wake of the discovery of the Ni–Cu ore body at Voisey's Bay (*cf.* Kerr, 1998). The most intense activity was conducted by NDT Ventures Limited over gossan zones within dioritic dykes and associated rocks close to Nain. Other claim blocks subjected to scrutiny included those under licence to Voisey's Bay Nickel Company covering dioritic and troctolitic rocks on Barth Island and South Alatsavik Island, to NDT Ventures covering anorthositic rocks and The Bridges intrusion on western Paul Island, to Noranda Exploration covering the north–south belt of gneisses south of Nain Bay, and to Kernow Resources covering dioritic and anorthositic rocks west of Sachem Bay. Assessment reports from the operators of all these projects are on file with the Geological Survey. The prospects close to Nain were re-examined in light of the local stratigraphy during the 1999 survey, but other properties were not visited.

The Nain prospects were initially documented in a report by Barbour and Dearin (1996). More recently, Kerr (1998), Hinchey *et al.* (1999) and Hinchey (1999), using their own field and core examinations, as well as the assessment reports and drill data of NDT Ventures, presented a far-ranging discussion of these prospects. The details need not be repeated here, suffice it to state that the mineralization is distributed over three main zones. The Valley zone gossans are related to opaque oxide and sulphide zones in ferrodioritic dykes. The Unity East zone seems to be related to an anastomosing vein system of massive sulphides that locally crosscuts anorthositic rocks (Hinchey *et al.*, 1999); the present survey has indicated that these veins transect foliation and layering in a unit of mesocratic to ultramafic "granulite" as well. The Unity West zone gossans are developed over oxide- and sulphide-bearing melanocratic ferrodiorite to pyroxenite dykes. The 1999 examination of the setting of these prospects confirms the observations of Kerr (1998) and Hinchey *et al.* (1999), that the mineralization is spatially, and probably genetically, related to the ferrodiorite dykes. These dykes postdate the fabric of the Unity Bay pluton, postdate the Akpiksai Bay pluton, but pre-date the Hosenbein Lake pluton. The latter relative relationship is based on an outcrop south of Nain Bay where a raft of Unity Bay leuconorite crosscut by a magnetite-rich pyroxenite to ferrodiorite dyke is enclosed by the Hosenbein Lake pluton.

There has been commercial exploitation, by the Torngaitujaganniavingit Corporation (a subsidiary of the Labradorite Inuit Development Corporation), of foliated, labradorite-bearing, leuconorite from a quarry on the south shore of Ten Mile Bay for 6 years (Meyer and Montague, 1993). A recent attempt to establish a second extraction site in the Quarry leuconorite in the small cove south of Two Mile Bay (Figure 1) was not successful because the subsurface stone proved to be too fractured and to have too many veins to provide a product of marketable standard (F. Hall, personal communication, 1999).

Labradorite is not abundant in rocks apart from those of the Quarry leuconorite. The exception to the foregoing statement is anorthosite and leuconorite exposed on the coastline from Southern Point to Kauk Harbour, which is here included with the Unity Bay pluton but is remarkably similar to rocks of Ten Mile Bay. Deep blue labradorescence is displayed by many fractured and partly recrystallized very coarse-grained plagioclase in parts of the Mount Lister pluton along the south shoreline of Nain Bay, 7 km west of Kaiktusuak Point (Khairtorsoakh); some of the better preserved of these large plagioclase crystals may yield enough homogeneous material to make it attractive to the lapidary trade. An unusual yellowish-green to pale bluish-green schiller is exhibited by some of the finer grained anorthosite and leuconorite on both shores of Shoal Tickle and on the north shore of the largest island in the bay on the east side of Base Island.

DISCUSSION

The gneissic and plutonic rocks of Nain display fairly straightforward patterns regionally, but the apparent simplicity becomes less so when considered in the context of the geological history of northern Labrador. The 1999 survey has provided much data that can be used to offer alternative explanations for many of the features seen in these rocks.

It has been shown that the gneissic rocks between the NPS plutons are granulite-facies migmatites, some of which may be early Archean. A laminar fabric, within which most of the convoluted migmatite structure is replaced by a more regular layering, occurs adjacent to the Mount Lister pluton, probably the largest (and oldest?) of the NPS anorthositic intrusions.

There are several areas underlain by plutonic rocks of Paleoproterozoic age, and rocks of this age may be more widespread than presently suspected.

Anorthositic rocks assigned to the NPS can be subdivided into many amalgamated plutons, in a pattern similar to the nesting and coalescence of intrusions in batholithic terranes worldwide. Most such intrusions display evidence of plagioclase accumulation by gravitational forces, perhaps enhanced by current activity. Orthopyroxene is an intercumulus mineral in even the coarsest of the anorthositic intrusions, but it also occurs as trains of anhedral xenocrystic megacrysts. Olivine also seems to be xenocrystic in some of the anorthositic plutons, but it is also locally a cumulus mineral which, in many rocks, is overgrown by orthopyroxene. External contacts of plutons vary from strongly foliated to undeformed, and indicate a range of emplacement styles from "tectonic" to passive stoping.

Troctolitic rocks outside the main anorthositic subdivision comprise at least two different intrusions. There is no contact between troctolite and anorthositic rocks on Barth Island, but circumstantial evidence suggests that it is younger. Troctolite at Sachem Bay is older than the nearby leuconoritic rocks.

Ferrodiorite of the Nain Bay area crosscuts several anorthositic plutons, but aeromagnetic patterns are compatible with leuconorite intruding ferrodiorite north of the Bay. The physical mechanism by which the steeply inclined basinal shape of the "Barth layered structure" developed is not readily obvious, and the concentric and nested form of the units is puzzling, but it seems that the model of its evolution and deformation put forward by de Waard (1976) needs to be re-assessed. The aeromagnetic pattern (Figure 2b) and the previous mapping (*cf.* Rubins, 1971) of the western side of the "Barth layered structure" indicate a very abrupt truncation or drastic thinning of the ferrodiorite against the margin of the Mount Lister intrusion, but the significance of this (intrusive or tectonic) is unknown. The relationship between the "lower" ferrodiorite, the coeval granite, the older troctolite and anorthosite of the Barth Island area appears to be a simple intrusive one where a combined ferrodiorite-granite system evolved in a tabular conduit (ring dyke structure?) that in part exploited an existing contact between troctolite and anorthosite. The setting of the "upper" massive ferrodiorite, which lacks layering and associated felsic rocks, seems unrelated to the lower unit. Mingling of felsic and ferrodioritic magma, similar to that seen at the western part of Barth Island, is also evident in the ferrodiorite unit that lies north of Sachem Bay.

The sulphide mineralization in the vicinity of the town of Nain is related to a sulphide–oxide liquid directly and indirectly associated with ferrodiorite dykes that postdate some of the plutons but predate others. Preliminary interpretation of the relationships imply that mineralization having the age and setting of the Valley and Unity zones will not be found, for instance, west of the contact between the Hosenbein Lake pluton and the Unity Bay pluton.

The 1999 project has demonstrated that a number of problems need to be resolved in the geology of the Nain area. Some of these have been alluded to in foregoing parts of this contribution. For example, is the mylonitic overprint on the gneisses west of Nain related to the emplacement of the Mount Lister intrusion or is it an older feature? If the "spots" in mafic gneisses are decompression pseudomorphs of former garnet, when did the decompression reaction occur? What is the age of the layered mafic and ultramafic rocks south and west of Akpiksai Bay (Archean or Paleoproterozoic or Mesoproterozoic? (*cf.* Barbour and Dearin, 1996)) and what is the nature of the contact against all the abutting rocks? How much of the plutonic terrane in the Nain area is older than the NPS? Could some of the high-magnetic anorthositic rocks proximal to Nain be Paleoproterozoic intrusions? Is the plethora of mafic and felsic dykes in these intrusions, compared to similar rocks to the east, indicative of a Paleoproterozoic age? How many different plutons exist among the anorthositic rocks of the Nain area? Why are so many of the intrusions (anorthositic, ferrodioritic, and granitic) in the NPS foliated, and how many different processes were responsible for this facet of the rocks? What is the age of, and what caused, the widespread chlorite–actinolite–epidote alteration in the plutonic rocks near Nain?

It became evident from the work of Berg (1974) and Wiebe (1976) that, with the recognition of intrusive contacts and the demarcation of coherent areas of similar rock, the regionally monotonous and batholithic mass of anorthositic rocks within the NPS could be subdivided into separate components. These could be interpreted to represent individual intrusions or parts of individual intrusions that had coalesced to form the whole. With this realization came the potential to elucidate the construction history of the anorthositic part of the NPS, a goal that was pursued by the writer and associates during regional surveys undertaken in the Okak Bay – Staghorn Lake area in 1996 and 1997 (*cf.* Ryan *et al.,* 1997; Ryan *et al.,* 1998). The new approach to NPS subdivision – utilizing criteria such as crosscutting relationships and textural integrity – to define and demarcate the areal extent of different intrusions made it apparent that Wheeler's "facies" concept held little practical value in trying to understand the internal architecture of the NPS. This is further reinforced by the results of the survey reported here. For example, "pale facies" rocks proximal to Nain that were illustrated as a single unit by Wheeler (1969) and Rubins (1971) and subsequent workers, can be readily subdivided into a number of smaller separate plutons, some of which may not even be part of the NPS. Anorthositic rocks from Base Island to Paul Island are characterized by olivine, a mineral diagnostic of Wheeler's dark facies, even though Wheeler (1969) indicated rocks in this area to be "pale facies". The facies concept should now be abandoned, and more effort directed toward unraveling the relative and absolute chronology of all rocks in the NPS. Repetitive magmatism leads to identical rocks of more than one age, and it is only by determining the exact nature of contacts that a chronology of intrusion will be established.

ACKNOWLEDGMENTS

I was ably assisted in the field by Dixon Byrne, whose interest in the geology of the Nain region went well beyond that of most students with his background. His thirst for new information kept me mentally stimulated both in the field and at home-base in Nain. He was most efficient in all tasks he undertook. Ron Webb of Nain provided his usual boat support for our coastal work, and he and other members of the Webb family enveloped us in their hospitality for the whole summer. I thank John Myers, newly appointed Paterson Chair in the Department of Earth Sciences at Memorial University, for his perspectives on the Nain rocks during the several days he spent with us, as well as the Voisey's Bay Nickel Company and its staff for providing helicopter support at that time. The summer was also made enjoyable by field and office discussions of the various facets of the Nain rocks with geologists from Falconbridge Exploration and the Labrador Inuit Development Corporation. I wish to acknowledge the logistical and moral support of Wayne Tuttle and Barry Burden, especially for traveling to Nain at the beginning of September to pack up and ship my gear back to Goose Bay when a death in the family forced an abrupt end to my field season.

REFERENCES

Ashwal, L.D., Wiebe, R.A., Wooden, J.L., Whitehouse, M.J. and Snyder, D.
1992: Pre-Elsonian mafic magmatism in the Nain igneous complex, Labrador: the Bridges layered intrusion. Precambrian Research, Volume 56, pages 73-87.

Barbour, D. and Dearin, C.
1996: Geological assessment report on the Unity claims, Project No. 44, Voisey's Bay, Labrador. Unpublished NDT Ventures report on file with the Geological Survey, File 14C/0070.

Berg, J.H.
1974: Further study of the Hettasch Intrusion and associated rocks. *In* The Nain Anorthosite Project: Field Report, 1973. *Edited by* S.A. Morse. Geology Department, University of Massachusetts, Contribution No. 13, pages 107-119.

Berg, J.H., Emslie, R.F., Hamilton, M.A., Morse, S.A., Ryan, A.B. and Wiebe, R.A.
1994: Anorthositic, granitoid, and related rocks of the Nain Plutonic Suite. Guidebook to a field excursion to the Nain area, August 4-10, 1994. International Geological Correlation Program Projects #290 and #315, 69 pages.

Bridgwater, D. and Schiøtte, L.
1991: The Archaean gneiss complex of northern Labrador: a review of current results, ideas and problems. Bulletin of the Geological Society of Denmark, Volume 39, pages 153-166.

Connelly, J.N. and Ryan, B.
1996: Late Archean evolution of the Nain Province, Nain, Labrador: imprint of a collision. Canadian Journal of Earth Sciences, Volume 33, pages 1325-1342.

1999: Age and tectonic implications of Paleoproterozoic granitoid intrusions within the Nain Province near Nain, Labrador. Canadian Journal of Earth Sciences, Volume 36, pages 833-853

de Waard, D.
1976: Anorthosite–adamellite–troctolite layering in the Barth Island structure of the Nain complex, Labrador. Lithos, Volume 9, pages 293-308.

de Waard, D. and Mulhern, K.
1973: The Barth layered structure. *In* The Nain Anorthosite Project, Labrador: Field Report, 1972. *Edited by* S.A. Morse. Geology Department, University of Massachusetts, Contribution No. 11, pages 71-80.

de Waard, D. and Hancock, S.
1974: Gabbroic–granodioritic dyke in the Nain anorthosite massif, Labrador. *In* The Nain Anorthosite Project, Labrador: Field Report, 1973. *Edited by* S.A. Morse. Geology Department, University of Massachusetts, Contribution No. 13, pages 97-99.

Emslie, R.F.
1980: Geology and petrology of the Harp Lake Complex, central Labrador: an example of Elsonian magmatism. Geological Survey of Canada, Bulletin 293, 136 pages.

Emslie, R.F., Morse, S.A. and Wheeler, E.P.
1972: Igneous rocks of central Labrador with emphasis on anorthositic and related intrusions. Guidebook, Field Excursion A54, 24th International Geological Congress, 72 pages.

Grimley, P.H.
1955: Showings in Nain and Tikkoatokak Bay areas, Labrador. Unpublished BRINEX report on file with the Geological Survey, File 14D/9 (12)

Hamilton M.A., Emslie, R.F. and Roddick, J.C.
1994: Detailed emplacement chronology of basic magmas of the Mid-Proterozoic Nain Plutonic Suite, Labrador: insights from U–Pb systematics in zircon and baddeleyite. Eighth International Conference on Cosmochronology and Isotope Geology. United States Geological Survey Circular 1107, page 124.

Hinchey, J.
1999: Magmatic sulphide-oxide mineralization in the Nain Hill area, northern Labrador: a petrological and geochemical study. B.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 131 pages.

Hinchey, J., Kerr, A. and Wilton, D.
1999: Magmatic sulphide-oxide mineralization in the Nain Hill area (NTS 14C/12), northern Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 99-1, pages 183-194.

Kerr, A.
1998: Petrology of magmatic sulphide mineralization in northern Labrador: preliminary results. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 98-1, pages 53-75.

Levendosky, W.T.
1975: The geology of the Barth layered intrusion, Labrador. Unpublished M.Sc. Thesis, Syracuse University, New York, 73 pages

Maijer, C. and Padget, P.
1987: The geology of southernmost Norway: an excursion guide. Norges Geologiske Undersøkelse, Trondheim, 109 pages.

Morse, S.A.
1971-1983: Nain Anorthosite Project, Labrador: Field Reports. Department of Geology, University of Massachusetts, Amherst, Contributions 9, 11, 13, 17, 26, 29, 38 and 40.

Morse, S.A. and Wheeler, E.P.
1974: Layered anorthosite massifs along Tikkoatokhakh Bay. *In* The Nain Anorthosite Project, Labrador: Field Report, 1973. *Edited by* S.A. Morse. Geology Department, University of Massachusetts, Contribution No. 13, pages 129-132.

Meurer, W.P. and Boudreau, A.E.
1998: Compaction of igneous cumulates, Part 2: Compaction and the development of igneous foliations. Journal of Geology, Volume 106, pages 293-304

Meyer, J. and Montague, E.
1993: The Ten Mile Bay anorthosite quarry, northern Labrador. *In* Ore Horizons. *Edited by* A. Hogan and H.S. Swinden. Newfoundland Department of Mines and Energy, Geological Survey Branch, Volume 2, pages 129-141.

Mulhern, K.
1974: Petrography and structure of the northern margin of the Barth layered structure, Labrador. Unpublished M.Sc. thesis, Syracuse University, New York, 48 pages.

Planansky, G.A
1971: The Bridges Layered Series and associated anorthosites. *In* The Nain Anorthosite Project, Labrador: Field Report 1971. *Edited by* S. A. Morse, Department of Geology, University of Massachusetts, Amherst, Contribution 9, pages 47-59.

1973: The Bridges area. *In* The Nain Anorthosite Project, Labrador: Field Report 1972. *Edited by* S. A. Morse, Department of Geology, University of Massachusetts, Amherst, Contribution 11, pages 83-89.

Rubins, C.C.
1971: The Barth Island troctolite body: granulite–adamellite–anorthosite relations at the northern margin. *In* The Nain Anorthosite Report, Labrador, Field Report 1971. *Edited by* Morse, S.A., University of Massachusetts, Department of Geology, Contribution 9, pages 35-42.

1973: Structural, stratigraphic and petrologic relations of rocks south of the Barth Island layered intrusion. Unpublished Ph.D. thesis, Syracuse University, New York, 100 pages.

Rubins, C.C. and de Waard, D.
1971: Granulite zones in anorthosite near Nain, Labrador. Proc. Kon. Ned. Akad, v. Wetensch., Amsterdam, B74, pages 263-268.

Ryan, B.
1990: Geological map of the Nain Plutonic Suite and surrounding rocks (Nain–Nutak, NTS 14SW). Newfoundland Department of Mines and Energy, Geological Survey Branch, Map 90-44, scale 1:500 000.

1991: New perspectives on the Nain Plutonic Suite and its country rocks. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 91-1, pages 231-255.

1993: Further results of mapping gneissic and plutonic rocks of the Nain area, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 93-1, pages 61-75.

Ryan, B. and Morse, S.A.
1985: Nain Plutonic Suite. *In* Lexicon of Canadian Stratigraphy, Volume VI: Atlantic Region. *Edited by* G.L. Williams, L.R. Fyffe, R.J. Wardle, S.P. Colman-Sadd and R.C. Boehner. Canadian Society of Petroleum Geologists, pages 266-267.

Ryan, B. and Emslie, R. F.
1994: Pre-Elsonian mafic magmatism in the Nain Igneous complex, Labrador: the Bridges layered intrusion - comment. Precambrian Research, Volume 68, pages 179-181.

Ryan, B., and Connelly, J.N.
1996: Paleoproterozoic plutonism in the Nain area: similar rocks (but differing origins?) to the Mesoproterozoic Nain Plutonic Suite. *In* Proterozoic Evolution in the North Atlantic Realm: *compiled by* C.F. Gower. COPENA-ECSOOT-IBTA conference, Goose Bay, Labrador, July 29-August 2, 1996, Program and Abstracts, pages 156-157.

Ryan, B., Hynes, A., and Ermanovics, I.
1997: Geology of the Nain Plutonic Suite and its country-rock envelope, Alliger Lake area (NTS 14E/1), Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 97-1, pp. 29-47.

Ryan, B., Phillips, E., Schwetz, J. and Machado, G.
1998: A tale of more than ten plutons (Geology of the region between Okak Bay and Staghorn Lake, Labrador, parts of NTS maps 14E/2, 7, 8). *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey, Report 98-1, pages 143-171.

Van Kranendonk, M.J.
1996: Tectonic evolution of the Paleoproterozoic Torngat Orogen: evidence from pressure-temperature-time-deformation paths in the North River map-area, Labrador. Tectonics, Volume 15, pages 843-869.

Wheeler, E.P.
1933: A study of some diabase dikes on the Labrador coast. Journal of Geology, Volume 41, pages 418-431.

1942: Anorthosite and related rocks about Nain, Labrador. Journal of Geology, Volume 50, pages 611-642.

1960: Anorthosite-adamellite complex of Nain, Labrador. Geological Society of America, Bulletin 71, pages 1755-1762.

1969: Minor intrusives associated with the Nain anorthosite. *In* Origin of Anorthosite and Related Rocks. *Edited by* Y.W. Isachsen. New York State Museum Science Service, Memoir 18, Albany, New York, pages 189-206.

Wheeler, E.P., Bridgwater, D., Grimley, P.H., Morse, S.A., Piloski, M.J., Rubins, C.C., de Waard, D. and Westoll, N.,
1984: Geological maps of the Nutak, Tasisuak Lake, Nain, and North River map sheets (compiled by A. Harris). Newfoundland Department of Mines and Energy, Mineral Development Division, Maps 80-12 to 80-15, Scale 1:200 000.

Wiebe, R.A.
1976: Geology of northern Tunungayualok Island and vicinity. *In* The Nain Anorthosite Project, Labrador: Field Report, 1974. *Edited by* S.A. Morse. Geology Department, University of Massachusetts, Contribution No. 17, pages 37-47.

1990: Evidence for unusually feldspathic liquids in the Nain Complex, Labrador. American Mineralogist, Volume 75, pages 1-12.

1992: Proterozoic Anorthosite Complexes. *In* Proterozoic Crustal Evolution. *Edited by* K.C. Condie. Elsevier Publishing Company, Amsterdam, pages. 215-261.

Xue, S. and Morse, S.A.
1993: Geochemistry of the Nain massif anorthosite, Labrador: magma diversity in five intrusions. Geochimica et Cosmochimica Acta, Volume 57, pages 3925-3948.