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NAIN AREA GEOLOGY: OBSERVATIONS ON SELECTED ISLANDS, AND THE AREA SOUTH OF NAIN BAY (NTS 14C/6, 14; 14D/9)

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ABSTRACT

Islands southeast and northeast of Nain surveyed in 1991 are underlain by an amphibolite- to granulite-facies Archean gneiss complex comprising quartzofeldspathic orthogneiss and subordinate amounts of quartzitic supracrustal and mafic gneisses. Deformed and recrystallized noritic and monzonitic rocks akin to those of the Middle Proterozoic Nain Plutonic Suite (NPS) in the area are of unkonwn absolute age. All of the above are intruded by a swarm of variably deformed and recrystallized basic dykes ranging from lamprophyre to gabbronorite (mafic granulite) in composition.

An area of survey south of Nain Bay is underlain by granulite-facies enderbitic to charnockitic gneiss and garnetiferous paragneiss that occupy a northward-tapering wedge between plutonic rocks of the NPS. The NPS of this area has been divided into a gneissic anorthosite-norite, a variably foliated and recrystallized white leuconorite–anorthosite, an undeformed leuconorite, and several elongate, variably deformed intrusions of olivine–clinopyroxene diorite and monzonite. Dykes of the undeformed leuconorite cutting gneissic norite locally contain sulphide mineralization. The deformation of the NPS may be a manifestation of diapiric intrusion of some of its plutons but other explanations are also compatible with the features in these rocks. A discussion of the applicability of a diapiric intrusion model to the plutonic rocks of the Nain Bay area is presented.

INTRODUCTION

A mapping project was undertaken in 1990 to examine a narrow septum of Archean gneisses located between plutons of the Nain Plutonic Suite (NPS) (Ryan, 1991a). As a result of that project, several new aspects of Nain area geology were highlighted. Foremost among these was the recognition of several generations of deformed and metamorphosed basic dykes within the gneisses, and the documentation of strongly deformed and recrystallized rocks within the NPS. The follow-up 1991 project was designed to investigate the areal extent of these phenomena. Gneisses were examined principally on the archipelago northeast and southeast of Nain; a smaller area of gneisses and the enclosing plutonic rocks were surveyed south of Nain Bay (Figure 1). In addition, several helicopter-supported reconnaissance-type sub-projects were undertaken within the NPS to briefly examine selected units of interest shown on unpublished manuscript maps of E.P. Wheeler II, and to collect rock samples for geochronological analyses.

Work on the archipelago was severely hindered during the 1991 season by heavier than normal ice conditions. Access to Nukasusutok Island by boat, to set up the first field camp, was not possible until August 4, and it was six days later before the ocean between there and Seniartlit Islands could be navigated for survey purposes. Rough sea conditions during the latter part of the season precluded satisfactory coverage of the islands east of South Aulatsivik Island.

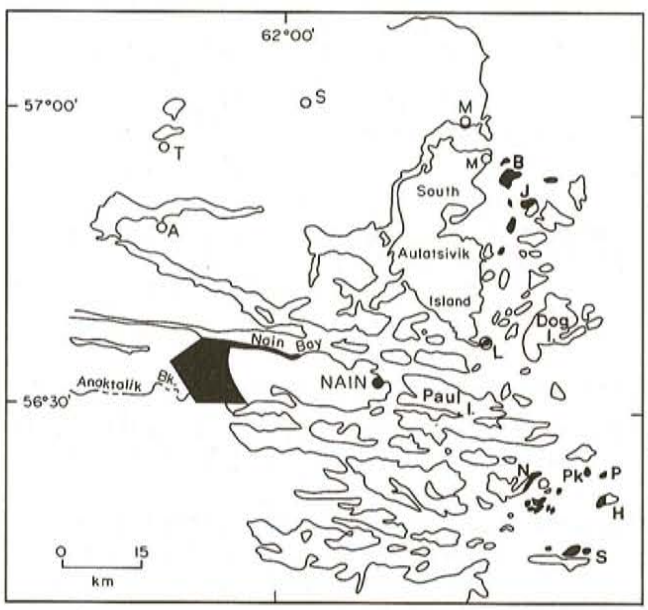

Figure 1. *Map showing the areas surveyed (black) during the 1991 field season. Three areas were examined in detail–between Nain Bay and Anaktalik Brook, south and east of Nukasustok Island (N), and east of South Aulatsivik Island. S = Seniartlit Islands, H = Humbys Island, P = Potuk Island, Pk = Poktoghusekh Island, B = Bouverie Island, J = Jonathan Island. Circles are areas examined briefly and/or rock units collected for geochronological study; L = Loon Island, S = Sheet Hill pluton, M = Manvers granite, T = layered troctolitic body, A = deformed anorthosite–norite.*

GEOLOGY OF THE OFFSHORE ISLANDS

Two areas of Archean gneisses were investigated within the Nain archipelago (Figure 1). These were (i) a cluster of

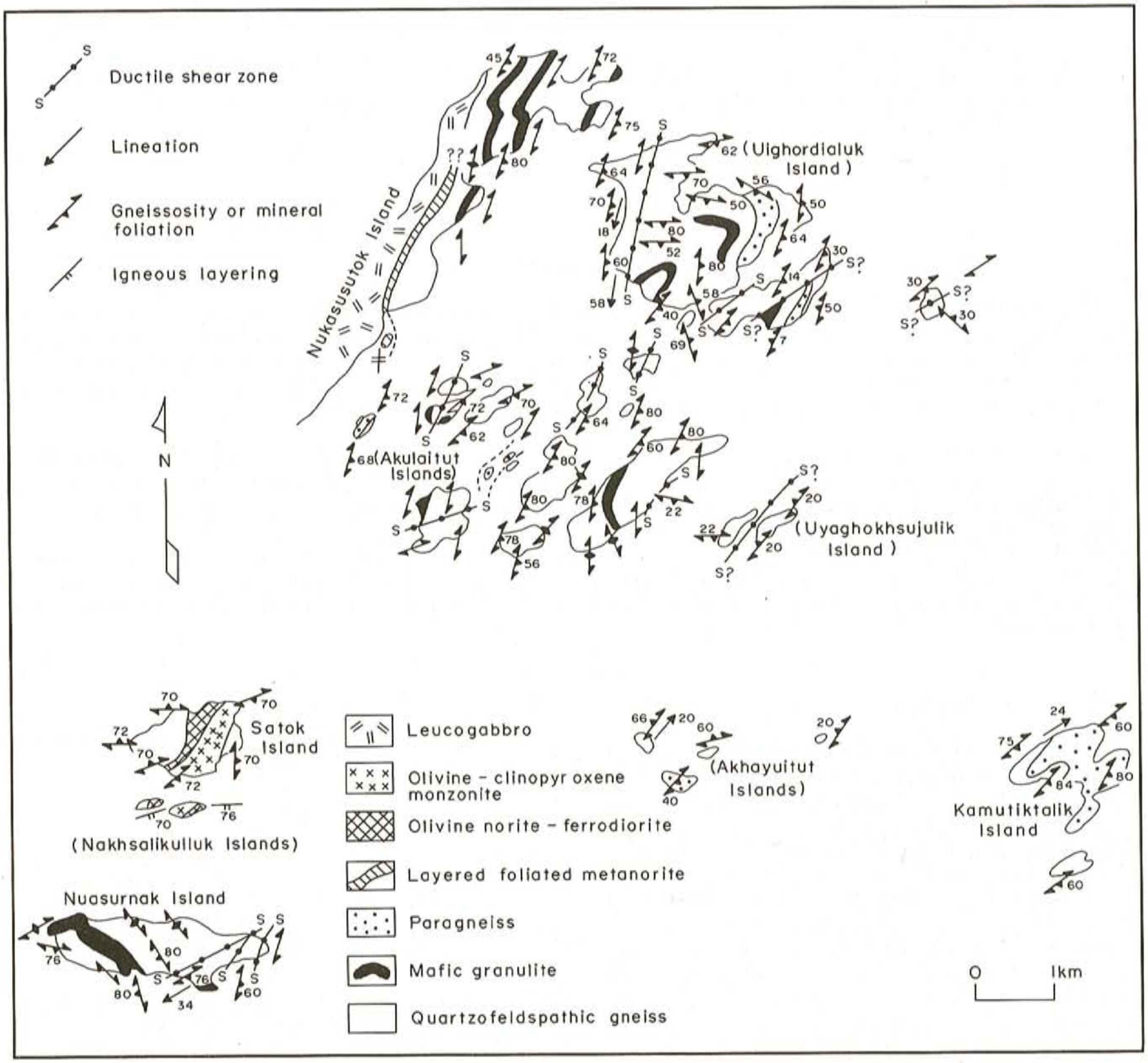

Figure 2. *Geological map of the area east and south of Nukasusutok Island. Geographic names in parentheses are taken from Wheeler (1953). Names of islands in text that fall outside the boundaries of this map can be found on Figure 1.*

islands east and southeast of Nukasusutok Island and (ii) several islands east of South Aulatsivik (Black) Island.

NUKASUSUTOK ISLAND AREA

Archean gneisses underlie all of the islands directly east of Nukasusutok Island (E.P. Wheeler, manuscript maps; Taylor, 1977; Davies, 1974; Figure 2). Gneisses also occupy the three northernmost islands of the Seniartlit group (Figure 1), the only ones examined. During a brief reconnaissance of Satok Island and small islets directly south of it in 1990, a norite–olivine monzonite sequence of uncertain affinity was discovered; the full extent of these plutonic rocks was determined this year.

The Archean gneisses of the southern project area are dominated by granulite-facies quartzofeldspathic rocks that vary from diffusely layered to distinctly migmatitic. Mafic gneisses are widespread but not abundant; metasedimentary gneisses are also rare. Several generations of granular and schistose mafic dykes intrude all rock types. Ductile shear zones have been identified within this area; these shears postdate some dykes but appear to provide avenues for other (syn-tectonic?) dykes.

Quartzofeldspathic Gneisses

Several types of quartzofeldspathic gneisses have been identified. The majority display granulite-facies mineralogy or are rocks that have retrogressed from the granulite facies. Mesoscopically, these rocks fall into four types: (i) well-layered yellow-brown to grey gneisses with a migmatite component, (ii) schlieric and ghost-layered gneisses, (iii) massive to diffusely layered and agmatitic brown granulite having a pervasive pink granite pegmatite component, and (iv) veined garnetiferous gneisses in which a garnet ± orthopyroxene melt component forms an irregular and sub-parallel network, akin to the Kiyuktok gneisses of Kerr (1980).

Well-layered gneisses (Plate 1) predominate in the central part of the Akulaitut Islands, on Uighordialuk Island and on the Seniartlit Islands. These are variably migmatized, with a *lit-par-lit* and slightly discordant, white to pale pink neosome. Most commonly these rocks are grey to grey brown, reflecting their amphibolite- to granulite-facies metamorphism. Mafic inclusions are abundant throughout these gneisses, but are not of sufficient extent to define units at the 1:50 000 scale of mapping.

Plate 1. *Layered migmatite, Seniartlit Island.*

Schlieric and ghost-layered gneisses have been derived from polyphase granitoid rocks. They contain rafts of older quartzofeldspathic migmatite, mafic gneisses and metasedimentary gneiss, and are the dominant rock type on the northwestern part of the Akulaitut Islands group. A weakly foliated, granulite-facies granitoid, intrusive into mafic granulite units, is the main rock type on the eastern part of Nukasusutok Island and may belong to this same orthogneiss unit.

Brown, rather massive, granulite-facies gneisses underlie the easternmost of the Akulaitut Islands and the southernmost of the central part of the group. Throughout this area, the gneisses contain abundant mafic and ultramafic rafts, and are intruded by a pink pegmatite network of at least two generations. These rocks also outcrop on the two islands south of Uighordialuk Island, on Humby's Island, on Potuk Island and on the northern part of Nuasurnak Island. Retrogressed gneisses, such as those on Poktoghusekh Island, are white weathering.

Kiyuktok-type quartzofeldspathic gneisses (cf. Kerr, 1980; Collerson *et al.*, 1982) are a variation of all the above-mentioned rocks. These gneisses are characterized by garnet ± orthopyroxene-bearing felsic segregations discordant to layering. They are present on parts of the three westernmost islands of the Akulaitut Island group and on the west shore of Poktoghusekh Island. Retrogression of the garnet and orthopyroxene gives these rocks a distinctive blebby texture.

Mafic Gneisses

The mafic gneisses include mafic granulite and amphibolite, the latter being derived by retrogression of the granulite. They occur as small (1 to 10 m^2) podiform bodies or rafts within the quartzofeldspathic gneisses and as units that are hundreds of metres wide and traceable for a kilometre or more along strike. The degree of migmatization is highly variable and individual occurrences may be massive, strike-continuous, banded rocks or they may be pervasively invaded by adjacent gneiss or younger granitoid veining so as to form 'exploded' bodies within a background of quartzofeldspathic material. The most coherent of the mafic gneisses form prominent units on the northeast part of Nukasusutok Island and on west-central Nuasurnak Island.

The mafic gneisses are typically greenish brown or black weathering. They locally have a blotchy texture defined by clots and oikocrysts of black hornblende, and in many outcrops are characterized by irregular veins and 'sweats' of granitic composition that contain conspicuous porphyroblasts of orthopyroxene.

Metasedimentary Gneisses

Gneisses of unequivocal sedimentary parentage are not common in the map-area. The most obvious rocks of this type are quartzites that outcrop on eastern Uighordialuk Island, underlie two small islands of the Akuliatut group, form one island within the Akhayuitut Island group, and appear to be the major rock type on Kamutiktalik Island.

The quartzites are white, grey and buff-coloured, faintly banded, coarsely crystalline rocks; cordierite-, sillimanite- and garnet-bearing pelitic and psammitic units occur with the quartzites on Uighordialuk Island and Akhayuitut Islands. Kamatiktalik Island was not entirely examined, but appears to be largely underlain by grey to brown impure quartzite. These rocks are quartz-rich, biotite-bearing, quartzofeldspathic gneisses that locally contain deep red oikocrysts of garnet. Thin (1 to 3 m) layers of less abundant quartzite, containing thinner (5 to 50 cm) units of orthopyroxene + garnet + cordierite-bearing pelitic gneiss occur at the southern end of the westernmost member of the Akulaitut group, where they are associated with mafic granulite.

Ultramafic Rocks

Orthopyroxenite pods are locally common components within the gneisses, especially in the brown granulite gneisses. They rarely form coherent units at 1:50 000 map scale, but

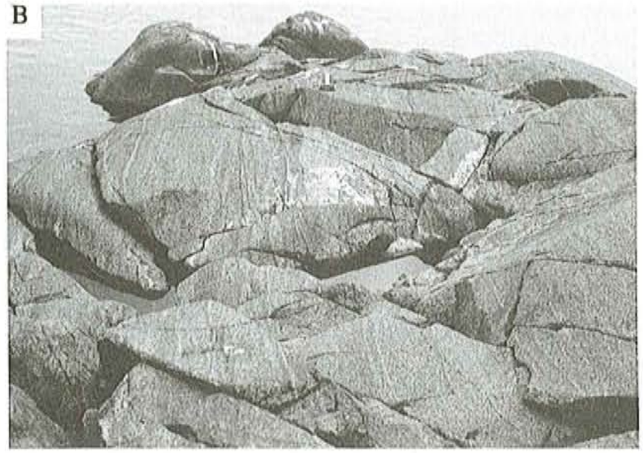

Plate 2. *Metaigneous rocks on Satok and nearby islands. a) Recrystallized noritic blocks in brown monzonite; b) diffuse igneous layering in olivine-bearing noritic phase.*

several of the smaller islands along the northern edge of the Akulaitut group are largely an agmatite of ultramafic blocks within an orthopyroxene-bearing granitoid. The ultramafic rocks are normally pale brown-weathering, but may be dark green or black when clinopyroxene and/or hornblende are present; biotite selvedges occur on such pods in gneisses that have retrogressed. The ultramafic rocks are fine to coarse grained, and vary from massive to well-layered, the latter feature being a relict primary trait of these rocks.

Metaigneous Rocks of Satok Island Area

A short visit to Satok Island during the 1990 field season revealed that the eastern half of the island is dominated by buff- to brown-weathering olivine + clinopyroxene monzonite containing white noritic inclusions (Plate 2a) and cut by deformed hornblende-rich 'amphibolite' and carbonate-bearing lamprophyric dykes (Ryan, 1991a). Further mapping during the 1991 project has defined the extent of these igneous rocks.

The monzonite is a fairly homogeneous, fine- to medium-grained rock and, except for narrow shear zones and a weak foliation, is internally undeformed. Its eastern contact with the gneisses is a mylonite/shear zone, and here the deformation is more severe—the rock has a strong fabric, and lamprophyric dykes are disrupted and drawn out parallel to the contact.

The monzonite is bordered on the west by an oxide-rich, black to rusty brown-weathering, hornblende-rich olivine norite or diorite. The southern contact of this unit with gneisses on Satok Island is a narrow shear zone and the rock is strongly foliated. On the northern part of the island the actual contact with country rock was not observed, but here primary textures, including a diffuse layering, are well preserved. However, the primary character of the mafic rocks is best exhibited in exposures on the Nakhsalikulluk Islands, just south of Satok Island. Here the rock retains many igneous features including a well-developed primary layering in the east (Plate 2b), rafts of leuconorite, rapid textural and grain-size changes, and, in the west, a layered, plagioclase–porphyritic melanocratic gabbroic phase having oikocrysts of black hornblende. The westernmost contact with gneisses, as on Satok Island, is a tectonic one in which a mylonitic structure is present in both rocks. Narrow amphibolitized shear zones also occur in the central part of the unit on these islands.

Metanorite of the Nukasusutok Island area

Wheeler (1969; manuscript maps) defined a 'granulite of uncertain origin' bordering the plutonic rocks on the east side of Nukasusutok Island. Davies (1974) also recognized this unit as being distinct from the surrounding gneisses and referred to it as a 'marginal pyroxene granulite'; she concluded, however, that it is most likely part of the country rock because it is intruded by the Middle Proterozoic igneous rocks of the Nain Plutonic Suite that form the bulk of the island.

The rock is grey to brown weathering and is well layered. The composition is noritic, and in many places on the small island near Nukasusutok Island it still retains vestiges of primary igneous textures (Plate 3a). The mesoscopic layering is on the order of 10 cm to a metre (Plate 3b), and, although enhanced by deformation, is largely an original igneous feature produced by grain size and compositional variations. Some layers are ilmenite and sulphide bearing. Isoclinal folds of the layering are also present, especially in high-strain zones.

The Basic Dykes

Metamorphosed, foliated and folded basic dykes, including rocks with kimberlitic and lamprophyric affinity are present on almost all the islands examined east and south of Nukasusutok. As in the area between Dog Island and Ford Harbour investigated in 1990, several generations are common in many outcrops, and morphological features akin to those described for the Dog Island–Ford Harbour area (Ryan,

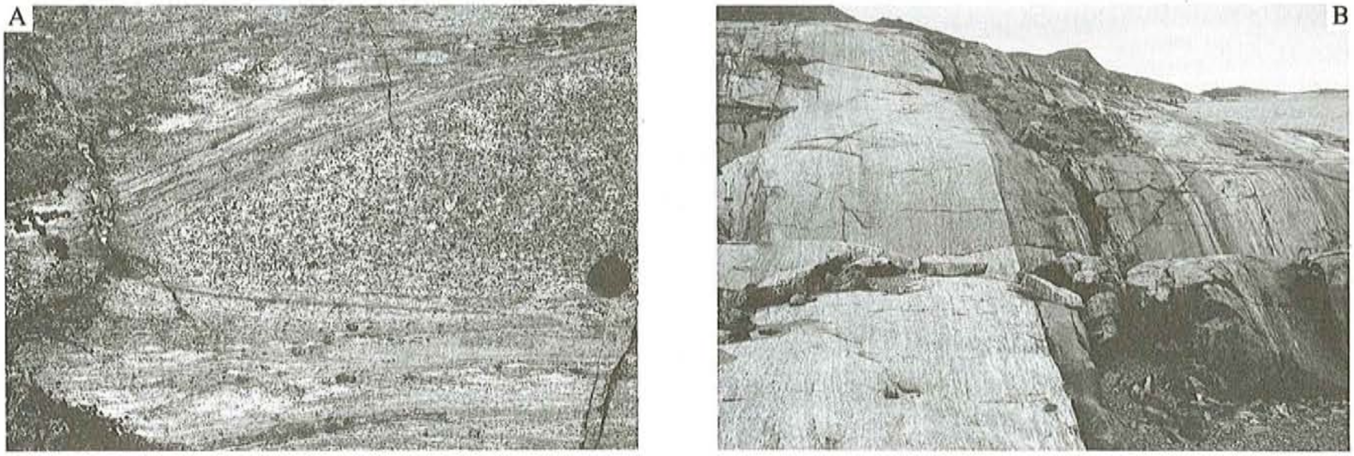

Plate 3. *Deformed, layered metanorite, Nukasusutok Island. a) Inhomogeneous deformation: recrystallized igneous texture in an augen of low deformation surrounded by more highly strained rock; b) compositional layering, reflecting original variations in igneous rock. Darker unit is an ilmenite–sulphide-bearing coarser norite.*

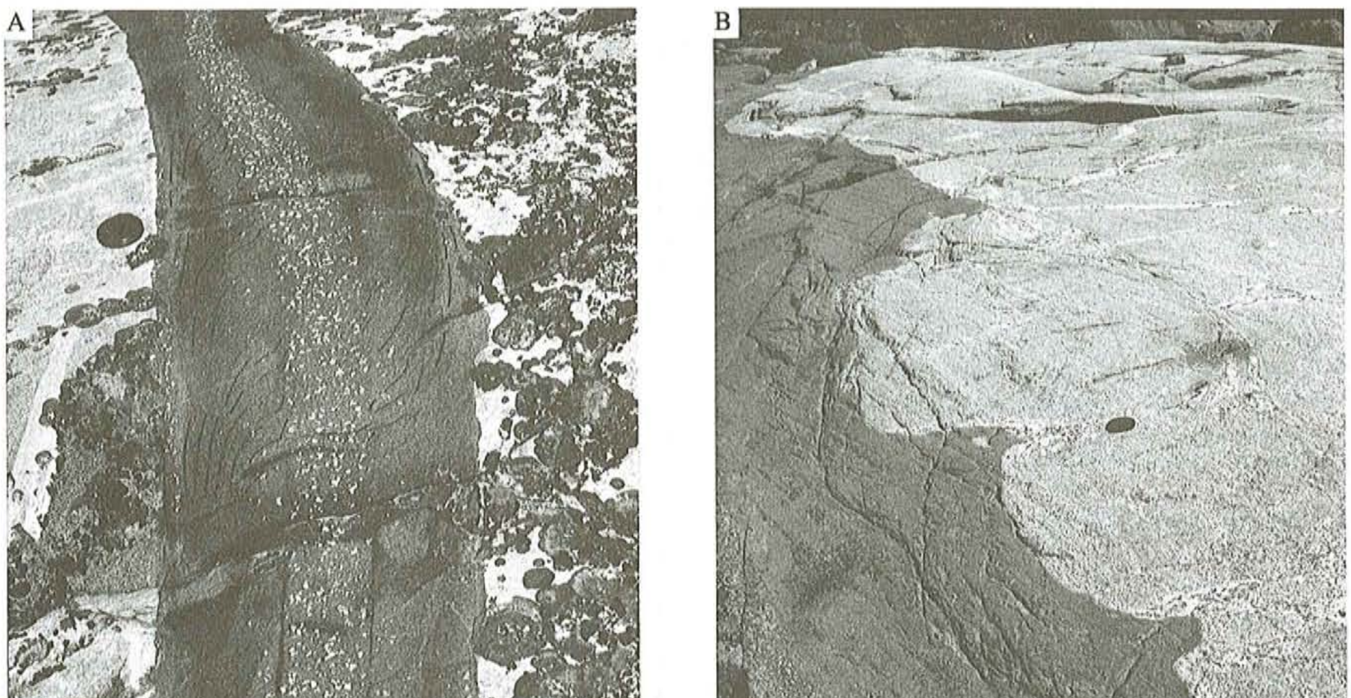

Plate 4. *Metamorphosed basic dykes. a) Basic dyke with central zone of plagioclase concentration and a sigmoidal foliation; symmetry of fabric indicates sinistral shear along plane of dyke. Seniartlit Islands; b) pronounced cuspate margin on basic dyke in grey schlieric gneiss; quartzofeldspathic melts at the tip of the dyke protusions may have been generated at time of dyke intrusion, but similar zones in gneiss distal from the dyke suggest they are earlier features; Akulaitut Island.*

1991a) characterize the dykes observed this year as well. For instance, foliated dykes are common; the foliation is sigmoidal (Plate 4a), oblique and parallel to the walls of the dykes. Folded dykes are less common than foliated ones. Cuspate margins characterize many dykes (Plate 4b), but most are straight-walled. Podiform and pinch-and-swell dykes are also present. Most dykes are steeply dipping, but subhorizontal and moderately dipping dykes occur on the easternmost islands such as the Akhayuitut group, Kamutiktalik Island, and Seniartlit Islands.

The intrusion of some dykes along, and probably concomitant with the formation of, shear zones is clearly demonstrable in many outcrops. It is also apparent that some dykes predate shear-zone development, and in some cases were themselves reactivated as shear zones following intrusion of a crosscutting set of dykes.

The dykes are predominantly black, massive amphibolite and granular mafic granulite. However, a variety that also occurs widely is a greenish brown 'granulite' in which irregular oikocrysts of black hornblende form a random interconnecting network. These hornblende networks produce a discontinuous streaky black fabric in the deformed dykes. Porphyritic dykes, in which plagioclase phenocrysts are concentrated in central or peripheral parts of the dykes, are present locally.

Indications of lamprophyric dykes in the region were noted on southern Satok Island last year (Ryan, 1991a) where black carbonate-rich dykes intrude olivine monzonite. Lamprophyric dykes have now been observed cutting the gneisses on Nuasurnak Island and several of the islands east of Nukasusutok. Most are dense, black, hornblende ± biotite ± carbonate-bearing rocks that exhibit a diffuse compositional layering. They form a sub-parallel group in monzonite along the southeast coast of Satok Island near the contact between the monzonite body and the gneisses. Other dykes of this type are zoned, pitted (weathered ocelli?), greenish black olivine–pyroxene–phlogopite rocks of probable kimberlitic affinity. Lamprophyric dykes are folded and truncated by a northeast-trending shear zone on Nuasurnak Island, plainly indicating that they predate at least one period of zonal ductile deformation in the gneisses.

SOUTH AULATSIVIK (BLACK) ISLAND AREA

The dominant rock type is a brown, diffusely layered to massive quartzofeldspathic granulite, especially well displayed on Little Fish Island and Bulldog Island (Figure 3). Screens and fragments of mafic granulite and ultramafic rock are common. On Little Fish Island and the northern part of Bouverie Island, the gneisses are intruded by numerous northeast-trending dykes of pink granite (probably related to the Manvers granite; Morse, 1969a). A massive grey to pink, diffusely layered granite that outcrops on the western coast of Bouverie Island (Figure 3) may be the same age as these dykes. Grey-brown, well-layered and migmatitic gneisses extend from Turnagain Island northward through Jonathan Island. The interior of Sculpin Island is a rather featureless white granitoid.

An enigmatic unit of layered granulite occurs along the western margin of the Jonathan Island anorthositic-troctolitic intrusion on Jonathan Island and on an adjacent small island. This unit has attributes of mafic rocks adjacent to massive igneous rocks of the NPS on Carey Island and at Higher Bight (Ryan, 1991a). It is a brownish-weathering, equigranular rock characterized in part by an irregular interconnecting network of brown pyroxene veins that, where pervasively developed, give it a brecciated appearance. A fine-grained, equigranular, grey-purple anorthositic to noritic component forms layers within the granulite and both are folded. The anorthositic part is, however, clearly of intrusive origin for it locally randomly transects the more massive pyroxene-veined rock and contains fragments of it. In thicker dykes and sheets it appears to be

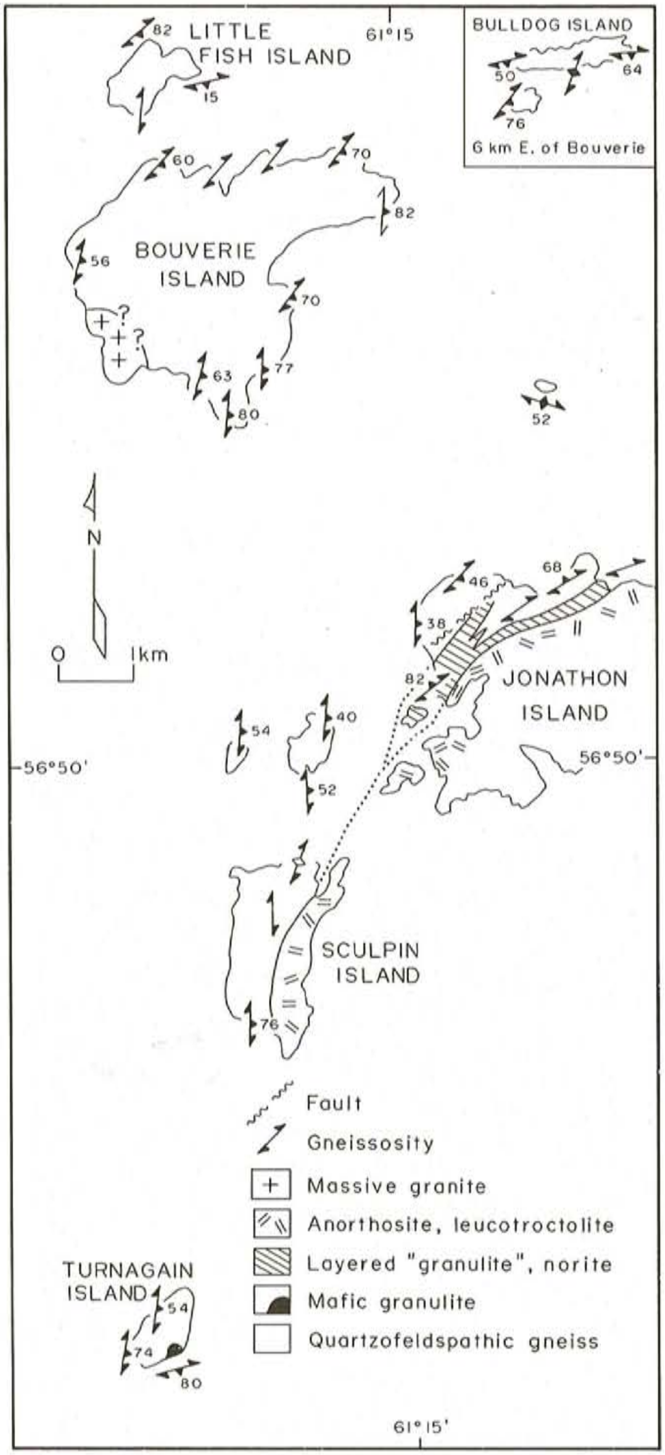

Figure 3. *Geological map of the islands east of Black Island village, South Aulatsivik Island.*

monzonitic, having a white speckled appearance that may denote the presence of potassium feldspar (cf. Berg and Breigel, 1983). On the northeastern shore of Jonathan Island the purplish noritic rock forms the matrix to a breccia that contains fragments of white granular anorthosite (Plate 5). Here the noritic rock also contains sulphides, that give rise to small gossan zones.

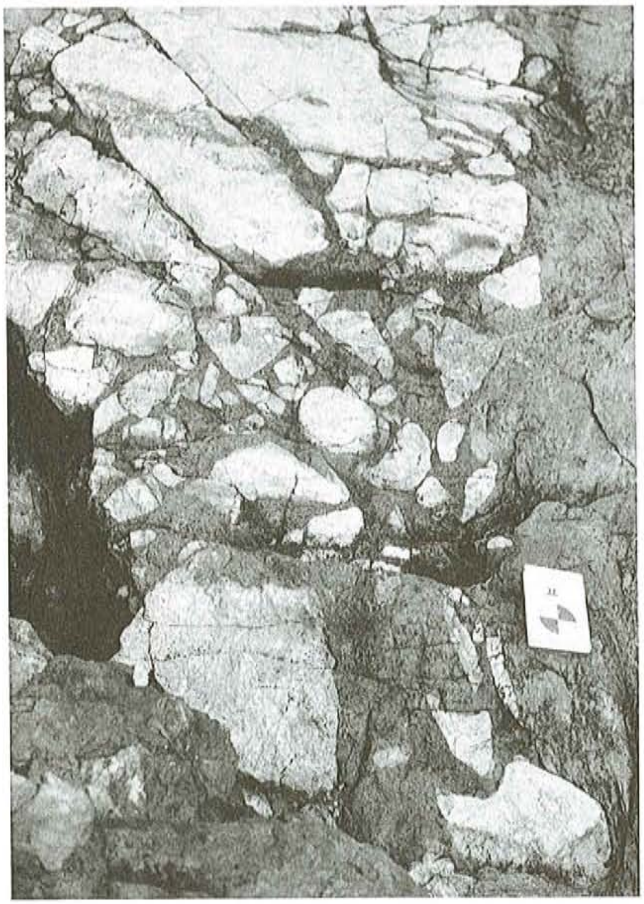

Plate 5. *An intrusion breccia of white fine-grained anorthosite fragments within purple-grey sulphide-bearing norite, northern Jonathan Island.*

Metamorphosed and deformed basic dykes are present throughout the island chain east of Black Island. The south side of Bulldog Island provides a spectacular exposure of such dykes; here east-trending north-dipping dykes within south-dipping, brown, granulite-facies gneisses produce a subhorizontal striped pattern to the nearly vertical 80 m cliff that can be seen from several kilometres distance. Crosscutting relationships in many outcrops point to at least two generations of such dyke intrusions on the islands. Two dykes worthy of note are (i) a curved coarse-grained, 50-m-wide granulite dyke that forms a conspicuous body west of the Jonathan Intrusion on northern Sculpin Island (cf. Berg and Breigel, 1983) and (ii) a foliated 060°-trending granular dyke that contains fragments and globular trains of white norite on the eastern point of Little Fish Island. The former may be related to the Jonathan intrusion, whereas the latter provides more evidence that there are foliated dykes that postdate or are contemporaneous with some of the anorthosites. Several plagioclase porphyritic dykes have been noted, and one of these, an east–west dyke on the eastern headland of Bouverie Island, has a streaky hornblende foliation oblique to its walls and has been dextrally offset, by up to 20 m, along several local north-trending ductile shear zones.

GEOLOGY OF THE AREA SOUTH OF NAIN BAY

A brief reconnaissance of the gneisses in the region between Nain Bay and Anaktalik Brook in 1990 revealed the presence of deformed anorthositic and granitic rocks (Ryan, 1991a). An attempt was made during the 1991 season to further define the extent of the foliated plutonic rocks and also to investigate the nature of the gneisses. It is clear that at least three units of granulite-facies gneiss and several units of anorthositic and dioritic rocks are present (Figure 4).

THE GNEISSES

Layered Migmatitic Gneiss

The easternmost unit is a well-layered, somewhat migmatitic, yellow brown-weathering enderbitic and charnockitic gneiss, that locally contains more quartz-poor compositions such as leucocratic mangeritic gneiss, gabbronoritic gneiss and noritic gneiss. In some areas, the gneisses tend to have a more chaotic or agmatitic structure in which mafic pods occur in a rather homogeneous charnockitic host, or charnockitic rocks occur as rafts engulfed by a pink granitoid host. Coherent and podiform mafic granulite units are locally present; these are generally less than 5 m thick and are interpreted to be derived from mafic dykes. Isoclinal folds of the layering are present in some outcrops, but overall the unit is not structurally complicated on a regional scale.

Garnetiferous Gneiss (Tasiuyak Gneiss ?)

The layered charnockitic–enderbitic unit described above is bordered to the west by garnetiferous granitic gneiss and graphitic garnetiferous paragneiss in its northern part, but by a homogeneous, buff-weathering, diffusely layered quartzofeldspathic granulite (see below) to the south. The garnetiferous paragneiss is similar to Tasiuyak gneiss, but differs from it in (i) being garnet-poor and having smaller garnets, (ii) being indistinctly layered, and (iii) being more biotite-rich. In addition the assemblage commonly contains orthopyroxene, a mineral uncommon in typical Tasiuyak gneiss. The occurrence of regional (?) orthopyroxene and the preservation of garnet implies contact metamorphic conditions that differ from the Tasiuyak gneiss within anorthositic plutons elsewhere in this region (cf. Lee, 1987) where garnet is destroyed adjacent to the plutonic rocks. Interbanded with the graphitic and garnetiferous paragneiss are garnetiferous granitoid sheets. These have a *lit-par-lit* morphology, and commonly contain screens of the more biotite-rich metasedimentary rocks.

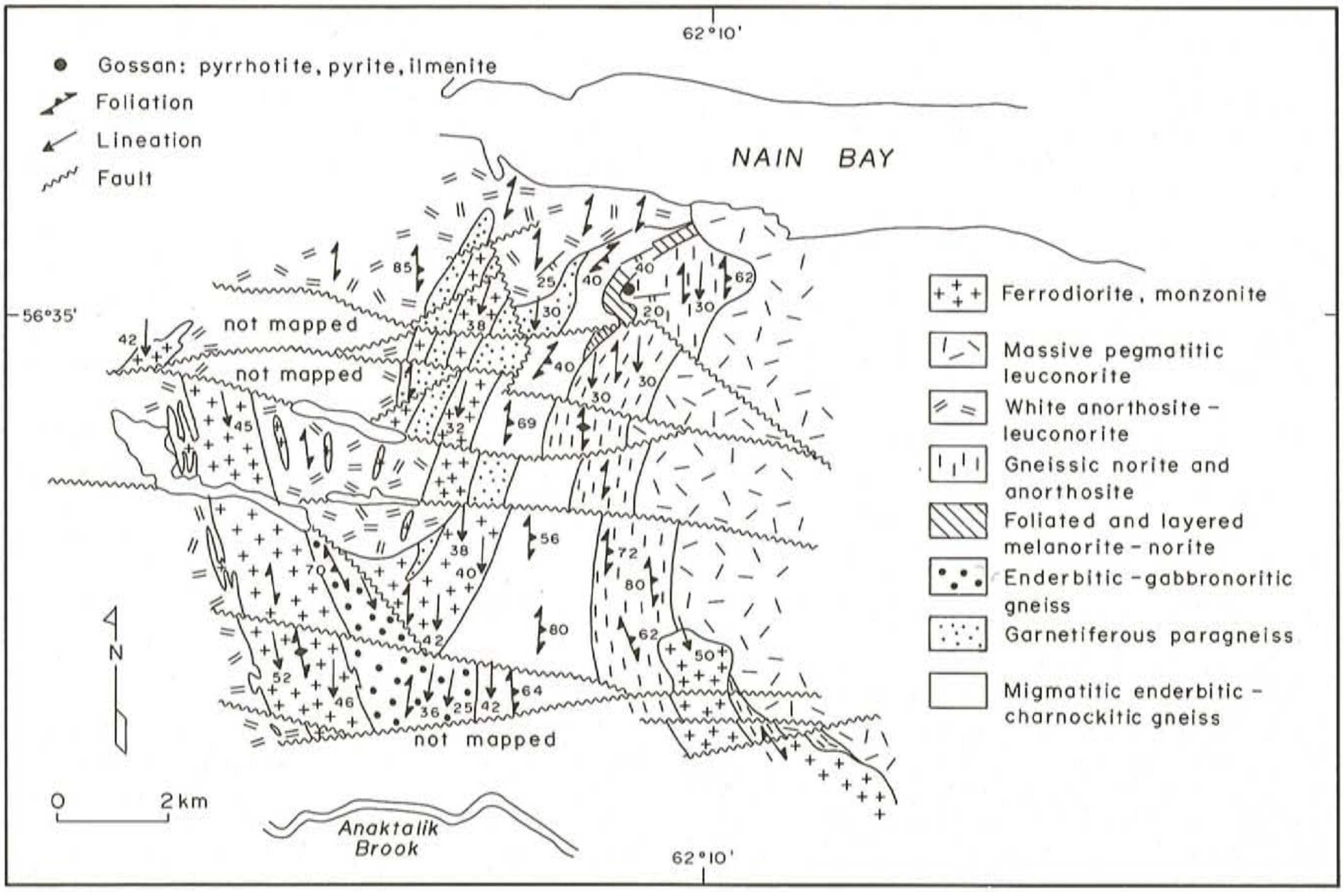

Figure 4. *Geological map of the gneiss–anorthosite–ferrodiorite–monzonite terrane south of Nain Bay. Some contacts are based on unpublished maps of E.P. Wheeler II.*

Diffusely Layered Enderbitic–Gabbronoritic Gneiss

The third gneiss type in the area between Nain Bay and Anaktalik Brook is a diffusely layered, buff- to orange-brown-weathering, enderbitic to gabbronoritic gneiss. It is not as well-layered as the gneiss of the similar overall composition to the east of it described above, and in places it is simply a foliated igneous rock. It locally contains discrete rafts of older gneiss, and it displays a shallowly south-plunging mineral-streaking lineation. In places it is difficult to distinguish from the foliated, brown-weathering, charnockitic plutonic rocks of the NPS (see below). It resembles, in overall character, an enderbitic to gabbronoritic rock south of Anaktalik Brook that has been dated at ca. 1909^{+33}_{-21} Ma (Krogh and Schärer, 1987).

THE PLUTONIC ROCKS

The plutonic rocks comprise anorthosite–norite and monzonite–diorite types. At least three different units of anorthosite–norite type can be defined, and three elongate diorite–monzonite plutons and numerous dykes of the same are present both in adjacent gneisses and within the anorthosites. The anorthositic rocks display textures that range from strongly foliated and gneissic to massive and subophitic-textured; they are interpreted to include at least three different generations of intrusion. With the exception of deformational foliations and enhanced primary compositional banding in the gneissic unit, oriented structures within the anorthositic rocks are rare. However, an indistinct compositional layering, generally dipping gently to the south can be seen in the cliffs of Nain Bay. The dioritic–monzonitic rocks form three elongate plutons and numerous small dykes in the area. Where emplaced into the gneisses, the larger units are concordant to gneissosity on a regional scale, but slightly transgressive on an outcrop scale. Dykes highly oblique to gneissosity are also present. The two western bodies are locally strongly foliated and exhibit a well-developed lineation, but the southeastern unit is much less deformed. These rocks appear to be all olivine-bearing, and are very conspicuous by their dark to rusty brown-weathering colour.

Gneissic Anorthosite, Leuconorite and Norite

Gneissic anorthosite, leuconorite and norite form a 1200-m-wide unit directly east of the layered gneisses, south of Nain Bay (Figure 4). The unit is compositionally variable over small areas, but a granular white rock of leuconoritic composition prevails. A narrow western border just south of Nain Bay comprises layered brown norite and black hornblende-rich melanorite and lesser ultramafic compositions which, in places, are texturally akin to the metanorite of Nukasusutok Island. The gneissic unit varies mesoscopically from a wispy-foliated rock to a banded gneiss; on hand-specimen scale it is equigranular and thoroughly recrystallized. Some of the feldspar shows rare labradorescence. Very coarse-grained orthopyroxene crystals are present locally, but more commonly they have recrystallized to a granular aggregate, and in most cases are strung-out to give the foliation–banding (Plate 6). Much of the orthopyroxene in the foliated anorthosite–norite is accompanied by, and appears to have been replaced by, hornblende ± biotite. Homogeneous mafic layers ('mafic granulite') occur in parts of the unit, both as strike-continuous or podiform bodies. At several locations in the leuconorite unit, the foliation is crosscut by slightly deformed metamorphosed basic dykes. The southernmost part of this unit is intruded by white to pink aplitic dykes that generally follow the foliation, but are not themselves foliated.

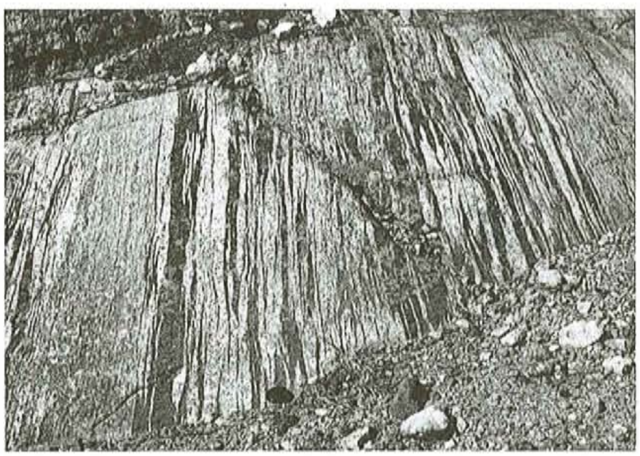

Plate 6. *Discontinuous, streaky aggregates of orthopyroxene, interpreted to be derived from attentuated and recrystallized coarse-grained crystals, south of Nain Bay.*

Foliated Leuconorite and Anorthosite

White-weathering, coarse-grained, ilmenite-bearing, leuconorite and anorthosite, commonly exhibiting a deformational fabric and recrystallized plagioclase, form the westernmost part of the area examined south of Nain Bay. Along its contact, more noritic variants are present, and it is transected by many massive and foliated brown ferrodioritic to monzonitic dykes. The foliation in this rock is not developed to the same extent as it is in the unit above, and is chiefly an augen-type fabric where subophitic pyroxene is drawn into lozenge-like shapes or it is a discontinuous streaky feature defined by flattening of the 'clotted fabric', the latter term coined by Wheeler (1955) for a texture of the anorthositic rocks in which pyroxene is concentrated in irregular zones rather than distributed uniformly through the rock. Directly south of Nain Bay, the foliation is strike-normal to an apparent diffuse layering seen at a distance in steep cliff faces, but where the contact between the gneisses and the southern margin of this pluton was observed, the fabric and compositional layering are parallel to the contact. Internally, this pluton is extremely coarse grained, having kinked crystals of orthopyroxene up to a metre in size; this pluton is probably the same coarse igneous rock that continues westward and hosts the spectacular coarse labradorite of the Pearly Gates area (cf. Watson, 1980).

Pegmatoidal Massive Leuconorite

The easternmost part of the area investigated south of Nain Bay comprises an undeformed, white to grey, coarse-grained leuconorite. This pluton has a well-exposed intrusive contact with the foliated and gneissic anorthosite to metanorite unit described above, and is considered to be the youngest of the anorthositic rocks in this area. The contact with the gneissic norite–anorthosite can be seen on the plateau south of Nain Bay, where a zone, 800 m wide, marks a transition between foliated rock with a stockwork of discordant pegmatitic ilmenite-bearing leuconorite (Plate 7), to leuconorite in which the older rock forms rafts. Where this younger unit has been examined in the north, it is a regionally homogeneous pegmatoidal ilmenite-bearing leuconorite, but a diffuse subhorizontal layering is visible in the 500 m cliffs that form the southern shoreline of Nain Bay. In the south, it is a seriate-textured rock that may in fact belong to an entirely different intrusion.

Plate 7. *Recrystallized metanorite having a streaky foliation, intruded by a pegmatoidal dyke of leuconorite; dark area in dyke is a coarse orthopyroxene crystal, south of Nain Bay.*

Western Diorite–Monzonite

The westernmost diorite–monzonite unit is completely enclosed by white weathering anorthosite in the north, but separates anorthosite from charnockitic gneiss in the south. It appears to encompass compositions from olivine meladiorite to olivine–clinopyroxene monzonite (akin to that on Satok Island) and varies from fine grained to coarse grained. Both varieties can be seen in single dykes in many parts of the area. Its western margin is marked by a subvertical sheeted complex of anorthosite and brown monzonite–diorite (Plate 8). Numerous dykes of the monzonitic rock occur throughout the region; the dykes, like the large body, are variably foliated. Inclusions of foliated and recrystallized, white-weathering anorthosite and norite, and of the country-rock gneisses are present in many parts of the intrusion.

Plate 8. *Sheeted contact between anorthosite (white) and ferrodiorite–monzonite comprising approximately 50 percent older and younger rock; note the lensing-out and boudinage of the anorthosite zones.*

Central Diorite–Monzonite

The central dioritic–monzonitic unit is similar to the above, but tends to be overall coarser grained and is more noticably quartz bearing. Unlike the western unit, the central diorite–monzonite is confined largely to the gneisses, and, as noted earlier, is disposed as dyke-like bodies parallel to the regional structural grain. It locally has a megacrystic texture, with some of the perthitic megacrysts having a narrow plagioclase mantle. In this respect, this intrusion is like the undeformed olivine- and clinopyroxene-bearing rapakivi granites that form larger masses within the NPS (cf. Ryan, 1991b). The deformation of the central monzonitic unit is very strong in places (Plate 9). In the originally megacrystic rocks, it has produced an augen structure in which dark streaks of olivine and clinopyroxene are wrapped around the feldspar megacrysts. The foliation is of L>S type in most outcrops.

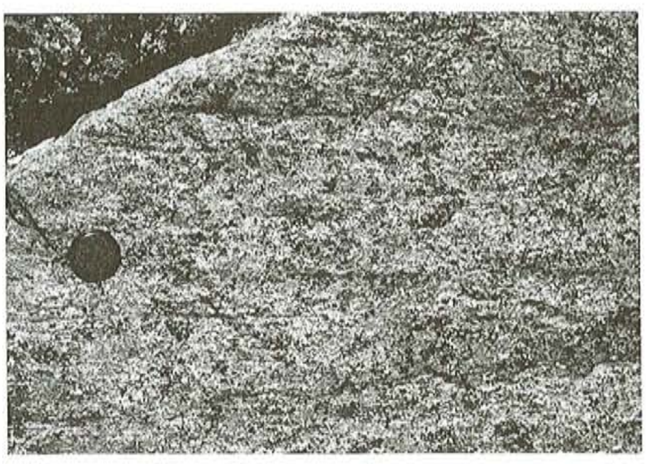

Plate 9. *Foliation in central olivine-bearing diorite–monzonite unit south of Nain Bay; phenocrysts of potassium feldspar stand out in relief.*

Southeastern Diorite–Monzonite

The southeastern body is the least deformed of the dioritic–monzonitic intrusions, although it does display a weak foliation and a south-plunging lineation; the foliation is best defined by the (primary?) orientation of the long axes of tabular potassium feldspar rather than the streaks of mafic mineral aggregates that form the fabric in the two units to the west. In addition to K-feldspar, clinopyroxene and quartz, outcrops also show dark-grey plagioclase xenocrysts in places. Some euhedral to ovoid potassium feldspar phenocrysts have a narrow plagioclase rim. At its southern end this intrusion becomes more granitic, and is characterized by light grey 'drop' quartz, and has abundant gneissic inclusions.

Other Areas Visited

A couple of days at the beginning of the 1991 field season were devoted to helicopter-supported field checking of geologically interesting areas highlighted from an examination of E.P. Wheeler's unpublished manuscript maps, and to collecting samples for geochronological study from difficult-to-reach parts of the NPS. These brief surveys (Figure 1) were carried out in collaboration with R.F. Emslie of the Geological Survey of Canada. In addition, a day was spent with J. Hodych of the Department of Earth Sciences, Memorial University, who collected specimens of mafic dykes for paleomagnetic study.

Among the areas visited in the interior of the NPS is an area 10 km north of Kingurutik Lake (Figure 1, T) shown on E.P. Wheeler's manuscript maps as 'granulite of uncertain origin'. A brief examination indicates this to be a well-layered melatroctolite (or olivine melagabbro) to leucogabbronoritic body having compositional variations on the order of a few centimetres to a metre. The unit is about 1 km in maximum width and is traceable along strike for at least 6 km. Its western boundary with brownish-weathering leuconorite was not investigated, but on its eastern side it is intruded by a massive dark grey to light grey leuconorite to norite.

Wheeler's unpublished maps also show a zone of 'granulite of uncertain origin' stretching several kilometres southward from the central south shore of Kingurutik Lake. A brief visit to one outcrop near the lake's shoreline (Figure 1, A) indicates this unit is foliated and recrystallized, layered, yellow- to white-weathering norite and leuconorite and brown, layered olivine-bearing melagabbronorite akin to rocks that occur on a small island west of Barth Island (Ryan, 1991a). The full extent of this assemblage is unknown since Wheeler's mapping is of a reconnaissance nature in this area, and the writer has not attempted to define the distribution of the deformed rocks outside the outcrop examined. It is likely, however, that gneissic zones of this kind occur elsewhere in the interior of NPS.

The Sheet Hill granite pluton (Figure 1, S; Berg, 1973) was briefly examined, and specimens were collected for zircon geochronological study. This pink-weathering, massive, fluorite-bearing potassic granite was described by

Berg (1973) as being intrusive into the nearby Hettasch layered basic intrusion, although he noted that it was locally 'strongly foliated' and appeared to be in 'gradational contact' with adjacent gneisses. This writer's brief visit to the Sheet Hill granite, suggests the pluton may be older than Hettasch intrusion. The massive interior part of the granite is somewhat misleading, since the conversion of basic dykes within it to hornblende schists implies that a penetrative deformation has affected the granite, and was preferentially absorbed by the dykes. Since the Hettasch intrusion is not deformed, the implication from the deformed dykes is that the Sheet Hill granite is older than the layered basic intrusion. Possible correlations are the Early Proterozoic granites recently identified by Emslie and Loveridge (1991; *in press*) in the Okak Bay area to the north, although the low-magnetic signature of the Sheet Hill granite (G. Kilfoil, personal communication, 1991) sets it apart from the Okak granites. It is possible that the nearby Alliger Lake granite (see Ryan, 1990) is also of Early Proterozoic age.

The Manvers granite, which intrudes the Kiglapait intrusion, was collected at two localities for geochronological study (Figure 1, M), one just west of Village Bay on the shore of Port Manvers Run, the other south of Port Manvers Run at Medusa Bluff (see Plate 1 in Morse, 1969a). The Manvers granite is the name used by Morse (1969a) for a series of dykes within the Kiglapait intrusion that vary from pink aplitic to white pegmatitic rocks; the coarser members contain topaz, fluorite, beryl and amazonite. A sample of homogeneous, pink, medium- to fine-grained granite and a sample of a white pegmatite dyke were collected at Medusa Bluff. Pink granite having zoned plagioclase phenocrysts and opaline ovoid quartz, and a grey, aplitic, speckled biotite granite were collected west of Village Bay. Previous Rb–Sr and K–Ar investigations by Barton (1974) suggest intrusion ca. 1275 Ma, but this is probably a minimum age.

Foliated pink, potassic, hornblende granite and grey-pink granodiorite form the major rock type on the western half of Loon Island (Figure 1, L; cf. Barton, 1977). The granitic rocks are intruded by recrystallized and foliated basic dykes having a variety of orientations, but crosscutting contacts between dykes were not observed during a brief examination of the island. The Loon Island granite resembles granites that intrude mafic granulite and other gneisses on the Red Islands (Ryan, 1991a). All the granites are cut by deformed dykes, and all are of unknown absolute age. A sample suite was collected for U–Pb zircon dating, to ascertain if Barton's (1977) Rb–Sr data indicating a Middle Proterozoic emplacement age were a valid signature.

Several of the metamorphosed and deformed mafic dykes that cut the gneisses were collected during the 1991 field season for geochronological study (see Connelly and Dunning, 1990). Sample sites on Misfit and Dumbell islands (Ryan, 1991a) were revisited during the 1991 field season, and samples of dykes were taken by J. Hodych for paleomagnetic study. Results from these dykes could augment the field and geochronological interpretations and allow constraints to be placed on the time(s) of dyke emplacement and/or metamorphism. At present there are few data on the age(s) of the dykes. Barton (1973) reported preliminary Rb–Sr and K–Ar results that indicated the possibility of three distinct intrusive episodes, namely 1200, 1380 and 1615 Ma. Wiebe (1985) conducted K–Ar whole-rock analyses of two fresh dykes cutting the NPS that indicated minimum ages of 1042 ± 54 and 977 ± 44 Ma.

STRUCTURE AND METAMORPHISM

The overall regional structure of the gneisses of the area is fairly simple. A few large folds can be identified, but no complex patterns are apparent at the mapping scale, although in some outcrops there are clear mesoscopic interference patterns resulting from superimposition of two or more fold generations.

Unique to the Nukasusutok Island area are discrete, ductile high-strain zones in the gneisses (Figure 2). In some cases, these are expressed as layer-parallel zones of abnormal strain within otherwise migmatitic and layered gneisses, but in many instances are highly discordant zones both at outcrop and map scale that juxtapose gneisses with differing orientations. These zones vary from a few centimetres to hundreds of metres in width, and in some cases are occupied by younger, or perhaps contemporaneous, mafic dykes (Plate 10). The post-shear or synkinematic age assignment to these dykes is based on the observation that in some shear zones the dykes are straight-walled and show no penetrative fabric, yet in others the dykes have pinch-and-swell form and exhibit a sigmoidal, oblique or dyke-parallel foliation. It is also apparent, however, that some dykes predate shear-zone formation, for there are dykes that are truncated or drawn into parallelism with the shear zone. Perhaps the best large-scale example of this shear zone–dyke relationship occurs in a cove on the south shore of Nuasurnak Island where lamprophyric dykes in the gneisses are reoriented and folded with their host rocks upon entering a northeast-trending shear zone (Plate 11). Relations between dykes and gneissic layering within the zone indicate initial transposition and rotation of dykes into parallelism with the gneissosity, followed by folding of both as the shear evolved. The shear zones that were examined appear to record two ages of movement at different crustal levels. Some zones retain the high-grade minerals of the adjacent gneisses (i.e., upper amphibolite to granulite facies), whereas others are chloritized, epidotized, and hematized and reflect much lower-grade metamorphic conditions at time of formation. Both types of assemblages can be seen in individual zones, implying the high-grade shears were re-activated at lower P-T conditions during crustal uplift.

Metamorphic assemblages in the gneisses record upper-amphibolite to granulite-facies conditions. The granulite-facies rocks are much more widespread in both the Nukasusutok Island–Humbys Island area and the Bouverie Island–Bulldog Island area than they are in the Dog Island area that was mapped last year. The presence of cordierite as a pseudomorph after sillimanite and garnet in pelitic rocks, by comparison with this transformation elsewhere in the region,

Plate 10. *Sinistral shear zone in gneisses, Akulaitut Islands; three foliated mafic (granulite) dykes occur within the 'straight gneisses' of the shear zone.*

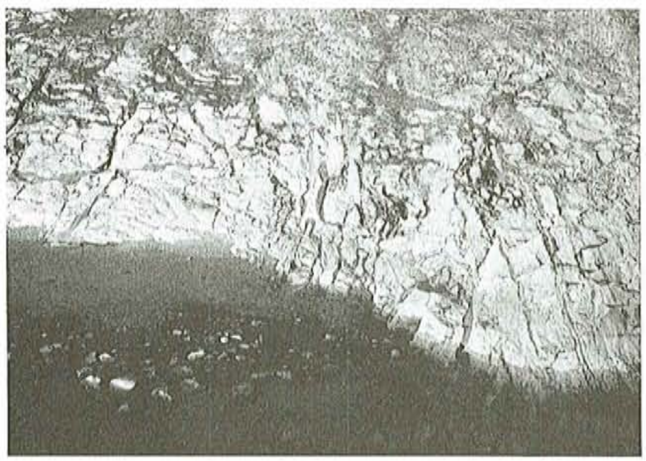

Plate 11. *Oblique aerial view of the margin of a shear zone on Nuasurnak Island; note that lamprophyric dykes on left hand side of photo are folded and truncated by the shear; similar dykes in the shear zone are folded with their host rocks.*

is evidence to support a localized contact thermal overprint from the NPS. It is thus not certain if granulite-facies assemblages in gneisses near the plutons reflect regional or contact effects, or a combination of both.

The dykes in both the Nukasusutok and South Aulatsivik areas record evidence for both granulite- and amphibolite-facies metamorphism, with mineral assemblages that mirror those present in the Dog Island–Ford Harbour area (Ryan, 1991a). The problem of the origin of the granular orthopyroxene-bearing dykes (i.e., are they metamorphic or igneous rocks ?) was outlined last year, and is no more easily resolved based on the present work. It is quite apparent that such dykes are both massive and foliated, and some of them follow the shear zones mentioned above. Assemblages may in some cases be related to proximity to the NPS, but this correlation has not been firmly established.

The gneisses and deformed plutonic rocks south of Nain Bay are cut by many east–west, largely sinistral, faults that displace contacts tens to hundreds of metres. Northeast- and northwest-trending faults in some cases may be splays of the east–west structures, but in other cases seem to be an unrelated set. The gneisses to the west of the deformed norite–anorthosite generally dip steeply beneath the latter (Figure 4). Along the northern junction, however, the contact is shallow, and the layered melanorite unit seems to define an overturned fold structure plunging gently to the southwest. An interesting link between most of the rocks in this area is a regionally developed shallow- to moderately-south plunging mineral-streaking lineation. The attitude of this lineation is unlike that which occurs in gneisses of the Churchill Province to the west, the latter being generally subhorizontal. The fact that the streaking lineation is recognizable within gneisses, anorthositic rocks and the granitoid rocks is suggestive of a common origin.

The region south of Nain Bay was interpreted by Ryan (1990), to contain the Nain–Churchill (Rae) boundary. This was based on the geological mapping of E.P. Wheeler, whose manuscript maps showed a distinct change in rock types within the gneissic terrane of this area (see discussion in Ryan, 1991a). There now seems to be no firm basis for this interpretation. If a tectonic assignment has to be made, the writer now favors inclusion of all rocks here within the Churchill (Rae) Province, since no obvious structural break exists between any of the three gneissic units in this area.

MINERALIZATION

The quartzofeldspathic gneisses appear to have little mineralization. A narrow rusty zone in which coarse-grained pyrite and/or pyrrhotite occurs, was discovered in a mafic granulite by S. Swinden, of the Mineral Deposits Section, during a brief visit to the field area in August. The mineralization occurs near a ductile shear zone on one of the northwestern islands of the Akulaitut group.

Dense, rusty, ilmenite–sulphide-bearing stratiform zones occur within well-layered rocks on a small island just east of Nukasusutok (Figure 2; Plate 3b). These are the southernmost exposures of layered, deformed, and recrystallized norite that, according to Davies' (1974) map, extends northward across Nukasusutok Island proximal to the eastern margin of the massive anorthositic rocks that underlie most of the island. More mineralized rocks of this type are thus probably present northward along strike.

The largest mineralized zone found during the 1991 season occurs within a 5- to 10-m-wide pegmatoidal north-trending norite dyke that intrudes recrystallized, equigranular anorthosite and banded norite and melanorite on the western margin of the gneissic anorthosite–norite unit south of Nain Bay (Figure 4). Crystal faces of pyrrhotite on the order of several centimetres in size are visible in the pegmatite from the least indurated parts of the gossan zone. In some cases, the sulphide appears to be a surface encrustation or replacement of coarse orthopyroxene, whose morphology in the sulphide-free pegmatoidal rocks is identical to that of the coarse sulphide. Chalcopyrite occurs interstitial to the pyrrhotite–pyrite in some parts of the showing. Although this is the most spectacular of the rusty zones in the anorthositic rocks of this area, it is not the only occurrence of this type. Several other rusty ilmenite-bearing leuconorite dykes intrude foliated norite and sugary recrystallized anorthosite to the east, and locally form stockworks that exceed the amount of older rock in outcrop. In addition, Grimley (1955) has reported similar mineralization in 'small shear zones in anorthosite country rock' from the south shore of Nain Bay, which may be of the same age and origin as that described above.

SUMMARY AND DISCUSSION

The 1991 mapping has shown that the general subdivisions of the gneiss complex established last year for the Dog Island–Paul Island area can be extended southward to the Nukasusutok Island area. Northward, however, the gneisses are not easily subdivided, in part because the granulite-facies metamorphism makes subtle differences in the quartzofeldspathic rocks difficult to detect. As in the Dog Island area, as well, supracrustal rocks are not areally extensive at the 1:50 000 map scale. The paragneisses are predominantly quartzite (or perhaps recrystallized chert) akin to those around Ford Harbour. The mafic granulites and amphibolites distal from the plutonic rocks are typically black, hornblende-rich blotchy-textured rocks, whereas those adjacent to plutons (such as the Jonathan Island Intrusion) are equigranular pyroxene-rich rocks. The latter may be related to the adjacent plutonic rocks in some way, or their pyroxene-rich (and commonly olivine-bearing) character may be a function of contact metamorphism. The Jonathan Island granulite with its layers and sheets of purplish-grey granular norite is a typical example of these mafic gneisses, and can be used to illustrate the problems they pose. This unit was considered by Berg and Breigel (1983) to be of 'sedimentary origin', but they were somewhat perplexed by the igneous composition of the grey rock, especially where it occurred as a matrix to a fragmented white anorthosite. They concluded the brecciated anorthosite was probably a pyroclastic rock, a conclusion that is not favoured by the present writer. It seems more likely that the mafic granulite and white anorthosite are older igneous rocks that have been brecciated by intrusion of the grey-purple norite, and perhaps the whole assemblage is related to the Jonathan Island intrusion. White anorthosite layers are also present in the layered mafic rocks on Carey Island, suggesting continuity of this 'granulite' unit intermittently around the whole of the Jonathan Island intrusion (cf. Ryan, 1990).

Metamorphosed and deformed basic dykes occur in both the northern and southern areas of gneisses mapped during the 1991 season. As in the Dog Island area, there are several generations of such dykes, and they display morphological characteristics that indicate intrusion under brittle and ductile conditions of their hosts. Both granular and foliated dykes are present, exhibiting mineralogical characteristics of amphibolite- and granulite-facies metamorphism. Subophitic and porphyritic textures are recognizable in some dykes, but even these dykes have a metamorphic overprint. The attitude of the dykes in the Nukasusutok Island–Humbys Island area changes from subvertical in the west to subhorizontal in the east, possibly indicative of increasing distance from source eastward. The lamprophyric dykes are an intriguing suite that seem to be unique to the Nain area. Their absolute age has not yet been determined, but if related to NPS magmatism, they represent a newly recognized member of this anorogenic association.

Deformed anorthositic and granitic rocks that were discovered in 1990 south of Nain Bay (Ryan, 1991a) were investigated in more detail during the 1991 field season and found to be important components of the Nain Plutonic Suite in this area. These rocks present some of the most intriguing problems within the Nain region. Deformed and recrystallized anorthositic and noritic rocks form at least two geographically separate units south of Nain Bay, and one of these is intruded by massive pegmatoidal leuconorite. In all likelihood, more such zones of deformed anorthositic rocks occur within the NPS, as is suggested by the examination of a 'granulite of uncertain origin' on the south shore of Kingurirtik Lake. Ferrodioritic to monzonitic rocks in the Nain Bay area form dyke-like bodies intruded into already deformed anorthosite, yet are themselves strongly deformed. Unlike the non-foliated granitoid rocks of the NPS, which form somewhat bulbous and irregular intrusions plainly discordant to regional trends (see Ryan, 1990) the dyke-like bodies south of Nain Bay are concordant with the regional trend of the gneisses, clearly indicating a structural control on emplacement. It was the elongate shape of these granitoids on E.P. Wheeler's manuscript maps that in part prompted the writer to investigate this area.

The results of the 1991 mapping outlined above reinforce the conclusion from the 1990 work that the geological history of the Nain area is probably more complex than hitherto appreciated. Facts that point to this were discussed by Ryan (1991a)–specifically, the several generations of dykes and their metamorphic state, and the definition of deformed and recrystallized rocks within the NPS. Each of these will be briefly discussed in light of the results of the 1991 work.

The small database of precise dating from rocks in the Nain region has proven a hinderance to evolutionary modelling, so any proposal for its geological history is open to different interpretations as will be evident below. This is especially so with the basic dykes, for which no firm absolute ages are yet available. As noted earlier (Ryan, 1991a), certain dykes in the wispy granitoid gneiss of the Dog Island area appear to be syn-plutonic with the host. Preliminary zircon U–Pb data by J. Connelly (personal communication, 1991) of Memorial University of Newfoundland suggest that a late Archean age (ca. 2.54 Ga) is probable for both the gneiss and a dyke at one such outcrop, indicating a hitherto unknown period of basic dyke intrusion in the Nain Province. It is possible that some of the other dykes are also Archean. However, by comparison with the Hopedale and Saglek blocks, others are quite probably Early Proterozoic. This raises the (unlikely) possibility of Hudsonian deformation having encroached on this area as noted in a discussion of the 1990 mapping data (Ryan, 1991a, p. 248). However, if the assumption is made that at least some of the dykes with plagioclase phenocrysts and noritic fragments must be related to NPS magmatism, then foliated Middle Proterozoic dykes are present as well, and the tectonism of this age must be an effect of the emplacement of the plutons. It is unlikely that the sigmoidal foliations in such dykes result from magmatic flow, but instead attest deformation imposed upon the dykes as a result of post-emplacement stress. Foliations of this type are a result of lateral slip of the dyke walls either just prior to final and complete crystallization or are a result of post-consolidation reactivation of the dyke as a plane of shear (cf. Berger, 1971; Davidson and Park, 1978).

The deformed and recrystallized igneous rocks that form units distinct from adjacent gneisses on the islands also pose more questions and lead to alternative scenarios in reconstructing the geological history of the area. If, for instance, the melanocratic norite–monzonite association containing leuconorite inclusions on Satok Island is Late Archean instead of Middle Proterozoic in age, then the deformation that has affected it could be Late Archean or Hudsonian. This of course implies the existence of norites and leuconorites of Archean age that are mesoscopically indistinguishable from the deformed rocks of the areally more-extensive NPS. If it is of the same age as the Bridges layered intrusion (ca. 1650 Ma, L. Ashwal, personal communication, 1991), the deformation must be Middle Proterozoic but could be of Labradorian (1650–1620 Ma) rather than Elsonian (1320–1200 Ma) age. Likewise, if these igneous rocks are an integral part of the 1320–1290 Ma magmatism of the NPS, their foliation must have been impressed during Middle Proterozoic deformation. The same uncertainty of place must be used when discussing the deformed lamprophyric and kimberlitic dykes that intrude the monzonite and also intrude the gneisses on the nearby islands. These could similarly be Late Archean or Middle Proterozoic in age. By inference, the shear zones that truncate such dykes on Nuasurnak Island could be of Late Archean, Early Proterozoic, Labradorian, or Elsonian age! All these examples illustrate the problems encountered when tectonic models for the Nain area are contemplated.

The layered noritic gneiss of eastern Nukasusutok Island is another example of a rock whose relative position in the stratigraphy of the Nain area is unclear. E.P. Wheeler's sense of uncertainty about the origin of this rock is understandable. This 'granulite' differs from the hornblende-rich mafic gneisses of the main gneiss complex by (1) being noritic in composition, (2) having vestiges of primary igneous textures, (3) having a primary compositional layering, albeit enhanced by deformation, (4) lacking the granitic network and orthopyroxene-bearing 'sweats' that occur in the mafic rocks to the east, and (5) having abundant ilmenite, a mineral that is uncommon in the mafic granulites to the east. This rock thus has more in common compositionally, mineralogically, and texturally with the Middle Proterozoic plutonic rocks of the area than with the gneisses and, in fact, is texturally comparable to some of the deformed and recrystallized noritic rocks that occur south of Nain Bay. Its deformation, including ductile shear zones and isoclinal folds, sets it apart from the directly adjacent undeformed plutonic rocks, but it seems difficult to escape the conclusion that this rock was derived from a parent akin to or directly related to the NPS. A probable pre-NPS equivalent could be the Bridges layered intrusion, a locally deformed olivine-bearing gabbroic to noritic body near Nain that predates the emplacement of the adjacent NPS anorthosites (Planansky, 1971) and may be as old as 1650 Ma (L. Ashwal, personal communication, 1991).

Deformed and recrystallized igneous rocks that are presently considered to belong to the NPS are also problematical. Their recognition in 1990 debunked the widely-held belief that the NPS is a pristine anorogenic terrane that exhibits no significant deformation. The recognition of penetrative tectonic fabrics and recrystallization textures within the NPS, therefore, prompted Ryan (1991a, c) to examine two current alternatives to account for their presence. The two potential mechanisms for the tectonic overprint are (i) diapiric emplacement of semi-solid cumulates or (ii) penetrative deformation following solidification, totally divorced from the emplacement itself. Consideration of these models assumes the deformed anorthositic rocks are not older than the NPS. An Archean or Early Proterozoic age however is not entirely ruled out for some at this stage of investigation, since similar rocks appear to be part of the gneiss complex farther south (Ryan and Lee, 1986).

Deformed noritic and anorthositic rocks of the type found recently in the NPS were recognized decades ago in anorthositic rocks in Norway. There they appear to be confined to the margins of individual intrusions and their foliation attitude implies they form an external sheath to domal bodies (cf. Michot, 1969). They have been interpreted by J.C. Duchesne and colleagues (cf. Duchesne and Michot, 1987; Duchesne and Maquil, 1987; Maquil and Duchesne, 1984; J.C. Duchesne, personal communications, 1991, 1992) to be a product of marginal deformation of the plutons by frictional drag during their emplacement as crystal mushes. Inclusions of foliated anorthosite–norite within interior undeformed rocks are interpreted to be related to late-stage puncturing of the gneissic carapace by the rising magmatic core and root of the diapir, which is now expressed as the central part of the domes. Using the Duchesne model, the gneissic rocks south of Nain Bay (Figure 4) could be interpreted as the deformed margin of the massive leuconorite pluton to the east, the latter being the core of the diapir that ascended and pierced the enveloping gneissic sheath during the final expansion and flattening of the pluton. This model has at least one feature that can make it applicable to the Nain Bay area and elsewhere where similar rocks have been observed (cf. Ryan, 1991a), namely, the position of the deformed plutonic rocks relative to the main plutonic masses. Most of the strongly deformed anorthosite and norite seen to date by the writer occurs proximal to gneisses, suggesting a marginal locus for the foliated rocks. However, this observation may be biased by the focus of the project, namely the gneisses themselves; consequently, it is only near these gneisses that the plutonic rocks have been examined systematically. It is quite obvious from the Kingurutik Lake occurrence of gneissic norite that such zones also occur in the interior of the NPS.

There are a few features of the Nain Bay anorthosites that suggest a simple domal diapir model is not applicable. For instance, the country-rock gneisses locally dip gently beneath the gneissic norite–anorthosite rather than away from it. Thus, if the intrusion is diapiric, the foliated plutonic rocks of this area must represent a section through a part of the deformed carapace that has spread laterally above the gneisses in a mushroom-like pattern (cf. Jackson and Talbot, 1989). This implies nappe formation or oblique ballooning of the kind suggested, for example, by Martignole and Schrijver (1970) to have been operative during diapiric emplacement of the Morin anorthosite, Quebec, and by Courrioux (1987) for diapiric emplacement of the Criffel granodiorite–granite pluton in the Southern Uplands of Scotland. Lateral migration of anorthosite away from a semi-solid diapir as a nappe-like mass at Morin has, however, been rejected by Emslie (1975) who argued that the deformed rocks of the Morin intrusion are a consequence of post-solidification regional tectonism.

The presence of dyke-like masses of foliated diorite–monzonite in the western part of the Nain Bay map area, as noted above, is a pattern uncharacteristic of most of the other ferrodioritic and granitoid rocks of the NPS. The Martignole and Schrijver (1972) model would assign these as magmas that co-existed with a largely crystalline anorthositic diapir, essentially forming a 'liquid cap' above the diapir, and would be interpreted as keels of these sheets now infolded or squeezed into the roof of the diapir. Alternatively, they could be dykes injected downward into fractures in the anorthosite (Emslie, 1975, p. 33). Several problems arise with these interpretations. Although these intrusions do occur within anorthosite, others occur totally within the country-rock gneisses, and therefore, are not part of a cap singularly associated with the anorthosite of this area. Under the above models, however, the dioritic rocks could perhaps be accommodated as downward tapering wedges expulsed obliquely from the diapirs, with a morphology akin to curved flange intrusions (cf. Walker, 1975).

The sheeted contacts noted earlier that mark the junction between the diorite and anorthosite could represent regions where forceful downward injection of magma resident above the diapir has taken place, as suggested by the models referred to above. However, these contacts are here interpreted as zones in which vertical *upward* intrusion of the younger rocks was abnormally intense—the writer knows of no contacts between anorthosite and the large bodies of granitic rocks within the NPS that are of this type. Perhaps this signifies a greater depth of erosion than for the other granitoids of the area, and may in fact be a reflection of features that characterize the deeper contacts between all the anorthositic and granitic rocks within the NPS. These sheeted zones and dyke-like bodies could thus represent the migration routes for ascending magma that formed the more irregular granitic plutons that represent higher levels of the igneous terrane (cf. Morse, 1969b). Apparently, marginal zones between anorthositic and gneissic rocks to the west and north are marked by similar dyke networks (Wheeler, 1969).

Another problem that arises in the consideration of the diapiric model is that it requires the diapir to comprise a lubricating interstitial liquid (of noritic composition?) between crystals of plagioclase and orthopyroxene. As noted last year, evidence for existence of this liquor seems to be lacking, and the favoured interpretation is that all the deformation seen in the NPS is imposed upon already crystalline masses (see also Emslie, 1975, p. 31). This is obvious from observations that subophitic intergrowths of plagioclase and orthopyroxene are deformed, implying solid-state deformation. Diapiric rise of a solid anorthosite–norite body seems to be a mechanism for which little information is available, but Emslie (op. cit.) notes that significant buoyant uprise of igneous bodies is inhibited once advanced solidification has occurred. Subvertical flow alignment of the plagioclase and orthopyroxene is also unknown; such preferred orientations should be present in mobile, diapiric crystal mushes.

A dichotomy of the diapiric model of anorthosite emplacement within NPS is that only certain plutons show the foliated zones (usually interpreted as margins) attributed to synemplacement deformation of semi-consolidated masses. If anorthositic terranes are constructed via coalesence of nearly solid crystal mush diapirs, rather than by intrusions of plagioclase saturated liquids (Wiebe, 1990) or liquid-enriched crystal-laden magma, then why do only certain plutons display the foliated margins? It would seem logical to assume, using solely the crystal mush diapir model, that all anorthositic plutons should have gneissose zones separating them from adjacent country rock and from older components of the NPS itself. This is plainly not the case, as is clearly demonstrated by the many igneous (intrusive) contacts that have been described from within the NPS. Similarly, in the Rogaland massifs of Norway, even though the Egersund–Ogna has a foliate margin and is interpreted as a diapir, the younger Helleren massif does not (Duchesne and Michot, 1987, p. 49). Wiebe (1991) acknowledged such differences between plutons and proposed different mechanisms of intrusion for plutons of the NPS on Paul Island near Nain (Figure 1) that may account for morphological variation between plutons in such terranes. He concluded that the diapiric plutons—i.e., those to which he assigned a foliated carapace—are the early members. He observed that high-alumina orthopyroxene megacrysts appear to be restricted to this type, and he reasoned that such intrusions represent crystal mushes that rose 'from depth', prior to emplacement of the undeformed massive plutons, which are products of magma crystallization in upper crustal chambers. If this equating of the presence of orthopyroxene megacrysts and the degree of deformation with the depth of crystallization is correct, then it implies that potentially a major part of the NPS has been intruded diapirically from a deeper level. This conclusion is based on observations of the distribution of coarse orthopyroxene and deformed rocks, in conjunction with the re-interpretation of E.P. Wheeler's 'granulite of uncertain origin' (equated now with foliated norite) on the margins of the NPS (cf. Ryan, 1991a). The distribution of the 'granulite', based on its distribution on Wheeler's maps, suggests that the whole anorthositic core of the NPS from Anaktalik Bay to Okakh Bay (cf. Ryan, 1990) has been emplaced diapirically. If this is so, it represents an enormous volume of plagioclase that rose through the crust after the plutons had magmatically amalgamated at some greater depth.

The shallow to moderate plunge of the lineation within a generally steeply-dipping foliation plane in gneisses, noritic rocks and granitoid rocks in the area examined south of Nain Bay (Figure 3) does not appear compatible with subvertical transportation as implied by diapiric tectonics, but is more strongly suggestive of oblique-slip within both the gneisses and the igneous rocks. If diapiric tectonics are responsible, then movement has been strike-slip as well as dip-slip, and the pluton(s) responsible for this type of tectonic transport must have been subjected to lateral ballooning of an already solid margin as noted earlier. A problem with this model, however, is that the elongate diorite–monzonite plutons contain inclusions of foliated anorthosite-norite, and many smaller dykes within the western anorthositic mass south of Nain Bay crosscut a foliation in their host, so solid-state deformation of the basic rocks occurred before emplacement of the granitoids, after which further deformation affected both. Under the Emslie (1975) and Martignole and Schrijver (1972) models the diorite–monzonite intrusions represent infiltrations of the liquid cap into the solid, but fractured, carapace. It is difficult to percieve how actively ballooning anorthositic diapirs under ductile compressive stress from internal magma pressure could permit such large dykes of granitic material to penetrate them. Another problem with the diapir model is that there seems to be a lack of any subvertical linear fabric in the 'piercing plutons', which could potentially have been the rising diapir core (cf. Jackson and Talbot, 1989); as noted above, some primary alignment of crystals reflecting flow should be obvious in these rocks. In addition, plutons that appear to be candidates for the ascended diapir core (for instance, the pegmatoidal leuconorite south of Nain Bay; Figure 4) still display a megascopic-scale subhorizontal layering, not the steep chaotic structures of the type modelled in experiments of diapirism of stratified (i.e., already cumulate-layered, semisolid) bodies.

Ryan (1991a, c) has suggested previously that another mechanism may be responsible for the formation of the deformed rocks within the NPS, namely that they represent zones of shear that reflect episodic ductile faulting during the emplacement period of the NPS. Under this model the anorthosite–country-rock contacts and the elongate granitoid plutons (and smaller dykes of the same) become preferred zones of shear during imposed strain because of compositional contrast. The steep attitude of the foliation in all units indicates the shears are subvertical, except immediately south of Nain Bay where shallow dips and an apparently overturned fold suggest northward translation of the gneissic anorthosite over the quartzofeldspathic granulites. Regardless of layering attitudes in this region, the lineations are consistently south-plunging indicating a generally north-south movement direction. The fold may therefore be a function of re-activation of an original gneiss-pluton contact that was at a high angle to the shear direction. It is conceded that the proposed model has weaknesses, and is based on limited examination of the plutonic rock.

As noted earlier, deformed (foliated and lineated) ferrodioritic–monzonitic rocks contain rafts of earlier-deformed and recrystallized norite. The implication of this relationship is that the internal and marginal shear zones of the anorthositic rocks become zones of intrusion for the granitoids. These dyke-like bodies themselves then become the locus of movement in the same manner as the basic dykes in the country-rock gneisses as noted above. The latter feature is apparent in many of the smaller dykes of monzonite–ferrodiorite within the anorthositic rocks.

It is perhaps possible, as a first correlation, to link the development of ductile shear zones in the gneisses of the archipelago with the development of foliations and lineations in the igneous rocks south of Nain Bay. As noted by Ryan (1991a), it is not unreasonable to advocate episodic movement along subvertical fault zones during emplacement of the NPS. The presence of high-temperature ductile shears in the gneisses may be evidence of such fault zones. Their sites of generation mirror the high-temperature environment of the foliated and recrystallized rocks within the NPS; in the latter, orthopyroxene, clinopyroxene, and olivine are stable minerals. The gneisses and plutonic rocks thus record high strain at high temperatures along oblique-slip ductile translation zones. The high-temperature assemblages in these deformed rocks may reflect the ambient conditions of the crust due to the magma pooling underneath. If the proposal that shear zones in the gneisses and the deformed and recrystallized plutonic rocks of the NPS are a consequence of zonal deformation during the Mid Proterozoic is valid, then these features are a result of the tectonic regime that prevailed at the time of NPS emplacement. These indicate that subvertical oblique movements were dominant over subhorizontal crustal extension. It has already been suggested (Ryan, 1991b) that pluton emplacement and the location of shear zones within the NPS may be governed by ancestral structures originally developed in the underlying crust during collision of Nain and Churchill (Rae) provinces ca. 1800 Ma.

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