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NEW PERSPECTIVES ON THE NAIN PLUTONIC SUITE AND ITS COUNTRY ROCKS

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ABSTRACT

The archipelago east of Nain comprises a variety of Archean quartzofeldspathic gneiss, foliated granitoid rocks, metasedimentary gneiss and mafic gneiss, intruded by plutonic rocks of the Middle Proterozoic Nain Plutonic Suite (NPS). Emplaced into the Archean rocks is a swarm of diabase dykes, of at least three generations, which exhibit a variety of intrusive forms and a variable degree of metamorphism and deformation. A younger set of dykes that intrudes the NPS is fresh and undeformed. Field data suggest that both the Archean rocks and older dyke swarm have been subjected to post-dyke granulite-facies (pyroxene hornfels) metamorphism. Problems raised by the tectonized state of the dykes are discussed in relation to the regional geological framework of the Nain area. It is suggested that these dykes are, in part, related to the basic magmatism of the NPS because such dykes also intrude recrystallized and deformed plutonic rocks considered to be early members of the NPS.

Reconnaissance examination of the NPS west and north of Nain has shown that the plutonic rocks have been subjected to pervasive penetrative deformation and subsequent recrystallization. Present models on emplacement of the NPS ascribe such deformation to primary magmatic flow and 'stretching' within crystal mushes during diapiric emplacement. An alternative viewpoint presented here is that the fabrics and recrystallization represent post-emplacement processes within crystalline rocks, generated by zonal deformation and annealing in a high heat-flow environment.

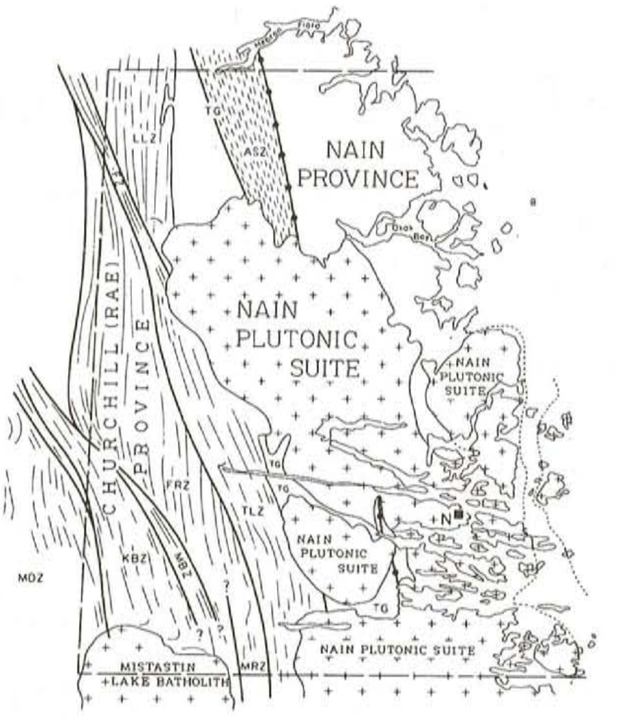
A model is presented to account for the features observed in the metamorphosed mafic dykes and NPS around Nain. It is proposed that many of the mafic dykes in the gneisses are a result of 'leaking' from a mafic magma reservoir that was the precursor of the main NPS event. Rise of NPS plutons to their present crustal levels, in an environment of episodic extensional shear and continued dyke emplacement, contributed to the metamorphism and deformation of the dykes in the gneisses and in early plutons.

INTRODUCTION

The Nain area has been a focus of interest for geologists for over two centuries, spurred mainly by the superb coastal exposures of labradorite-bearing anorthositic rocks. This interest was initially aroused by the discovery of 'Labrador stone' near Nain by the Moravian missionaries in 1770 (cf. de Waard, 1969). Studies of the Nain area formed the backbone of E.P. Wheeler's research between 1948 and 1974 (cf. Wheeler 1942, 1960; Emslie *et al.*, 1972) and resulted in an impressive series of 1 in. = 1 mile unpublished manuscript maps covering the area from Davis Inlet north to Okak, which are on file with the Department of Geology and Geography, University of Massachusetts, and with the Geological Survey Branch, Department of Mines and Energy (see Ryan, *this volume*). This pioneering work provided the impetus for a concentrated examination of anorthosite genesis by S.A. Morse and his colleagues under the Nain Anorthosite Project (NAP) between 1971 and 1981 (cf. Morse, 1971-1983). The focussed investigations of the anorthosite and associated plutonic rocks, now collectively known as the Nain Plutonic Suite (NPS), revealed a diversity of compositions (ultramafic, noritic, troctolitic, anorthositic, granitic), differing intrusion forms (e.g., small bulbous bodies, saucer-shaped layered intrusions, large dykes), and the existence of multiple intrusive events within superficially simple plutonic units. The ten-year NAP, especially, went a long way to elucidating some of the major problems associated with the emplacement and petrogenetic development of the NPS and anorthositic rocks in general. The NPS is now cited as a classic example of Middle Proterozoic anorogenic magmatism (cf. Morse, 1982).

The gneissic country rocks, into which the NPS was emplaced, have received less attention than the igneous rocks. Wheeler's initial mapping (cf. Wheeler, 1942, 1955, 1960, 1969) provided some of the first descriptions of these rocks. He recognized a major compositional difference between the gneisses of the eastern coastal sector and those of the western interior uplands, a distinction eventually used by Taylor (1979) as one of his criteria for the separation of Archean and Proterozoic gneisses into the Nain and Churchill structural provinces. Wheeler (1955, 1969) also recognized some contact metamorphism of gneisses adjacent to the Nain Plutonic Suite.

De Waard (1971) was the first to focus specifically on the gneisses of the Nain area, concluding that those on eastern Paul Island and adjacent areas were largely metamorphosed sedimentary rocks. He termed these gneisses the Ford



Generalized trends based on regional aeromagnetic patterns.

TECTONIC FRAMEWORK

Subdivisions in Churchill (Rae) Province, based on the interpretation of aeromagnetic patterns in conjunction with geological mapping, are as follows:

TG = Tasiuyak gneiss
LLZ = Lac Lomier Zone (Complex)
TLZ = Tasisuak Lake Zone
FRZ = Fraser River Zone
KBZ = Konrad Brook Zone (Complex)
MDZ = Mistinibi – Dihourse Zone
FZ = Falcoz (mylonite) Zone
MBZ = 'Moonbase' (mylonite) Zone
MRZ = Mistastin River (mylonite) Zone
ASZ = Abloviak Shear Zone

Figure 1. *Major tectonostratigraphic subdivisions of central and coastal Labrador (from Ryan, 1990). The north-trending area enclosed by the dotted lines east of Nain (N) is the septum of Archean gneisses that was the main focus of the 1990 field program. See Figure 2 for areas examined.*

Harbour Formation, and proposed that their present characteristics were largely attained after intrusion of nearby anorthositic plutons, a conclusion later challenged by Wheeler and Morse (1973). The gneisses of the Ford Harbour area have been examined most recently by Bridgwater *et al.* (1990), who attempted correlation of these rocks with the Archean gneisses of the Saglek area to the north and the Hopedale area to the south.

The specific studies of the Nain area cited above, and other investigations of northern Labrador geology up to 1990 (cf. Wardle *et al.*, *in press*), have led to regional subdivisions and a relative chronology of events, which, in simplified form is summarized below. This summary will serve as a foundation for later discussion in this paper.

REGIONAL GEOLOGY

Early to Late Archean (3.8 to 2.7 Ga) gneisses and less-deformed granitoid rocks constitute the Nain Province. The Nain Province was intruded by an areally extensive basic dyke swarm between 2300 to 2100 Ma and, following a period of peneplanation, was overlain by Lower Proterozoic supracrustal sequences. The Nain Province was juxtaposed against the Churchill Province (Proterozoic and reworked Archean gneiss) during Early Proterozoic transpressional orogenesis, along the collisional Abloviak shear zone (Figure 1). The Abloviak shear zone is in part co-incident with the Tasiuyak gneiss, a distinctive garnet-rich paragneiss and anatexite forming most of the easternmost margin of Churchill Province. The Nain gneisses, the basic dykes, and the supracrustals were deformed and metamorphosed adjacent to easternmost Churchill Province. The effects of the Early Proterozoic collision wane eastward across Nain Province. Lower Proterozoic tectonism appears to have abated by 1750 Ma. The boundary zone between the Nain and Churchill provinces was punctured during the Middle Proterozoic by batholithic masses of basic to felsic rock, collectively referred to as the anorthosite–mangerite–charnockite–granite (AMCG) suite (cf. Emslie and Hunt, 1990), of which the Nain Plutonic Suite is one example (Figure 1). Geochronological investigations of several units within the NPS indicate that at least some of the igneous activity occurred at ca. 1325 to 1290 Ma. This magmatism is advocated to have taken place during an anorogenic phase of crustal evolution of this area, possibly concomitant with limited crustal extension. The NPS was subsequently intruded by at least two suites of compositionally distinct, fresh, undeformed diabase dykes, possibly of Middle Proterozoic age (Wiebe, 1985), but some may be as young as Tertiary (Bridgwater *et al.*, 1990).

PROBLEMS DEFINED IN THE NAIN AREA

The 1990 field work in the Nain area (Figure 2) has revealed that its geological history may include events not recognized in the chronology presented above. In particular, as outlined below, observations call for a re-evaluation of the metamorphic evolution of the Archean gneisses and an explanation for deformed and metamorphosed dykes within them. Data from the 1990 field season also point to strong deformation and recrystallization in the NPS. The observations are especially relevant to present models of NPS emplacement, most of which portray the plutons themselves as being undeformed, and which advocate that the emplacement mechanism imposed only restricted metamorphic and structural imprints on the surrounding rocks.

This paper, then, will focus on the main points raised above. In terms of the problems that they bring to light, the 1990 field results may be stated as follows:

(i) Metamorphosed and deformed basic dykes have been found to be widespread in the gneisses on the archipelago east of Nain but their age and origin are uncertain; (ii) dykes with similar attributes intrude deformed noritic plutons akin to the NPS but it is unclear if these plutons are really a part of the NPS, or possibly belong to the country-rock gneiss complex; and (iii) north and west of Nain there are large areas of deformed and recrystallized anorthositic and granitic rocks within the NPS; the character of such rocks seems anomalous for plutons intruded in an anorogenic (non-stressed) environment.

It is now apparent that the Nain area may contain some of the most exciting geological problems in Labrador. In order to set the scene for the results of this year's survey, a short overview of previous work and ideas is presented at the beginning of some of the sections to follow.

NAIN PROVINCE GNEISSES AND THEIR METADIABASE DYKES

PREVIOUS WORK

It has been noted above that the gneisses of the Nain Province in the region around Nain have not received any detailed examination, except for the localized studies of de Waard (1971) and Bridgwater *et al.* (1990) in the area of eastern Paul Island. De Waard (1971) suggested that all the gneisses were derived from 'a eugeosynclinal pile of clastic sediments, volcanics and ultramafic rocks', and he termed them the Ford Harbour Formation. He proposed that their present high-grade and multiple-folded state was a consequence of events accompanying emplacement of an anorthositic pluton to the west; prior to emplacement of this intrusion, the Ford Harbour Formation was only mildly folded. This interpretation was not favoured by Wheeler and Morse (1973), who correctly pointed out that the character of the Ford Harbour gneisses is not unlike other Archean rocks of coastal Labrador, regardless of proximity to anorthosite, and therefore, the features of the Ford Harbour rocks are pre-anorthosite. Bridgwater *et al.* (1990) disagreed with de Waard's interpretation of the Ford Harbour gneisses as being largely of supracrustal origin, noting that, although there were obvious supracrustal components within them, these gneisses are in fact polygenetic, and include a significant component of layered grey orthogneiss and late pegmatite sheets. They considered the Ford Harbour gneisses to be akin to, and a continuation of, the Early to Middle Archean gneisses of the Okak–Saglek area of northern Labrador.

One of the most obvious features of the coastal outcrops of gneisses on the islands east of Nain is the diabase dyke swarm. These 'trap rocks' have been noted by all the pioneering geologists who have sailed along the Labrador coast (cf. Daly, 1902) but only Wheeler (1933) attempted to subdivide them. He recognized four types, based on mineralogy and degree of 'autometamorphism', and considered them all to be the same age and to have originated from a single magma by differentiation. Upton (1971, 1974) conducted a cursory field and geochemical examination of some of the dykes during the NAP, and seems to have been the first to recognize the presence of both metamorphosed (amphibolite) and unmetamorphosed types; the amphibolite dykes were considered to pre-date intrusion of the NPS (Upton, 1971). His geochemical investigation of the fresh dykes showed that both a tholeiitic and an alkalic suite are present. More recently, Wiebe (1985) has examined the fresh dykes that intrude the anorthositic rocks around Nain. The overall composition of the dykes examined by Wiebe (1985) is alkalic, but he subdivided them into two groups based on high and low incompatible-element contents, especially P_2O_5.

De Waard (1971, p. 16), Berg and Briegel (1983, p. 44) and Bridgwater *et al.* (1990, p. 232 to 233), like Upton (1971), also recognized that many of the dykes in the gneiss complex are metamorphosed and recrystallized to varying degrees. They also recognized that the dykes were locally deformed. De Waard (1971) offered no explanation for these characteristics of the dykes; Berg and Briegel (1983) felt that some of the dykes were related to the NPS; Bridgwater *et al.* (1990), following Upton (1971), considered the metamorphosed dykes in their study area on Paul Island to pre-date the nearby anorthositic pluton, but also stated that some dykes may be related to NPS magmatism.

REGIONAL SUBDIVISIONS OF THE GNEISSIC ROCKS

The gneissic rocks east of Nain comprise a north-trending septum between igneous rocks of the NPS (Figure 1). They are well-exposed on the archipelago that typifies the Labrador coast of this region, and were examined by the author on the islands between Carey Island and Sungilik Island (Figures 2 and 3). The Archean bedrock in this area comprises a variable suite of orthogneiss and foliated granitic (s.l.) rocks, metasedimentary gneiss, and mafic gneiss.

Quartzofeldspathic Gneiss and Foliated Granitic Rocks

These can be subdivided into several regionally recognized units. Predominant among them are the following:

Migmatized Tonalitic to Granodioritic Gneisses

These are by far the most abundant gneiss type, and vary from white to grey to brownish grey, the latter indicating rocks

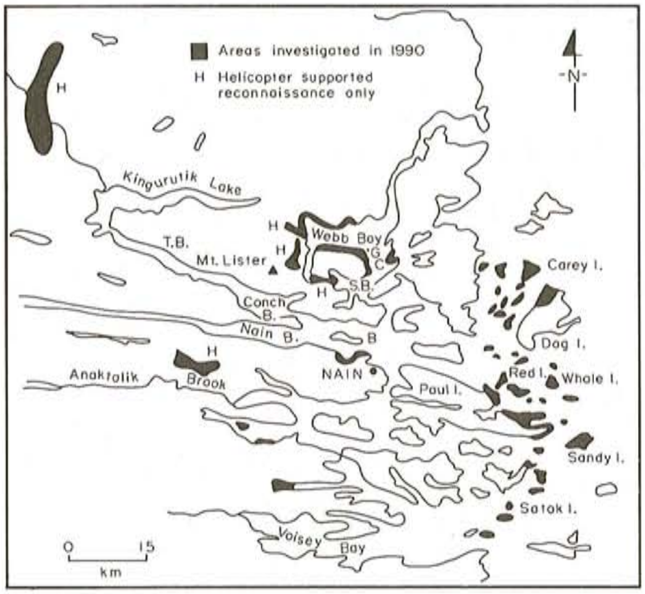


Figure 2. *Location map, showing in black, areas examined during the 1990 field season. T.B. = Tikkoatokak Bay, S.B. = Sachem Bay, B = Barth Island, C = Challenger Cove, G = Georges Island.*

are in the granulite facies of metamorphism. They are the predominant rock on northern Sandy Island, Lopear Island, Fermoy Island, Carey Island, Nest Island, Spruce Island and Dog Island (Figure 3). The migmatized polyphase character of these gneisses is best seen in areas where they are at amphibolite facies (Plate 1). In areas where granulite-facies metamorphism is still preserved, such as the west shore of Dog Island south of 'Camp Bay', the different quartzofeldspathic components are less distinct.

Whispy Granitoid Gneiss

The well-layered and migmatitic gneisses are intruded by a more diffusely banded and foliated polyphase granitoid varying from granodiorite through diorite in composition; locally this unit is porphyritic. Sheets of this type of whispy granitoid occur as subordinate lit-par-lit injections in grey gneiss on Lopear Island and the northeast coast of Fermoy Island. Limited examination of Henry Island suggests that sheets of this granitoid may comprise 50 percent of the western half of the island as well. It is the dominant rock type on Misfit Island, Dumbell Island, Central Island and the western half of Web Island (Figure 3), where screens of older gneiss containing pre-granite structure are locally present. Contacts between the various phases of this whispy granitoid are generally very diffuse (Plate 2); only contacts between melanocratic and leucocratic phases are sharp. In places, the whispy granitoid gneiss contains metamorphosed basic dykes that may be a product of coeval mafic magmatism (see later section on dykes). The lit-par-lit nature of this polyphase granitoid to the migmatitic gneisses on an outcrop to regional scale, combined with the diffuse layering and anastomosing style of the mineral fabric is suggestive of syntectonic emplacement.

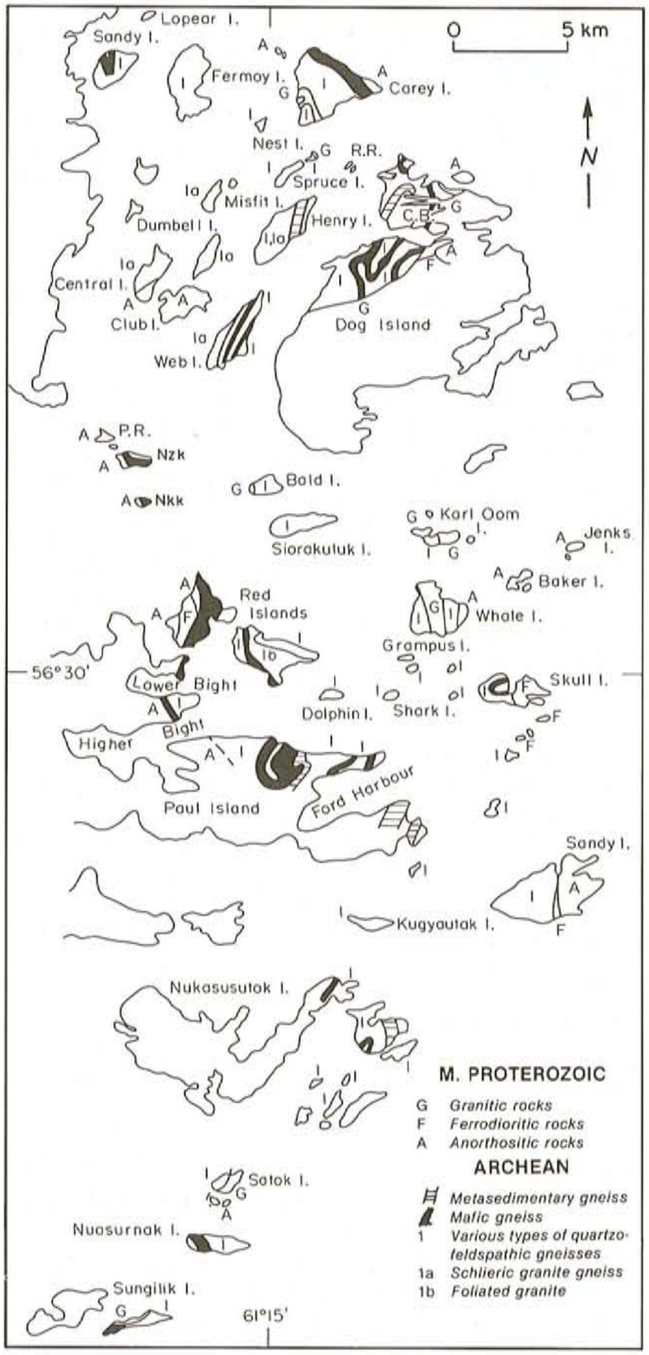


Figure 3. *Simplified geological map of the area between Carey Island and Sungilik Island. Only the largest regional units are shown. R.R. = Red Rocks, C.B. = 'Camp Bay', P.R. = Pat Rocks, Nzk = Noazunaluk Island, Nkk = Noazunakuluk Island.*

White to Pink Foliated Granitoid Rocks, Probably More than One Generation

These vary from the above in being more homogeneous overall, with a mineral foliation being the chief fabric-forming element. Narrow sheets of white-weathering leucogranite occur on Dog Island but the largest coherent area of these

Plate 1. *Grey migmatite in area of retrogressed granulite-facies rocks, south of Grampus Island.*

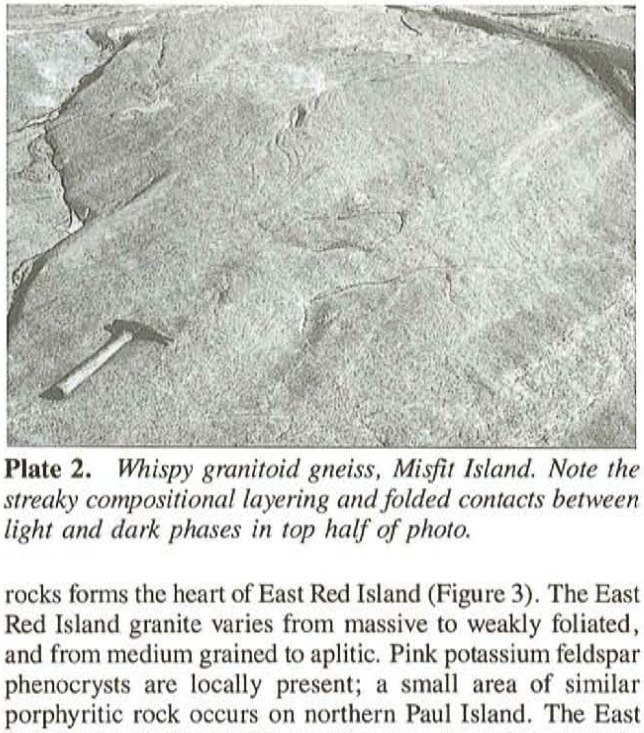


Plate 2. *Whispy granitoid gneiss, Misfit Island. Note the streaky compositional layering and folded contacts between light and dark phases in top half of photo.*

rocks forms the heart of East Red Island (Figure 3). The East Red Island granite varies from massive to weakly foliated, and from medium grained to aplitic. Pink potassium feldspar phenocrysts are locally present; a small area of similar porphyritic rock occurs on northern Paul Island. The East Red Island granite locally contains abundant older gneissic rafts and it is clearly intrusive into the mafic granulites as well as the quartzofeldspathic gneisses on the island. A rusty-weathering tinge suggestive of orthopyroxene-bearing assemblages is present in some places but no pyroxene could be identified in the field.

Pink, Potassic, Medium-Grained and Aplitic Granite Sheets

These rocks are marked by a biotite foliation and/or lineation, and are quite distinct units on West Red Island. It is an extensive area of this granite at the north tip of the island that gives rise to the geographic designation of that area as Red Cliff. These granitoids all occur as steeply dipping sheets slightly transgressive to the regional gneissosity of the mafic granulite and gneiss. Several of them on the southeast promontory of the island have veins of massive milky quartz and quartz-microcline graphic pegmatite developed within their central parts. Like the East Red Island granitoid, these pink granitoids also have a brownish hue suggestive of the presence of orthopyroxene. De Waard (1971) implies from his description of these rocks that they are melts generated by emplacement of the adjacent Proterozoic anorthositic rocks, but this writer suggests they may be instead an integral part of the pre-anorthosite complex.

Granulite-Facies Quartzofeldspathic Gneisses of Various Types

Granulite-facies gneisses predominate in the region southward from the Red Islands. For example, nebulitic quartzofeldspathic granulite-gneiss is widespread on the north shore of East Red Island and Dolphin Island. Schlieric granitoid to pegmatite-layered granulitic gneisses underlie the islands east of Nukasusutok Island (Figure 3) where they plainly intrude and disrupt older supracrustal sequences. These schlieric granulites give rise to agmatite zones in which the layering in the blocks commonly has random orientation with respect to external fabrics in the quartzofeldspathic host. Orthopyroxene crystals are readily identifiable in these rocks, but commonly these gneisses have a blebby characteristic, a result of orthopyroxene replacement by secondary minerals. *In situ* partial melt phenomena are local features in the granulite-facies gneisses; these are diffuse-bordered irregular and vein-like networks of orthopyroxene- (and lesser garnet-) bearing granitoid that disrupt the layering. Lit-par-lit migmatite, in which a grey brown foliated component is 'diluted' by pegmatoidal to aplitic orthopyroxene-bearing sheets, is well developed locally around Ford Harbour and on some of the islands east of Nukasusutok Island. In the latter area, these sheets postdate at least one period of earlier migmatization of the gneisses.

Granulite-facies gneisses also occur around Webb Bay (Figure 2). These rocks, part of the Webb Valley metamorphic complex of Berg (1973), were examined only briefly along the coast. A difference in these, compared to elsewhere, is that some of the parallel mafic layers and pods within them have plagioclase crysts, suggesting a comparison with one type of mid-Archean Saglek dyke of northern Labrador.

Metasedimentary Gneisses

Gneisses of metasedimentary origin are not common in the Archean terrane of the outer islands mapped to date; however, several discrete belts or zones of migmatized paragneiss have been outlined, occurring on Henry Island, Dog Island, and on Paul Island (Figure 3). Paragneisses have also been observed elsewhere, but are not as extensive or have not been fully outlined. These occur on Carey Island, the Karl Oom Islands, Grampus Island, on the headland on the south side of Ford Harbour, on Kugyautak Island and on the cluster of islands east of Nukasusutok Island.

Dominant among the paragneisses is biotite-rich rusty-weathering garnetiferous semipelite; locally there is abundant sillimanite and graphite. Garnet and sillimanite are variably replaced by combinations of cordierite + hypersthene and cordierite + spinel respectively, a pseudomorphous replacement that is attributed to pyroxene hornfels facies contact metamorphism by the plutonic rocks in the area. The replacement reaction is also seen in garnet-bearing granitoid sheets and irregular melt pods in the gneisses.

Quartzite is particularly prominent in paragneisses examined south of Dog Island. Grampus Island for instance is composed almost entirely of migmatized white quartzite and greenish-grey calcareous quartzite. Quartzites of this type also occur on the south side of Ford Harbour. Rusty sulphide-bearing dark-grey quartzite is common in a belt on the east coast of the large island east of Nukasusatok Island; here it forms large blocks, in association with ultramafic rocks, in an agmatite zone caused by intrusion of the adjacent quartzofeldspathic gneisses and pegmatites.

Mafic Gneisses

Mafic gneisses, mapped as both amphibolite and mafic granulite, are common in the area; the largest units are shown on Figure 3. Two discrete types are present, one of which may be intimately related to the anorthositic rocks.

The first is a massive to well-layered, black, commonly friable rock, interpreted to be derived from a gabbroic protolith. It is locally characterized by conspicuous blasts and segregations of black hornblende (Plate 3). Leucocratic layers are not uncommon, and sub-parallel and randomly oriented white granitoid sheets locally disrupt the layering. This type of rock outcrops for instance on Naozunaluk Island, through the centre of West Red Island, on the southern point of East Red Island and forms much of the prominent ridge 3 km west-northwest of Ford Harbour on Paul Island (Figure 3). At the latter locality it contains several orange-red dunitic units.

The second type of mafic granulite is well displayed on the eastern side of Carey Island and on the north shores of Lower Bight and Higher Bight on Paul Island. In all the localities mentioned above, the rocks are greenish brown to black weathering, well-layered and characterized by the presence of elongate 'stringers' and podiform pyroxene aggregates (Plate 4). Disrupted pods and segregations of norite are also present, and have been cited by Wiebe (1981, 1990) as examples of anorthosite dykes. Intrafolial folds of the compositional layering may be present, as well as slides of the layering with dislocation surfaces slightly oblique to layering trend. At Higher Bight, the noritic segregations and pods are both folded with the layering and also are emplaced along the axial-plane trend of these same folds. Mapping to date of the Carey Island granulite has indicated that several ultramafic bodies occur along its western margin.

The second type of mafic granulite maybe in part related to the adjacent noritic rocks, but if not, has certainly been 'soaked' by narrow noritic dykes that have been subsequently disrupted and deformed. Wheeler (manuscript maps) regarded some rocks of this type as 'granulites of uncertain origin', an apt name for such enigmatic units. At least some rocks of this type contain olivine (M.A. Hamilton, personal communication, 1990), a mineral that, from this writer's experience elsewhere in Labrador, is present only in the ultramafic portions of mafic granulite units within the Archean terrane. The occurrence of olivine here suggests that rocks in which it occurs should be included with the adjacent igneous suite. Therefore, these 'granulites' may represent early layered basic intrusions of the NPS, punctured later by the more massive noritic rocks. R.F. Emslie (personal communication, 1990) and G.A.G. Nunn (personal communication, 1990) have both observed rocks of this type along the margin of the Michikamau intrusion in western Labrador; these rocks pose similar problems of interpretation but are favoured to be of igneous origin by both Emslie and Nunn. Carey Island offers a good area to study these rocks in detail.

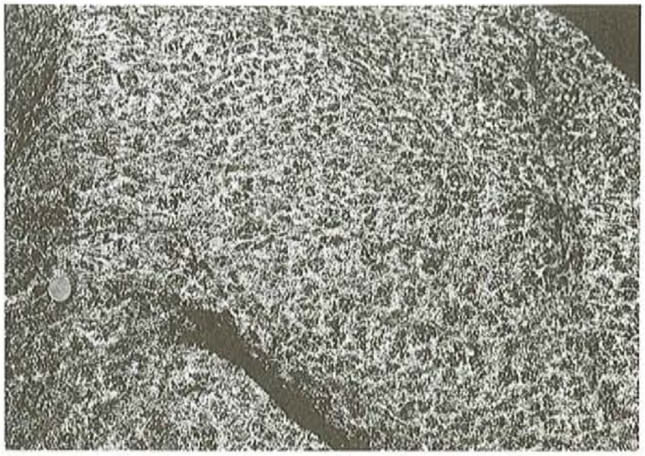


Plate 3. *Blotchy mafic granulite, East Red Island. Black spots are hornblende blasts. Probably derived from an original gabbroic protolith.*

Plate 4. *Layered mafic granulite, Carey Island. Darker layers are ultramafic in composition. Note the streaky concentration of pyroxene in lower centre, and dislocation surface at lower right.*

ATTRIBUTES OF THE RECRYSTALLIZED AND DEFORMED MAFIC DYKES

The profusion of mafic dykes, of at least four generations is one of the most noteworthy features of the field area. They pose some of the more intriguing problems of the area, particularly with regard to their diversity, degree of deformation and metamorphism/recrystallization. The following observations will give a brief overview of these features, which, without the benefit of petrography at this time, are based on field data only. It must be borne in mind that insufficient data are available to state that any one feature described below is unique to a particular age or trend of dyke. Therefore, the features are treated in very general terms, with the hope that future work on the dykes may characterize them more fully. Of the four generations of dykes recognized, three exhibit variable degrees of recrystallization and deformation; these are collectively referred to as metadiabase dykes and are described in this section. The fourth generation of dykes comprises fresh diabase and gabbros; these are described in a subsequent section.

The metadiabase dykes are rarely absent from any region underlain by gneisses although they are less common on the Red Islands than in other areas. They also occur in deformed plutons that bear strong similarities to the more pristine igneous rocks of the NPS (see below). They are nearly everywhere recrystallized and foliated, their primary pyroxenes appear to be largely replaced by secondary pyroxene aggregates and amphibole, and they locally exhibit folding that varies from gentle warps to nearly isoclinal structures. Some of the dykes are granoblastic rocks that were given the field designation 'granulite-facies dykes'; it is possible that these are noritic rocks in which the orthopyroxene is a primary mineral. This problem will hopefully be solved by petrography.

There are few mesoscopic features of the dykes that correlate with trend, and there is no firm correspondence between trend and relative age. The latter point can be demonstrated on eastern Fermoy Island, for instance, where two massive amphibolite dykes trending approximately 160° are temporally separated by another dyke trending 080° (Plate 5); this makes relative age designations among the isolated 160°-trending dykes somewhat risky. The overall trend of the dyke swarm as a whole is in fact quite variable, and may be consistent or widely disparate over small areas. The majority of the metadiabases on Dog Island for instance trend 070 to 090°, yet on Misfit Island they vary from 000 through 090 to 170°. However, that being the case, there is a tendency for certain trends to predominate. An approximation of relative orientations, based on some 150 measurements, indicates 71 percent of the dykes trend between 000 and 090°, with nearly half of these falling between 060 and 090°.

Only a few general observations on the dykes are given below, without any rigorous attempt at correlating their age of intrusion. A few examples of crosscutting dykes are cited as an indication of relative age at any one locality, but as noted above, these ages cannot be applied to isolated dykes.

Plate 5. *Intersecting dykes on Fermoy Island. The dyke trending across the photo is older than the dyke trending away from the viewer. At the water's edge the latter dyke is cut by a younger dyke with the same trend as the older dyke of this photo, but the youngest dyke cannot be seen due to slope of outcrop. The slight warp in the trend of the younger dyke in the photo may be a primary feature; this dyke is characterized by radial aggregates of tabular plagioclase (snowflake texture).*

General Morphology

The metadiabase dykes vary from a few centimetres to 20 m in width and, where examined, are generally strike-continuous for hundreds of metres; extrapolation of some dykes between opposite coasts of islands indicate that some are continuous for at least 2 km. For the most part they are rectilinear bodies, but mild undulations in strike direction are not uncommon. At some localities (e.g., Dumbell Island, East Red Island) it appears that dykes having highly discordant trends are in fact part of the same intrusive event. These may be interpreted as being emplaced into conjugate fracture systems, but there is little evidence that such a conjugate series of dykes is widespread. On Dumbell Island, the bifurcating dykes crosscut an earlier set of dykes and are in turn cut by a younger set.

The vast majority of the metadiabases are equigranular fine- to medium-grained, fairly homogeneous rocks. Discrete chilled margins are not always present, but are conspicuous on some, especially the wider dykes. They are overwhelmingly metabasaltic in character, though two composite dykes are present on western Misfit Island, one of which exhibits what appear to be deformed incipient mafic pillows adjacent to a grey granitic component.

Original igneous textures in the dykes are locally well preserved though the igneous minerals are either replaced by secondary assemblages or polygonized by the metamorphism. For instance several, feldspar-phyric, 070- to 090°-striking black troctolitic(?) dykes exposed on the eastern and southern parts of Fermoy Island are characterized by abundant clusters or aggregates of buff to white recrystallized plagioclase lathes. Many of these clusters have a radial or snowflake-like configuration of feldspars and they enclose pyroxene. Although superficially resembling the plagioclase form in feldspar spherulites (snowflakes) described elsewhere in the NPS by Berg (1980), a direct correlation between the shape and origin of the aggregate textures in the dykes here, and those described by Berg from troctolitic intrusions to the north, cannot be confidently proposed at this time. However, if these are metamorphosed troctolitic dykes and the radial textures are related, it implies that there are some troctolite magmas that were emplaced fairly early in this area and all such intrusions are not a 'late' event (cf. Morse, 1983a). This conclusion is based on the fact that these 'snowflake' dykes are at one locality on the east side of the island intruded by a younger massive mafic dyke and both are subsequently recrystallized. At the southern tip of the island the 'snowflake' dykes are intruded by a folded massive dyke.

Another textural variation noted at several widely spaced localities is the presence of conspicuous, large, dark grey to black plagioclase phenocrysts in the dykes. These phenocrysts are identical to the dark plagioclase of the noritic and troctolitic intrusions of the NPS, again suggesting that some of the metadiabases are an integral part of the NPS magmatic episode as proposed by Berg and Briegel (1983).

The dykes exhibit a number of features that may hold clues to their mode of emplacement. These will be outlined below as an indication of the variety of intrusion forms to be seen in the dykes. They are described in the following order: marginal contacts, terminal contacts and podiform structure. Foliation development and the relationship between structures in the gneisses and dykes will be noted where necessary, but will be discussed more fully in a section to follow.

As noted above, the majority of dykes are rectilinear intrusions with sharp contacts against the gneisses. Not all contacts are straight however; many are cuspate. Cusp-and-lobe features are not extreme. Usually they are gentle structures and may be present only on one margin of a dyke (Plate 6). However, where cusp-and-lobe structure is well developed, the cusps are formed by the mafic dyke whereas the more gentle lobes are occupied by gneiss. This is, of course, the normal relationship seen where dykes are deformed along with the enclosing rock in such a way that the dykes are shortened parallel to their length (cf. Jackson and Zelt, 1984). In such situations, the dyke is less competent than the gneiss, and thus the cusp represents the area where the dyke gets 'nipped-in' between the more open-fold structure of the gneissic lobe. However, there is no indication that the features in the metadiabases described here are produced by such a mechanism, for nowhere have foliations been observed as axial-planar features in such cuspate contacts. In fact, where fabrics are developed they are generally parallel to the dyke trend, i.e., perpendicular to the axial trend of the lobe-and-cusp features. Therefore, the lobe-and-cusp margins are primary features developed during dyke intrusion. The cusp-and-lobe relationships are, however, opposite to the normal situation seen in segmented or finger-like mafic dykes intruded into more competent hostrocks (cf. Nash, 1979; Pollard, 1987). Therefore, it is suggested that the lobe-and-cusp characteristics displayed by the dykes of the Nain area are a function of their emplacement into hot and somewhat 'plastic' (ductile) country rock (cf. Watterson, 1968).

Plate 6. *Cuspate margins on two small metadiabase dykes on Dumbell Island. Note that the left hand dyke has one straight margin, and that the dyke on the right has a very irregular outline that shows both cuspate and horn structure.*

One 030° schistose, plagioclase–porphyritic, dyke on the eastern shore of Web Island is also suggestive of intrusion into ductile and hot country rocks as proposed above. This particular dyke displays one very irregular margin that interfingers with the gneisses and is in places dismembered by felsic veins emanating from the adjacent gneiss. The very irregular margin of the dyke, in consort with dismemberment by (rheomorphic?) veins, point to an apparently mobile condition of the gneisses at time of magma intrusion.

Some of the dykes show the development of narrow apophyses, or horns, where the dyke–country-rock contact is offset. These features are common in basic dykes in any cratonized region, and are thought to be a function of intrusion of magmas into brittle fractures. Currie and Ferguson (1970) have suggested that, in some cases, the formation of such offsets is a direct consequence of fracture-opening caused by the rapid emplacement of a volatile phase directly ahead of the advancing magma. If this concept is applicable to the dykes in the Nain area showing the horned features, then it implies that volatile-influenced fracturing was instrumental in the emplacement of these dykes (see below).

Dyke terminations are of two types—flame-like and bulbous. Flame-like terminations at the end of some dykes are quite spectacular. A continuous 1-m-wide dyke for instance may pass abruptly into a series of parallel, thin, wedge-shaped streamers that penetrate into the gneisses in a closely set group. Other narrower dykes end in wedge-shaped terminations having feathered off-shoots that resemble tuffisite veining (Plate 7). Both these features imply brittle fracture, again perhaps under the influence of high volatile pressures.

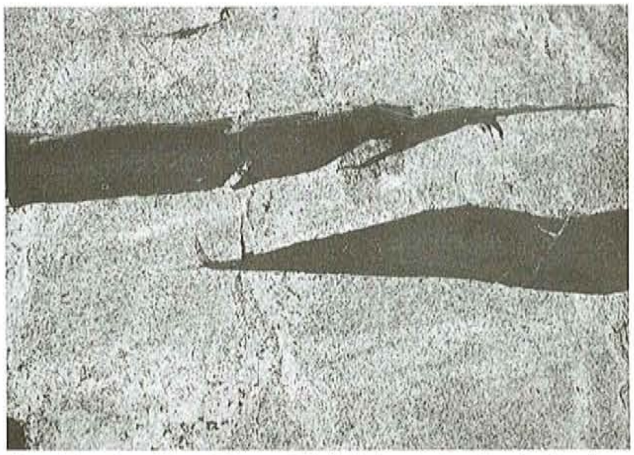


Plate 7. *An offset dyke on Misfit Island showing indications of emplacement into brittle fractures. Note the step-like and 'horned' contacts of the upper dyke and the fine 'feathered' termination of the lower one. The fine felsic veinlets that crosscut and follow the dykes seem to emanate from the country rock.*

One discontinuous amphibolite dyke in schlieric granite on the west shore of Misfit Island locally ends as a blunt, somewhat bulbous body having several sinuous flames. The termination has narrow veinlets of granitoid subparallel to dyke trend that do not appear to be rheomorphic phenomena. This particular dyke, plus a couple of others in the general area, may in fact have been synkinematic and coeval with the emplacement of the host granitoid and may be very early dykes in comparison with the discrete discordant ones. These synplutonic(?) dykes are crosscut by later metadiabase (amphibolite) dykes trending roughly east-west.

Although the majority of the metadiabase dykes are strike-continuous, some show a pinch-and-swell and irregular podiform morphology (Plate 8), while others terminate abruptly, then appear to 'jump' laterally and continue along strike. The pinch-and-swell and podiform dykes are locally similar to basic intrusions described from West Greenland by Nash (1979), and may represent different horizontal sections through vertical fingered sheet intrusions (cf. Pollard *et al.*, 1975). In the Greenland examples, the shape of the dykes is considered by Nash (1979) to be a result of magma emplacement into an active shear zone. There is no consistent correlation between shear zones and podiform dykes in the Nain area, so again the irregular nature of the dykes must largely be a function of igneous emplacement processes rather than a tectonic (deformational) control (cf. Currie and Ferguson, 1970).

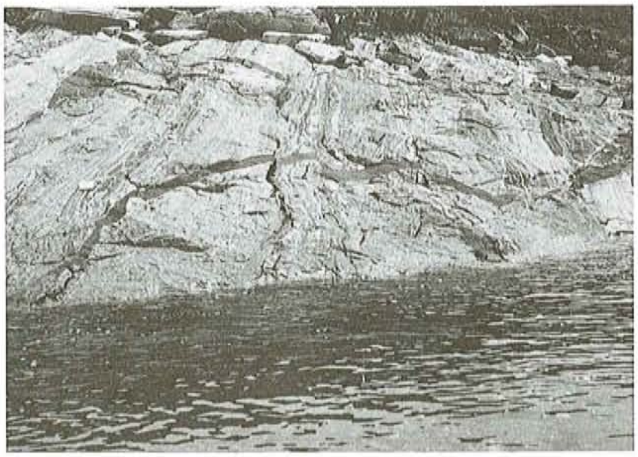


Plate 8. *An undulating metadiabase dyke on northern Web Island. The folding here is considered to be post-emplacement, but may be, in part, syn-intrusive. Note that on the right-hand side of photo the dyke continues along strike as a podiform intrusion with very irregular margins.*

Foliation and Recrystallization

Few of the dykes on the outer islands appear to have escaped recrystallization, and many display well-developed foliations and lineations even when not folded. Recrystallization has occurred under both amphibolite- and granulite-facies conditions but little can be concluded about the distribution and significance of these two different types of dykes at this stage. However, it might be of importance that at one locality on Fermoy Island a foliated 160° granulite-facies dyke is crosscut by a 090°-trending amphibolite dyke that still maintains primary textures. This is not to imply that all 090°-trending dykes are amphibolite; many are plainly at granulite facies (e.g., Carey Island, Misfit Island, Skull Island). In fact, one of the intriguing problems in this area is an explanation for the variable metamorphic character of the dykes. There seems little doubt that intrusion of adjacent plutons has contributed to the metamorphism, but the full effect of this is yet to be determined.

Dykes at both granulite and amphibolite facies occur throughout the gneiss complex, from Lopear Island in the north to the Sungilik Island area in the south. There is no relationship between trend and degree of metamorphism nor trend and style of deformation (foliation development, folding). Some dykes are folded with well-developed axial-planar foliation, whereas others, although not folded, have a margin-parallel fabric or an internally sigmoidal fabric oblique to dyke trend. Generally, these fabrics are not aligned with fabrics in the surrounding gneisses; the dyke fabrics do, themselves, however, show trend variations in some areas (see below). Some granulite-facies dykes are equigranular and lack obvious foliation, and could perhaps be primary noritic dykes; the lack of igneous texture is, however, inconsistent with primary magmatic crystallization. Orthopyroxene-bearing, streaky, discontinuous, 'sweats' are locally developed in some dykes, and these are parallel to the dyke fabric.

Foliations vary from a barely discernable mineral alignment to a pervasive penetrative foliation that locally gives rise to a fissile parting in the dyke. The foliations are not consistently oriented across the area. For instance, on Sandy and Fermoy islands the dyke fabrics trend roughly north-south regardless of dyke orientation and the foliation has S-symmetry. On Carey and Dog islands on the other hand, the majority of the foliations trend between 090 and 140° and have Z-symmetry. These variations in symmetry of foliation relative to dyke margin are suggestive of their development via a conjugate shear couple. However, it is not uncommon to encounter a wide array of dyke and foliation trends in any one area; e.g., on Misfit Island where 020-, 160- and 090°-trending dykes all have internal foliations comparable to dyke trend.

Some dykes appear to have been emplaced, perhaps synkinematically, into shear zones in the gneisses or have been affected by subsequent shearing. These shear zones are either discrete discordant zones into which an external gneissic foliation is reoriented or they are mylonitic high-strain zones (laminated gneisses) that follow the regional gneissic trend in a particular area. In these zones, the dykes are parallel to the trend of the shear and are likewise foliated. Examples of these relationships have been observed on Dumbell Island, south of Ford Harbour and on the large island east of Nukasusutok Island. These types of situations are not common however; more normally, the dykes cut sharply across the regional gneissic layering, which does not show significant deflection or displacement across them, even though the dykes have sigmoidal foliations. The development of sigmoidal, shear-zone type-foliations in discordant dykes, without any indications of shearing and parallel fabric development in the bounding gneisses, indicate that the dykes themselves acted as the loci of shear. The shear regime may even have been contemporaneous with the intrusion and crystallization of the dykes.

NAIN PLUTONIC SUITE

MASSIVE AND FOLIATED ROCKS ON THE ISLANDS

Previous Work

The plutonic rocks around Nain have traditionally been referred to as the 'anorthosite–adamellite suite' (cf. Wheeler, 1942, 1960). However, this duality is somewhat of a misnomer, given the diversity of compositions displayed by these intrusions, and the term Nain Plutonic Suite has been adopted as the formal stratigraphic name (Williams *et al.*, 1985). Four major subdivisions of the plutonic rocks of the NPS are recognized: norite–anorthosite, troctolite, ferrodiorite, and quartz monzonite–granite. For details regarding the general character of the NPS the reader is referred to Emslie *et al.* (1972), Taylor (1979), Emslie (1980) and the various NAP reports cited earlier. The regional distribution of each of the major subdivisions is shown on a recently published colour compilation of the Nain–Nutak area (Ryan, 1990a; *this volume*).

Nain Plutonic Suite in the 1990 Field Area

The NPS was not systematically examined during the 1990 survey. Only where the igneous rocks abut the gneisses were they examined on the outer islands and these few occurrences are dealt with below. Elsewhere where the NPS was encountered, the rocks are strongly deformed and recrystallized; these are dealt with in a subsequent section.

Medium- to very coarse-grained, dark grey norite cut by grey to white granite dykes forms the islets between Fermoy and Carey islands (Figure 3). A similar, although overall finer grained, rock occurs on the eastern point of Carey Island, where it contains rafts of pale grey leuconorite. These rocks are all considered to be part of the Jonathan intrusion (Berg and Briegel, 1983), a large layered intrusion that underlies several of the islands directly north of the study area. Grey-weathering leuconorite and anorthosite on the northern shore of Dog Island and adjacent smaller islands may be part of the same intrusion.

Dark grey to black norite, similar to that on eastern Carey Island, also underlies Club Island and the adjacent shore of Central Island (Figure 3). The norite here is plainly polyphase, with finer grained dykes disrupting a coarser grained variety, and the whole is cut by white granite dykes. Pale grey leuconorite underlies Pat Rocks and outcrops on the western part of Noazunaluk Island and Noazunakuluk Island. These rocks are part of an extensive noritic composite pluton that constitutes the nearby Hillsbury Island and Paul Island, and forms the western part of West Red Island (cf. Wiebe, 1990). On Noazunakuluk Island, the easternmost part of this unit is a foliated, recrystallized, sugary, biotite-bearing anorthosite, in which the fabric is parallel to that in nearby mafic granulite. The distribution of the foliated anorthosite was not investigated, but it does not appear to be as extensive as in some other areas examined during the 1990 season (see below).

Noritic and leuconoritic rocks were also observed on outer Whale Island, Baker Island, Jenks Island, parts of Skull Island, and the outer third of Sandy Island.

A group of iron-rich, fine- to medium-grained gabbronoritic rocks locally forms a distinctive, chocolate-brown-weathering assemblage within the NPS, usually separating anorthositic and granitic plutons. Within individual intrusions there is a range of compositions from gabbroic through to granodioritic with the former being most common. De Waard (1974a) proposed that these rocks be termed monzogabbro, a name that he felt reflected the median composition and stressed the abundance of pyroxene and scarcity of amphibole, or monzodiorite, reflecting the presence of andesine feldspar. R.F. Emslie (personal communication, 1990) refers to these rocks collectively as ferrodiorite, a name originally coined by Wager and Brown (1967) to refer to similar rocks in the Skaergaard intrusion of Greenland, in which the plagioclase feldspar is less calcic than An_{50} and the ferromagnesian minerals are iron-rich.

The ferrodioritic rocks outcrop on Dog Island (de Waard, 1974b) where they were examined in detail during the 1990 field season by R.F. Emslie of the Geological Survey of Canada. This same suite of rocks seems to continue southward through Skull Island and nearby islets to the south (Wheeler, manuscript maps) and also crops out along the south shore of Sandy Island (Figure 3). All these occurrences are characterized by spectacular examples of magma mingling in which gabbroic magma has interacted with a partially crystallized granitic magma. This has produced field features that range from simple intrusive relationships to total mixtures in which a mafic to intermediate host contains abundant ovoids of feldspar and quartz derived from the granite. At 'Camp Bay' on Dog Island, the northernmost contact of the ferrodiorite against the gneisses is characterized by a very strong, steeply dipping foliation. This is apparently not an uncommon feature in this area, for de Waard (1974b) describes the presence of 'flow structure' (interpreted by the writer to mean foliation) from this body elsewhere on Dog Island. More homogeneous ferrodiorite occurs on West Red Island (cf. Wiebe, 1981); here it is well layered and varies compositionally from diorite to pyroxenite with little indication of contamination by granitic magma. A weak foliation was noted in this rock at one locality visited, which, according to Wiebe's (1981) descriptions, is not the only deformational feature of this body. However, none of the deformational features seen by this writer in the ferrodioritic rocks described here are as intense or pervasive as in the plutonic rocks to be described in the following section.

The granitic rocks of the outer islands were examined on Carey, Dog and Whale islands and several other small islands between. In all cases, the rocks are hornblende-rich, with local indications that they may also contain olivine and pyroxene(s). The Dog Island granites have previously been investigated by de Waard (1973) who named the body north of 'Camp Bay' the 'Alagaiai adamellite' and that south of the bay the 'Iviksuak adamellite'. The southern body was examined in only a few outcrops, where it is a white to yellowish brown weathering, hypidiomorphic, hornblende granite that locally contains ovoidal feldspar and quartz. De Waard (1973) interpreted this granite as being in transitional contact with the nearby anorthosite via a 'granodioritic porphyry' (i.e., ferrodiorite).

The 'Alagaiai adamellite', where examined by the writer, is disposed in a series of east–west-trending hornblende–granodioritic dykes. The granodiorite exposed on Red Rocks and Carey Island is also interpreted to be part of the same dyke network (Figure 3). Rusty cores in hornblende and a greasy green colour to some fresh samples suggest the presence of fayalite.

Hornblende granite of the same type as above also outcrops on the Karl Oom Islands and through central Whale Island. The eastern contact between granite and gneiss on Whale Island is one in which granite sheets and gneissic screens alternate on the scale of a few metres to hundreds of metres.

Grey, hornblende- and biotite-bearing tonalitic dykes are not uncommon in parts of the gneiss complex. These are all late intrusions relative to other components in the gneiss complex, including the metadiabase dykes, but may themselves be of more than one age. They are fine- to medium-grained rocks, locally with internal compositional variations producing a polyphase assemblage, and usually occurring as 1- to 3-m-thick dykes. Dyke attitude varies from vertical to subhorizontal. Several dykes of this type display a well-defined lineation defined by a streaky alignment of mafic constituents.

Biotite-bearing, coarse-grained to pegmatoidal, pink, granite dykes are common on the two large islands directly east of Nukasusutok.

FOLIATED, RECRYSTALLIZED AND GNEISSIC ROCKS WEST AND NORTH OF NAIN

Some Early Descriptions of Foliated Plutonic Rocks

One of the most surprising facets of the 1990 season was the recognition of areally extensive zones of deformed and recrystallized noritic and anorthositic rocks in the Nain region. However, not only are there deformed basic rocks, but a brief examination of the Anaktalik Brook area indicates the presence of younger rusty-brown granitoid rocks in association with the basic rocks that are likewise deformed. A perusal of the existing literature, especially the Nain Anorthosite Project reports (Morse, 1971-1983) pertaining to the areas where deformed basic rocks have been observed by the writer indicates that some of the deformed rocks have previously been recognized, and, in some cases have been mapped as discrete geological units, but their origin was not always addressed. Wheeler's manuscript maps show many of the foliated noritic rocks as 'granulite of uncertain origin' and some NAP reports refer to 'stretched anorthosite' and 'foliated anorthosite'. In some cases, deformed rocks of the type described here seem to be designated as having a 'mineral lamination' or 'flow structure'. In all cases, the foliations in these rocks have been ascribed to pre-consolidation deformation. However, it seems that the extent of the deformation and recrystallization of the plutonic rocks has not been appreciated. Morse (1983a, p. 12,13) proposed that the 'stretched anorthosite' reflected an early anorthosite event in the overall emplacement history of the NPS, but acknowledged that the deformation exhibited by such rocks was problematic, probably not all of the same age, and could conceivably postdate consolidation.

From his earliest work on the rocks of the Nain area, E.P. Wheeler recognized that parts of the anorthositic terrane were texturally anomalous. For instance, in his 1942 paper he described (i) dark plagioclase crystals transected by white plagioclase veins, (ii) larger dark plagioclase crystals set in an equant fine-grained, white plagioclase matrix, (iii) warped cleavage planes in plagioclase and orthopyroxene, and (iv) the development of mortar structure. He also noted that hypersthene may form 'fluidal tongues' and that many of the larger grains exhibited a 'polysomatic' texture. He suggested at one point in this paper (p. 617) that the original subophitic texture of these 'non-diabasic' anorthositic rocks was destroyed by stress to produce the above features, but in a later part of the same paper maintained that the anorthositic rocks 'have not been subjected to any great degree of dynamic stress since their consolidation' thus implying that the destruction of the primary igneous textures must have occurred in the magmatic environment by 'differential flow during the late stages of consolidation' (cf. Wheeler, 1955, p. 1054). Wheeler (1960, p. 1761) noted that 'the available data give the impression that foliation in the anorthosite complex is best developed near margins'. He was also conscious of the unique character of the anorthosites in which white plagioclase was dominant—he erected a 'pale facies' to denote their marble-like paleness, and observed that within a regional context these rocks were most widely developed in the central part of the Nain 'complex' (Wheeler, 1960).

Wheeler (1960) initially believed that the development of foliation within the granitoid rocks was 'rare, if not absent', but he later (Wheeler, 1969) described 'adamellite' of the Nain Bay area having a penetrative fabric parallel to the margins of the intrusions. However, his manuscript maps indicate that in places, such fabrics are in fact quite discordant to pluton contacts. He attributed these foliations to primary igneous flow processes, namely, that they developed while the magma was being emplaced as crystal mush along a contact between gneiss and foliated anorthosite; the foliation was deemed to be a function of movements resulting from tectonic pulses during consolidation of the adamellite magma (see also Emslie *et al.*, 1972, p. 55).

Observations on Foliated Plutonic Rocks during the 1990 Season

A brief examination of anorthositic rocks adjacent to Tasiuyak gneiss northwest of Kingurutik Lake (Figure 2) was undertaken while conducting helicopter reconnaissance of the latter rocks (a septa of the Churchill Province rocks within the interior of the NPS). Contact metamorphosed Tasiuyak gneiss and associated charnockitic to gabbronoritic granulite is separated from 'pale facies' recrystallized anorthosite by a 300- to 400-m-wide zone of strongly foliated and recrystallized norite and noritic gneiss. Wheeler's manuscript maps for this area show these rocks as 'granulite of uncertain origin', but in a field guide by Emslie *et al.* (1972, p. 44), he noted the pale anorthosite and paragneiss of this region are separated by a zone of norite in which 'foliation becomes continuous and pronounced, and the texture becomes more gneissic'. He described a specimen from this zone as an 'apatite—ilmenite—orthopyroxene dioritic gneiss with anorthositic affinity'. Brand (1975, 1976), working in an area slightly south of that examined by the writer described a 'marginal anorthosite' displaying a 'foliation ..... of mafic minerals' and 'pyroxene lineation'; this writer interprets the 'marginal anorthosite' to be correlative with the foliated norite seen directly to the north. This indicates that in the Kingurutik area the zone of foliated and gneissic norite separating relatively pure (yet recrystallized) anorthosite from the surrounding gneisses is at least 20 km in length. Similarly, using Wheeler's distribution of 'pale facies' anorthosite as shown on his manuscript maps and in Wheeler (1969, p. 190, 191), implies that recrystallized anorthosite underlies a vast area in the Kingurutik River region. (It is interesting to note that Brand (1976) failed to recognize the contact metamorphic effects from plutonic rocks in this region; in fact, his descriptions of cordierite, hypersthene and spinel habits within the Tasiuyak gneiss indicate that these minerals are plainly a result of the replacement of garnet and sillimanite; cf. Ryan and Lee, 1986).

Wheeler's manuscript maps portray a zone of 'granulite of uncertain origin' bordering 'pale facies' anorthosite to the west and north of Webb Bay. This 'granulite' zone, too, is strongly deformed and recrystallized norite (Plate 9), noritic gneiss and anorthosite, which at outcrop scale forms a well-layered gneissic complex akin to nearby Archean quartzofeldspathic granulite, but without a migmatitic neosome. A brief examination of several outcrops on the western side of the bay (Figure 2) revealed that the foliated rocks are transected by post-deformational granitic dykes in which the feldspars are largely recrystallized to sugary polygonal aggregates as in the rocks they cut. The 'pale-facies' anorthosite to the west of the gneissic noritic rocks is likewise recrystallized, comprising grey plagioclase relicts in an otherwise white groundmass. The polygonal monomineralic nature of the recrystallized anorthosite rocks masks deformational fabrics if present; however, orthopyroxene in zones of 'clotted fabric' (cf. Wheeler, 1960, Figure 3) are plainly deformed, and the larger orthopyroxene megacrysts (locally with visible exsolved plagioclase lamellae) are tailed-out, their margins are recrystallized to polygonal aggregates, and their massive interiors have warped cleavage faces.

A brief reconnaissance of the near-coastal area south of Webb Bay indicates that this assemblage of rocks continues towards Nain. Certainly, Mount Lister (Figure 2) is composed of variably recrystallized anorthosite; basic (ferrodioritic?) dykes, prominent features in the steep cliff faces on the eastern flank of the mountain, are diffusely banded and foliated parallel to their trend. Similarly, white foliated anorthosite and more melanocratic noritic rocks also occur east of Conch Bay and on the islet west of Barth Island, where they have been previously included as part of the Archean basement (Rubins, 1971) or else 'granulite of uncertain origin' (Wheeler, manuscript maps). Recrystallized, but non-foliated, noritic rocks have been observed on the shoreline of Sachem Bay

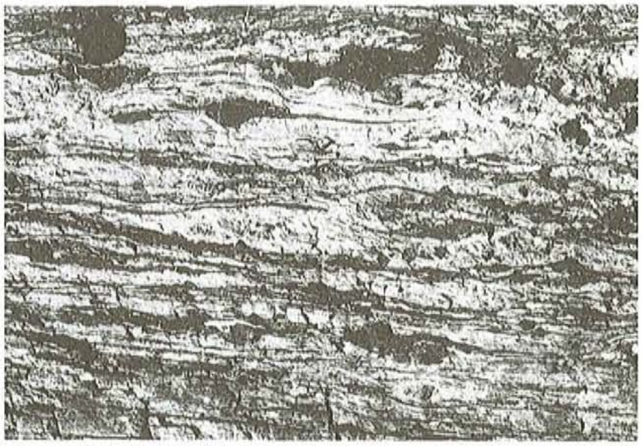


Plate 9. *Strongly foliated norite, Webb Bay. Black lozenges and streaks are orthopyroxene. Light grey areas are recrystallized plagioclase in which remnants of original larger grains are preserved (darker grey areas).*

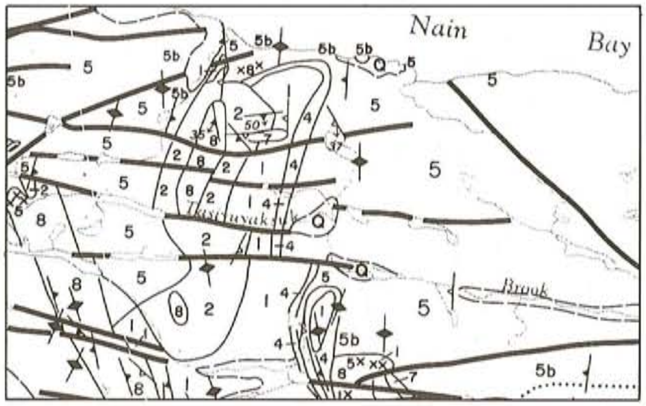


Figure 4. *Area directly south of Nain Bay examined during helicopter reconnaissance (see Figure 2) showing rock units according to E.P. Wheeler's manuscript maps (from A. Harris, 1980). See text for relevant unit descriptions and discussion of 1990 reconnaissance survey of this area.*

(Figure 2), close to banded noritic 'granulite' that may be equivalent to rocks on Carey Island and at Higher Bight described earlier. Rubins (1971) has mapped 'foliated anorthosite' and various basic granulites west of Nain village and north of Barth Island that are probably a continuation of the Webb Bay assemblage. A brief examination of one of Rubins' outcrops of 'foliated anorthosite' on the coast west of Nain indicates that it is a strongly foliated norite, with tailed-out pyroxenes and lozenges of grey plagioclase, a rock that is easily correlatable with the noritic gneisses west of Webb Bay. However, the Nain outcrop examined has deformed basic dykes subparallel to the foliation, and the foliated norite is, in one part of the outcrop, crosscut by a small dyke network of undeformed, subophitic-textured norite. Rubins (1971) failed to recognize that 'pale facies' anorthosite west of his foliated anorthosite is likewise a recrystallized rock in which, like at Webb Bay, a deformational fabric is visible only where orthopyroxene is present. Many basic dykes, visible in coastal cliffs of the white anorthosite, were not examined, but are quite likely similar to those on the east flank of Mount Lister.

At the end of the 1990 field season, a brief helicopter reconnaissance excursion was undertaken between Anaktalik Brook and Nain Bay (Figure 2), in areas shown on Wheeler's manuscript maps to be underlain by his Units 1 and 2 (Figure 4). Based on this writer's previous experience using the above maps, Wheeler's Unit 1 corresponds to Nain Province Archean gneisses, and his Unit 2 corresponds to Proterozoic Tasiuyak gneiss of the Churchill Province; the goal of the excursion was to define the nature of the Nain–Churchill boundary in this area. This area proved to be much more complex than is apparent from Wheeler's work, an inkling of which can be gleaned from the observations to follow.

For instance, three outcrops of his Unit 1 were visited. Two of these are granulite-facies quartzofeldspathic gneiss containing concordant mafic units derived from mafic dykes; the other outcrop is deformed anorthosite. This anorthosite is identical to rocks just south of Anaktalik Brook previously considered to be Archean anorthosite by Ryan and Lee (1986); however, based on the similarity between these rocks and the foliated anorthositic rocks from the Webb Bay–Nain area above, a re-evaluation of this earlier interpretation may be in order. (One can, of course, always entertain the possibility that all deformed noritic and anorthositic rocks are in fact Archean, and akin to similar rocks elsewhere in Labrador and Greenland.) 'Granulite of uncertain origin', designated by Wheeler as Unit 4, and shown to occur as a narrow zone in this area (Figure 4), is foliated and recrystallized norite like that of the Kingurutik River–Webb Bay–Nain area.

Wheeler's Unit 2 gneiss in this area is not Tasiuyak gneiss. In fact, his Unit 2 is quite variable. Predominant is a orange-brown-weathering rock that is a simply foliated and well-lineated megacrystic granitoid. Without its penetrative fabrics it is identical to some of the massive rapakivi-like granitoid rocks that are an integral part of the NPS. Wheeler, in fact, recognized this, and shows it on his manuscript maps as Unit 8 (his 'adamellite'), where there is no foliation present (Figure 4). There is no obvious compositional difference between his Units 2 and 8, and they are considered by this writer to be the same unit, exhibiting inhomogeneous foliation and lineation development. However, within this area, there are rocks that are certainly part of the Churchill Province. These are brownish-yellow enderbitic and gabbronoritic gneisses akin to those elsewhere in eastern Churchill Province.

Wheeler's 'pale facies' anorthosite (Unit 5, 5b, Figure 4) in the Anaktalik Bay–Nain Bay area is, where examined at least, recrystallized, albeit to varying degrees. Outcrops examined directly west of the foliated 'rapakivi granites' are all foliated and pervasively recrystallized white-weathering rocks, in places cut by rapakivi granite and brown ferrodioritic dykes that are also foliated and lineated; similar anorthosite and 'foliated orthopyroxene meladiorite dykes' have been described by Wheeler (1969) at Tessersoakh Lake, 10 km northwest of the area examined by this writer. Recrystallized anorthosite also occurs around the Pearly Gates, a small area between Anaktalik Brook and Nain Bay named for its iridescent labradorite, which, in places occurs in crystals up to a metre across. Recrystallization here, however, is limited to small irregular zones in which the otherwise dark-grey feldspar is replaced by a chalky-white equigranular aggregate. Common to the more massive grey anorthosite is a conspicuous, narrow white fracture pattern to the plagioclase; along some of the larger fractures the grey feldspar has polygonized to white sugary aggregates. These features correspond to Wheeler's descriptions of some of the anomalous characteristics of the 'non-diabasic' anorthosites noted earlier.

Wheeler's manuscript maps show several elongate bodies of 'adamellite' in the Anaktalik Brook–Nain Bay area (Unit 8, Figure 4). One of these was examined in one outcrop area only. At the locality visited, the rock is a slightly rusty-weathering monzonite, in which streaks of pyroxene (+ hornblende?) locally define a well-developed foliation. On fresh surface, the rock has the greenish hue common to olivine-bearing assemblages of the NPS; fayalite indeed occurs in a sample of this rock collected for geochronological studies by R.F. Emslie (personal communication, 1990). At the locality visited, the monzonite also contains rafts of white, recrystallized anorthosite that are common in this whole region.

An interpretation of E.P. Wheeler's manuscript maps, together with this writer's observations, prompts the predictions that 1) much, if not all, of Wheeler's 'pale facies anorthosite' inland between Anaktalik Brook and Okak Bay (cf. Wheeler, 1969) is, in fact, variably deformed and recrystallized rock, 2) much of his 'granulite of uncertain origin' in the same area consists of foliated and recrystallized norite, and 3) many of the 'adamellites' of this region (which have foliation symbols on his manuscript maps, Unit 8, Figure 4) are correlatives of the deformed monzonite and granite described above. Indeed, in the guidebook paper by Emslie *et al.* (1972, p. 55, 56), Wheeler provided good descriptions of such foliated adamellitic rocks on the north and south shores of Tessersoakh Lake, attributing the development of the fabrics to primary magmatic flow. Into this category of deformed and recrystallized rocks, this author would also include the Bird Lake Massif and Suzie Brook slab (Morse, 1983b), as well as foliated anorthosite described by Berg (1974) in the vicinity of Port Manvers Run. The North Ridge Gabbro (Berg, 1973), a foliated and lineated rock west of the Hettasch Lake layered intrusion, and the Bridges layered intrusion (Planansky, 1971) are probably also members of this group of rocks. The Bridges intrusion exhibits igneous layering, but its constituent minerals are strongly polygonized and recrystallized (R. Wiebe, personal communication, 1989). If future work confirms these predictions, it is obvious that the areal distribution of the foliated and recrystallized rocks is enormous. This has implications for emplacement mechanisms of the Nain Plutonic Suite.

AREAS OF DEFORMED/RECRYSTALLIZED PLUTONIC ROCKS OUTSIDE THE MAIN NPS

Outside the areas mentioned above, all of which on the basis of present knowledge must be considered to be part of the NPS, there are other areas discovered during the 1990 season where deformed and recrystallized plutonic rocks akin to those of the NPS occur. These are on Georges Island at the entrance to Webb Bay, at Challenger Cove, and on Satok Island (Figure 2).

The northern shore of Georges Island (the only part of the island examined) and an adjacent small island to the north comprise a black-weathering (olivine-bearing?) norite. This rock is thoroughly recrystallized (plagioclase is white and saccharoidal, pyroxene is altered to amphibole) and it is crosscut (on the small island) by two foliated and lineated metabasic dykes (now amphibolites). Across the bay mouth, at Challenger Cove, an identical rock occurs on the north shore, here transected by shear zones in which the rock is converted to a streaky amphibolite. On the southeast shore of the cove, the norite is characterized by a finer grain-size, and the presence of a 'clotted fabric'. Here, too, shear zones are developed, producing amphibolite from the original noritic rocks. The Challenger Cove rocks have been previously referred to as 'granulite of uncertain origin' by Wheeler (manuscript maps), and as 'gneisses of uncertain origin' by Woodward (1973).

The eastern half of Satok Island is composed of a variety of deformed and/or recrystallized plutonic rocks (Figure 3), which on existing maps (cf. Wheeler, manuscript maps; Taylor, 1979) are assigned an Archean age. However, this age designation is open to re-interpretation. Directly adjacent to the granulite-facies gneisses that form the western half of the island is a unit of foliated oxide-rich rock resembling some of the ferrodioritic members of the NPS. This is succeeded eastward by a narrow monzonitic zone, then a second gneissose mafic unit, and then an extensive pale-brown-coloured monzonitic zone containing rafts of white, recrystallized norite. The monzonite and its inclusions are cut by amphibolite dykes at one locality; in a nearby locality, a phlogopite–pyroxene–carbonate dyke is present, interpreted as a probable metamorphosed alkaline rock. The northeastern part of the island appears to comprise largely chocolate brown, oxide-rich ferrodiorite or rapakivi granite–syenite, whereas the eastern coast of the island is a fairly massive to slightly foliated white-weathering meta-anorthosite. A brief examination of the islets just south of Satok indicates these are largely black, (olivine-bearing?) recrystallized norite, like that on Georges Island. The full extent of this plutonic assemblage is not known.

LARGE DYKES OF NORITIC TO TROCTOLITIC COMPOSITION

The rocks included in this category include several prominent intrusions on northern Dog Island, a north-trending dyke on Dumbell Island, several dykes on Carey Island and a dyke on the long island east of Sungilik Island.

The Archean basement on the northern half of Dog Island (Figure 5) is intruded by several east–west- to southeast–northwest-trending dykes that appear on field examination to be olivine-bearing noritic to gabbroic rocks. These are older than the Dog Island granite, but their relationship to the other Middle Proterozoic rocks here is unknown. With the exception of the second east–west dyke north of 'Camp Bay', which is black, these are brownish-grey-weathering, equigranular rocks. Locally, the plagioclase appears to be recrystallized, and the dyke margins may be sheared. One such dyke is characterized by an igneous layering whose attitude is normal to the dyke trend; the layering is folded into moderate folds, which have a well-developed axial-planar foliation.

Northwest-trending dykes like those above also occur on Carey Island. At least one of these, a 15-m-wide dyke which has layering oblique to margins, crosscuts well-layered 'mafic granulite' that may be a marginal phase of the norite to the east. A larger dyke, that appears from aerial reconnaissance to extend northward across the island, is a recrystallized olivine-bearing noritic rock. It has a near-margin internal zone with a spongy, discontinuous type of layering, and a strongly foliated and lineated amphibolitized margin.

A massive, undeformed 8-m-wide brown-grey olivine gabbro forms a north-trending dyke on Dumbell Island and on the small island east of Misfit Island. This dyke shows no indication of a penetrative fabric, and it exhibits chilled margins against the Archean gneisses. This dyke may be related to the younger gabbro dykes described in the next section.

One short traverse across a long island east of Sungilik Island suggests that the east-trending central spine of this island is a large recrystallized olivine norite or ferrodiorite dyke. In places, it is characterized by porphyritic and mingled textures akin to the ferrodiorites on Dog Island and Skull Island, and is intruded by the pink aplite that underlies most of the north shore of the island. An outcrop on the central coast of the north shore comprises foliated brownish-weathering rocks resembling the dyke having folded layering on northern Dog Island. A rock of similar composition appears to form part of the western shore of Nuasurnak Island. Further work is necessary in this area to fully define the nature of these rocks and their relationships to the surrounding gneisses and other plutonic rocks.

FRESH DIABASE AND GABBRO DYKES

Dense, black to brownish-weathering, fresh diabase dykes were noted for instance on Noazunakuluk Island, Pat Rocks, on the northeast coast of East Red Island, on the northern tip of Whale Island, on the north shore of Higher Bright, on the large island east of Nukasusutok Island, and at Ford Harbour. These are all fine- to medium-grained rocks, rarely exhibiting black plagioclase megacrysts. Chilled margins are conspicuous on some dykes, and some are vesicular. The most spectacular example of a fresh dyke is a 60-m-thick coarse-grained gabbro that forms a prominent black band across the western half of Skull Island; Wheeler's manuscript maps show this dyke extending eastward across the whole island.

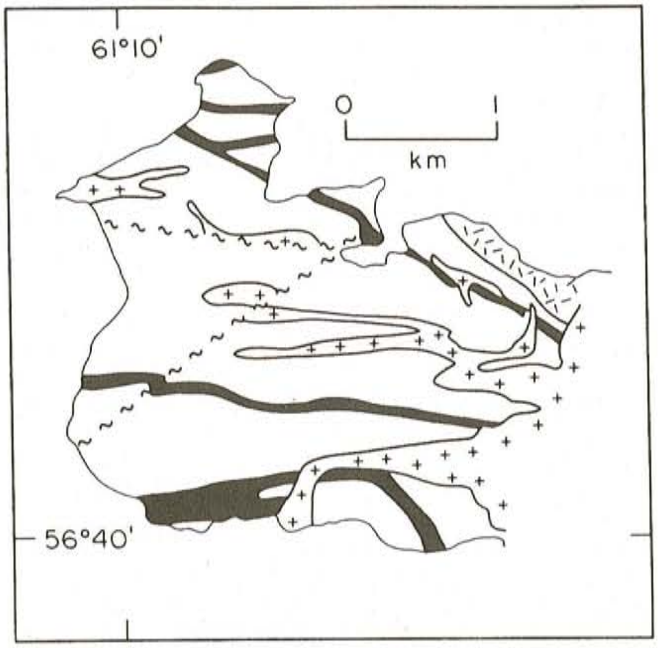


Figure 5. *Sketch map of northern part of Dog Island showing distribution of thick olivine-bearing basic dykes (black). The second dyke to the north may be part of the older (metadiabase) dyke swarm. The Archean gneisses are unornamented, norite is shown with random dashes, and granite is designated by crosses.*

Most of the fresh dykes trend within a few degrees of east-west, and since these intrusions occur within the basic plutons as well as within the gneisses, all such rocks are assumed to be post-anorthosite. None of the posttectonic granitoid rocks examined by the writer are cut by dykes but quite likely these dykes postdate the felsic plutons as well. Absolute ages may range as young as Tertiary as suggested by Bridgwater *et al.* (1990). Based on descriptions given by Wiebe (1985) they are probably correlative with his low-phosphorus series and illustrate the further extent of dykes that are considered to be broadly equivalent to the Harp dykes (Meyers and Emslie, 1977).

METAMORPHISM AND STRUCTURE

The islands surveyed during 1990 expose gneissic rocks that are part of a north-south septum between two plutonic masses of the NPS (Figure 1). It has been already well established that thermal effects from the NPS were responsible for contact metamorphic transformations in the regional assemblages of the gneissic rocks into which the plutons were emplaced (cf. Berg, 1977a; Lee, 1987). One of the most diagnostic mineralogical changes, and one that is easily recognized in the field, occurs in paragneisses that are adjacent to the intrusions. In rocks at pyroxene hornfels facies, garnet is replaced by hypersthene and cordierite, and sillimanite is replaced by cordierite and spinel. Since these transformations are apparent in the paragneiss units throughout the islands surveyed this year, it is not unreasonable to conclude that the imprint of pyroxene-hornfels-facies contact metamorphism has blanketed all of the gneissic country rocks. The fact that garnet and sillimanite pseudomorphs still retain their pre-replacement shapes (ovoidal and streaky, respectively) shows that the gneisses were not subjected to deformation during this metamorphism.

Dykes similarly show assemblages that conform to pyroxene hornfels (granulite) facies, but as has been noted previously, the metamorphism of the dykes appears to be a complex affair, and must await petrographic study before definite conclusions can be advanced. It may be, for example, that the dykes all predate the NPS and the assemblages of the amphibolite dykes represent varying degrees of retrogression from a 'regional contact' metamorphism of pyroxene hornfels (granulite) facies or else reflect greater distance from the pluton. On the other hand, the granulite-facies dykes may predate the NPS while the amphibolite-facies dykes may represent intrusions into the gneisses as the thermal effects from the NPS were waning.

Although the gneisses and their dykes have been subjected to a pyroxene-hornfels thermal metamorphism, it is also evident that the gneisses had reached granulite facies prior to dyke intrusion. This is based on observations that basic dykes plainly transect rocks with orthopyroxene-bearing 'sweats' that had formed before dyke emplacement. If the dykes that cut such melts are Early Proterozoic in age, then this high-grade metamorphism is quite probably Archean. If, on the other hand, the dykes are Middle Proterozoic, then this metamorphism may have been Hudsonian, or even related to events accompanying emplacement of early NPS plutons, which are also cut by such dykes.

Amphibolite-facies gneisses in the area show indications of having been at granulite facies, and blebby retrogressed granulites are locally a distinctive member of the quartzofeldspathic rocks. To date, there is insufficient data to compare metamorphic assemblages in the gneisses with those in the dykes that cut them, so the relative timing of the retrogression is unknown.

De Waard (1971) pointed out that the deformational history of the gneisses on Paul Island is plainly polyphase, but he felt that the major features were developed as a result of anorthosite intrusion. However, this seems unlikely, for it is obvious from the map pattern that the plutonic rocks on Dog Island clearly cut across earlier interference patterns in the gneisses (Figure 3). In addition, on a mesoscopic scale, mafic dykes crosscut tight folds, open folds, and interference patterns in the gneisses; even if some of the dykes are related to the incoming plutons, this relationship shows that the fundamental features of the gneiss complex were attained prior to this Middle Proterozoic plutonism.

As noted above, interference folds in outcrop and on map-scale indicate a polyphase deformational history. The continuity of structures through the area is somewhat tenuous, mainly because of the scale of mapping. It is obvious that on a regional scale there is considerable variation in trend of the gneissosity (Figure 6). On Dog Island, for instance, the foliation attitudes and distribution of supracrustal gneisses point to map-scale interference fold structures. However, on the islands to the west, the gneisses maintain a more consistent north-northeast trend. Southward toward the Red Islands, the gneissosity swings eastward in an apparently simple manner. It defines fold structures with east-trending axes on East Red Island and Paul Island, but this too is a simplified picture since the mafic units north of Ford Harbour outline earlier structures, and coastal reconnaissance south of Ford Harbour indicates shallowly plunging dome and basin patterns. East of Nukasusutok Island the trend of the gneissosity and distribution of supracrustal units again define north-northeast-trending fold structures.

The gneisses locally display zones of high strain in which the gneissic banding has a mylonitic aspect. The two best-developed zones of this type occur on the south shore of Carey Island and the south shore of the large island east of Nukasusutok Island. On Carey Island, the 'straight gneisses' are gently dipping and have a well-developed lineation; the gentle dip is a function of re-orientation by open, shallowly plunging fold structures. The zone is cut by a massive metadiabase dyke. East of Nukasusutok, a similar straight belt with a moderately S-plunging lineation is steeply dipping, and is in part occupied by a foliated amphibolite dyke. The age of formation and the extent of such zones has not been fully evaluated.

Rarely does there seem to be any direct relationship between mesoscopic structures in the deformed dykes and in the enclosing gneiss. This requires an explanation. The development of foliations and lineations in the dykes, yet not in adjacent gneisses, indicates that at the time of their deformation the basic intrusions were far more susceptible to recrystallization, perhaps an indication that they were hot and therefore, weaker than the host rocks at the time of deformation (cf. Watterson, 1968). It should also be noted that folded dykes tend to be those that were originally oriented nearly normal to the trend of the gneissosity in the country rock; the majority of the highly discordant dykes, however, are not folded.

DISCUSSION

The geological history of the Nain area appears to be much more complicated than can be appreciated from existing information on the area. This section presents some brief comments on possible correlatives of the regional gneiss terrane, but focusses mostly on the problems posed by the basic dyke swarm and by the recognition of the extent of the deformed and recrystallized plutonic rocks within the NPS. With respect to the final points, several fundamental questions are posed.

1. What is the age and origin of the basic dyke swarm in the gneisses?

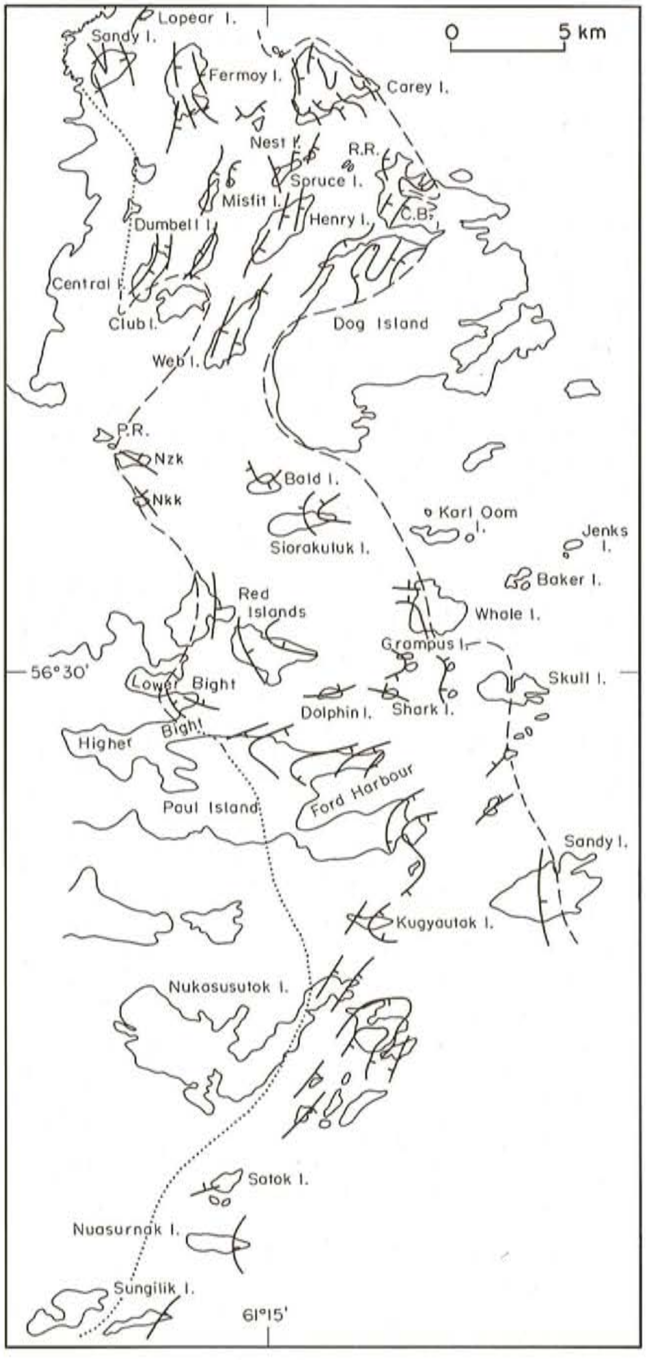


Figure 6. *Generalized trend of regional gneissosity shown as heavy lines with barbs. Broken line is approximate contact between plutonic rocks and gneisses, dotted where compiled from other sources. Note that effects of late strike-slip faults have been ignored for purposes of this sketch. See Figure 3 for key to islands.*

2. Is there more than one discrete episode of basic magmatism?

3. What caused such regionally developed deformation and metamorphism of the dykes? and,

4. Why are there deformed and recrystallized plutonic rocks in an anorogenic igneous suite?

THE REGIONAL GNEISS TERRANE

The Archean quartzofeldspathic–orthogneiss complex is obviously a polygenetic series of rocks, comprising multi-generation migmatite at granulite and amphibolite facies and a variety of more homogeneous granitoid rocks. The layered gneisses have no distinct features to suggest direct correlation with the Early Archean of northern Labrador, but the presence of Saglek-dyke type mafic units at Webb Bay are suggestive of such correlation (see also Bridgwater *et al.*, 1990). The development of orthopyroxene- and garnet-bearing melts is another feature that this area has in common with Late Archean granulite-facies metamorphism in northern Labrador. The multiphase whispy granitoid gneisses that intrude the migmatite grey gneiss in the Henry Island–Dumbell Island area resemble the 3050 to 3000 Ma Nûk gneisses and other polyphase mid-Archean gneisses of West Greenland; large areas of rock directly correlative with these ca. 3000 Ma Archean units of Greenland have yet to be firmly identified by isotopic dating in Labrador, but the Dumbell Island–Misfit Island rocks are good candidates. The presence of apparently syn-plutonic basic dykes in the whispy granitoids of Labrador is also a feature of the Greenlandic mid-Archean gneisses (cf. Chadwick and Coe, 1983).

Supracrustal rocks are not nearly as abundant in the Nain area as they are in the Saglek area, perhaps reflecting an overall greater volume of middle Archean orthogneiss than in the north. The apparent abundance of quartzite around Ford Harbour and on some of the islands is also a characteristic of the supracrustal rocks here that differs from northern Labrador.

THE BASIC DYKE SWARM

The profusion of basic dykes represents one of the most intriguing features of the rocks around Nain, and the following discussion focusses on these. The younger undeformed dykes are not addressed here, since these have been adequately discussed by Wiebe (1985); instead the comments are restricted to the metamorphosed and deformed dykes. Unfortunately, although it is easy to demonstrate several generations of such dykes in many gneissic outcrops around Nain, there is no firm evidence of their absolute age. As pointed out earlier, determinations of relative age between isolated dykes is also a problem, since the data at present do not allow firm correlation between trend and age. Similarly, there does not seem to be any correlation between particular morphological characteristics and dyke trend. In addition, there is no obvious correlation between dyke trend, relative age, the presence or absence of deformation and the degree of metamorphism. All these features make discussion of the significance of the dykes somewhat difficult, so a simple premise is adopted as a foundation for discussion. This premise is that there are potentially at least two discrete episodes of basic magmatism represented by the dyke swarm: (i) an Early Proterozoic one and (ii) a Middle Proterozoic one. In addition, the occurrence of features in some dykes in the whispy granitoid gneiss akin to those seen in synplutonic mafic dykes from felsic igneous terranes suggests these may be approximately the same age as their Archean host, thus introducing yet an earlier set of dykes. Similarly, some of the dykes, sub-parallel to the gneissosity, may be earlier than the majority of the layer-discordant dykes. However, for purposes of discussion below, only dykes that obviously postdate the regional gneissic layering are dealt with here.

By analogy with the Nain Province at Saglek to the north and Hopedale to the south, it is proposed that some dykes are Early Proterozoic. Specific dykes of this age are, of course, difficult to identify in the field, but if the premise is valid, then some of the metadiabases must pre-date emplacement of the Middle Proterozoic NPS by 500 million years or more. Metamorphism and deformation could then be either pre-NPS or related to NPS (see below).

That some of the dykes must be Middle Proterozoic is based on the fact that amphibolite dykes like those in the gneisses occur within recrystallized and deformed metaplutonic rocks of the area that are considered to be members of the NPS. Dykes of this age are likewise difficult to pinpoint, but a few specific textural features may be diagnositc. For instance, those dykes with abundant clusters of skeletal plagioclase may be a variation on the snowflake textures seen in some of the NPS troctolitic rocks. Similarly, some dykes contain large megacrysts of black plagioclase that are identical to the feldspars in some olivine-bearing members of the anorthosite suite.

It is obvious that in order to distinguish the two intrusive episodes (Early versus Middle Proterozoic) in massive metamorphosed dykes, some criteria, perhaps a distinct geochemical fingerprint, must be found. If, as proposed above, there are Middle Proterozoic dykes, then it is possible that they may retain original geochemical characteristics that will provide important clues to the nature of the mantle and/or magma pond underlying this area at the time the NPS was being generated. Therefore, these dykes may provide another avenue to study the composition of the precursor magmas to the anorthosite suite.

Without adequate absolute age criteria it is also difficult to comment on intrusion mechanisms relative to Early or Middle Proterozoic emplacement. Features noted earlier indicate that some dykes appear to have been emplaced along active shear zones; other dykes display morphological attributes that imply emplacement into relatively hot and soft countryrock; other dykes exhibit a style that is consistent with emplacement under conditions of high hydrostatic pressure. It may not be too far-fetched to suggest that some of these features can be accommodated in an environment of anorthositic plutonism if the crust is 'softened' by heat liberated from an underlying magma pond at the crust—mantle interface, and that some of the leaking from this magma pond is being accomplished by way of hydrostatic fracturing and devolatization. Such fracturing may be induced by the fluids liberated as the lower crust was dehydrated above the magma pond. It is unlikely that the volatiles may be 'boiling off' the magma pond itself, since abundant evidence exists that the source magma for the anorthositic rocks was anhydrous.

It is perhaps appropriate at this point to address the deformation and metamorphism seen in the dykes. Using the present models of geological evolution of northern Labrador, two causes come to mind, viz. (i) a Lower Proterozoic (Hudsonian) overprint from events that produced the Churchill Province as outlined at the beginning of this paper, assuming the dykes are all Early Proterozoic, or (ii) tectonic and contact effects associated with the emplacement of the Middle Proterozoic plutons, assuming that the dykes are, in part, Middle Proterozoic in age. Each of these will now be considered.

It has been noted earlier that recent studies have shown that Hudsonian effects transgress eastward across northern Nain Province, such that the least imprint occurs in the Saglek—Nachvak area in the north and the greatest in the south at Okak (see for instance Ryan, 1990b; Ermanovics and van Kranendonk, 1990). At Okak, for instance, Early Proterozoic dykes display greenschist-facies metamorphism and deformation, attributed to Hudsonian overprint, some 50 km east of Churchill Province. Conceivably, therefore, the thermotectonic overprint in the dykes at Nain may be attributed to Hudsonian deformation. The metamorphism in the dykes examined this summer, however, shows plainly that these rocks have been at granulite facies, and such a degree of Hudsonian metamorphism is unknown east of the Churchill Province elsewhere in Labrador. Such a radical change in the character of Hudsonian overprint on the Nain Province here could only be accommodated by models such as one advocating overthrusting (cf. Wardle *et al.*, *in press*) of a (now eroded) thick slab of crust from the west during Hudsonian plate collision. It seems improbable therefore that the deformation and metamorphism seen in the dykes are entirely Early Proterozoic phenomena.

It is hard to escape the conclusion that some of the metamorphism and deformation must be Middle Proterozoic, concomitant with emplacement of the NPS. Accepting the premise that all the foliated and recrystallized noritic and anorthositic plutonic rocks described earlier in this paper are an integral part of NPS magmatism, then the foliated mafic dykes that occur within these units must owe their characteristics to events accompanying this magmatism. If mafic dykes occur within the plutons, in all likelihood equivalent mafic intrusions occur within the gneisses. A model to account for these features could entail early leaking from a subcrustal magma pond (Emslie, 1980) in the form of the dyke swarms. Emplacement of the anorthositic rocks probably occurred in pulses, separated by periods of renewed dyke intrusion. As a consequence of crustal processes active at this time, the dykes and plutons may then have undergone varying degrees of deformation and metamorphic recrystallization. This will be discussed further below.

It has previously been established that contact metamorphic aureoles of variable width are developed adjacent to the intrusive rocks of NPS. In all cases, these aureoles are statically developed; that is, the development of the contact aureole assemblages occurred under non-stressed conditions. This is especially evident in the Tasiuyak gneiss (Lee, 1987) and in paragneisses described in this paper, both of which contain cordierite–hypersthene pseudomorphs of garnet and cordierite–spinel pseudomorphs of sillimanite folia that preserve the ovoidal and lenticular characteristic, respectively, of the original regional metamorphic assemblage. This non-stress replacement of regional minerals in the Nain area is difficult to reconcile with the obvious development of penetrative fabrics in dykes that cut these same rocks. The most obvious solution is that the dykes were preferentially deformed because of the competency (and temperature?) difference between these intrusions and their host rocks allowed the dykes to deform more readily. Alternative explanations are (i) that the deformational fabrics in the dykes are in fact an artifact of Hudsonian (or earlier?) deformation that have not been eradicated by the pyroxene hornfels grade metamorphism or (ii) the fabrics are primary emplacement features, and the mineral assemblages in such dykes reveal crustal conditions at time of intrusion (amphibolite-facies dykes could thus postdate peak contact metamorphic conditions).

MODELS TO ACCOUNT FOR THE FEATURES SEEN IN THE FOLIATED ROCKS OF THE NPS

Foliated and recrystallized plutonic rocks within the NPS have not been specifically discussed in any great detail in previous literature on the anorthosite and granitoid rocks of the Nain region. As noted above, Wheeler simply assigned the foliated noritic rocks to a unit on his manuscript maps that he designated as 'granulite of uncertain origin'. However, in some cases, he realized that foliations occurred within rocks that otherwise had all other attributes of undeformed members of the NPS, and he concluded, as noted earlier, that these were indeed part of the NPS and that their structures represented protoclastic foliations and primary flow fabrics related to emplacement (see also Morse, 1969, p. 186). An outgrowth of his flow-fabric concept entailed emplacement of crystal mushes in the form of mushroom-shaped plutons (cf. Wheeler, 1969; Emslie *et al.*, 1972). This concept was enhanced and modified by de Waard (1973, 1974b, c, 1976) in which the deformational fabrics were accounted for by variations on gravitative collapse and/or density overturn within partially solidified igneous bodies, perhaps caused, in part, by diapiric piercement of older, partially crystallized rocks by younger, more buoyant plutons. Morse (1983b) has also used the concept of gravitational foundering and block rotation, caused by emplacement of younger magmas, to account for 'hot plastic stretching of megacrysts' in the Suzie Brook slab, a steeply dipping 9-km-wide unit of deformed leuconorite south of Tikkoatokak Bay. (This writer briefly examined this unit in 1989, and formed the impression that there is really no difference between the structure seen in these rocks and in the foliated norites seen between Webb Bay and Nain in 1990). A common thread running through all the above references is that the deformation of the plutonic rocks is a process intimately related to magmatic (emplacement) processes, not to post-crystallization events. This can also be seen, for instance, in Morse's (1983b, p. 39) conclusion that the development of a foliation in the Bird Lake Massif, also on Tikkoatokak Bay, suggests 'deformation before the end of crystallization', and Wiebe's (1976, p. 26) proposition that the major cause of 'considerable deformation' in anorthosite on Tunungayualok Island 'was most probably due to relative movement of adcumulates, orthocumulates and liquids within the developing anorthositic intrusion'.

Emslie (1985), in a wide-ranging overview of numerous Proterozoic anorthositic massifs, noted that recrystallization and deformation are not uncommon features in some intrusions, but because many of these intrusions occur within orogenic terranes having an obvious younger tectonic overprint, the origin of the foliations in the anorthosites is sometimes ambiguous. He does cite references to complexes in Norway and Quebec where the deformation and metamorphism have been attributed to diapiric emplacement of plagioclase-rich crystal mushes and/or fully consolidated plagioclase-rich plutons (see also papers by Duchesne and co-workers, *in* Maijer and Padget, 1987). Emslie proposed that buoyant rise of composite diapirs—an anorthositic core surrounded by a granitic envelope—was probably the mechanism by which all such plutonic suites are emplaced.

It is timely to note here a statement from Emslie's (op. cit, p. 57) review to the effect that '... although the existence of dispersed, bent, warped and kinked crystals has been widely observed in pristine massifs of central Labrador and elsewhere, evidence for large strain components in near solid anorthosite is not abundant.' From the data presented in this paper, it is now apparent that evidence of high strain is indeed present, and that the proportion of such rocks in the NPS has been underestimated. The presence of strongly deformed rocks in an area that has not ben affected by major orogenic events since the time of pluton emplacement should be used as a cautionary note when interpreting similar features of anorthositic rocks in areas that have been subjected to later regional deformation.

The degree and extent of deformation and recrystallization present in the NPS indicate that the cause of such features is an important factor to be considered in discussing the tectonic regime and emplacement mechanisms for these plutonic rocks. It is clear from the existing database (especially Wheeler's maps, and the NAP reports) that these are regional features in the NPS, not just locally developed phenomena. It is also probable that the deformation and metamorphism of the dykes in the gneisses is linked with the development of high-strain fabrics in the plutonic rocks.

It may be worthwhile to consider mechanisms other than primary flow fabrics, magmatic 'squeezing' and diapiric emplacement to account for the features observed in the NPS. While conceding that the following discussion is based on very limited data, and the diapiric model may be valid, an alternative model is considered to account for the relationships observed during the 1990 field season. This alternative model incorporates the basic concepts advocated for anorthosite intrusions already expounded by Emslie (1980), Morse (1982) and Wiebe (1990). It differs, however, in that it views the foliations and recrystallization seen in the plutonic rocks not as characteristics developed in an unconsolidated/incompletely crystallized magma mush, but rather as products of post-emplacement/post-crystallization deformation. The same tectonic regime that produced the strain fabrics in the NPS is also considered to be manifest in the deformation and metamorphism of the mafic dykes in the country rocks east of Nain.

The underlying 'engine' driving the anorogenic magmatism of the NPS is considered to be a subcrustal accumulation of tholeiitic magma that ascended from the mantle and spread along the crust-mantle interface. The crust was buoyed upward and subjected to localized extension, and dykes began to leak off the magma pond. As a consequence of the heat of crystallization, dehydration and anatexis of the overlying crust commenced. Another result of the increased heat flow from the subcrustal magma pond would have been that the crust became more ductile, thus providing environments in which the basic dykes could be emplaced both as planar and irregular bodies, in part, initiated by hydrostatic fracturing induced by the dehydration. Some of these dykes may in fact have crystallized with 'primary' metamorphic mineral assemblages; some may have been accompanied by granitoid melt and formed the composite dykes. Fractionation processes in the magma pond may ultimately have led to emplacement of hyperfeldspathic liquids into higher level magma chambers where they underwent final crystallization. These 'permitted' intrusions would have then imposed their thermal effects upon the surrounding crust, including the dykes that had previously tapped the magma pond below. A long-lived basic magmatic event of this type would lead to several discrete generations of basic dykes in the country rock and also to earlier crystallized plutons being cut by basic dykes produced by the periodic leaking of magma from the underlying replenished subcrustal pond. Any particular voluminous magma intrusive event would not only include anorthositic rocks, but also the ever-present ferrodioritic and granitic members. Thus, within the NPS as a whole, there should be a variation in the absolute age of particular members, e.g., both older and younger basic dykes and rapakivi granites should exist.

The formation of the foliations in the anorthositic and other plutonic rocks of the NPS is considered to be a function of tectonic events that affected them shortly after their emplacement and crystallization. Current models of the tectonic setting for the NPS advocate an extensional regime (cf. Berg, 1977b), but regional geological considerations imply very limited lateral motion and suggest instead that perhaps subvertical movement (megablock stoping) played a key role in promoting and permitting magma emplacement (cf. Ryan, *in press*). It is logical that during the limited extensional regime under which the anorogenic magmatism was occurring, there would be long-lived, but periodic, formation of extensional faults and shear zones. These may have been triggered by episodic magma underplating at the base of the crust. The deformation caused by these extensional crustal events would, of course, affect members of the plutonic suite already emplaced. It appears that the contact zones between the plutons and the enveloping gneisses were intensely deformed during such movements, perhaps in a manner analagous to core complexes where crustal extension caused the country rock to slide off the plutonic core. Extensional (?) lineations are locally well developed, for instance in deformed plutonic rocks of the Anaktalik Bay area and at Webb Bay; they are consistently moderately S-plunging in all cases.

In some cases, as at Webb Bay, the deformed noritic rocks are intruded by post-deformational granite dykes. The fact that these felsic dykes are recrystallized in the same manner as the host implies that the polygonization of the deformed anorthositic rocks occurred as a post-deformational event. This static recrystallization is considered to have been triggered either by the ambient high heat-flow from the sub-crustal magma pond, or else by renewed heating of the deformed plutonic rocks by the local arrival of new magma. That ductile shearing was imposed upon the plutonic rocks, in some cases after emplacement of mafic dykes, is demonstrated by the shear zones seen in the Georges Island–Challenger Cove noritic rocks. Similar intrapluton shearing is shown by anorthositic rocks on Paul Island (de Waard, 1974c, p. 281). Of interest here too, is the observation that in these zones in the Georges Island–Challenger Cove area the noritic rocks and the dykes are amphibolitized, implying access of external aqueous fluids into otherwise 'dry' rocks. The concept of post-emplacement zonal hydration also addresses Morse's (1983b, p. 41) dilema regarding biotite along the western margin of the Bird Lake massif, and accounts for the biotite-bearing saccharoidal anorthosite observed on Noazunakuluk Island, since it still allows for the original 'dry' magmas demanded by the regional contact metamorphic assemblages.

The deformation and recrystallization in the NPS is considered to be post-emplacement and post-crystallization for several reasons. Chief among these is that there is no firm evidence in any of the anorthositic rocks examined this summer that these rocks were ever mushes at time of deformation. On the contrary, all indications favour the argument that they were in fact crystalline. For example, there is no evidence of any residual liquid having been expelled, as would be expected in the case of deformation of a crystal mush. There is, however, abundant evidence that pyroxene had already crystallized in a subophitic habit prior to deformation. This can be readily demonstrated by the progressive deformation of 'diabasic' textures in shear zones and by the fact that the larger pyroxene lozenges in the deformed rocks retain their original massive solid cores whereas their margins are deformed and subsequently annealed. A similar argument can be used for the foliated rapakivi rocks north of Anaktalik Brook in which large feldspar augen are surrounded by a fine, granular, annealed matrix that preserves the foliation outlined by streaks of mafic minerals. There is no indication of the primary megacryst alignment that would be expected from magmatic flow; instead the field textures suggest post-consolidation deformation of the granitoid, followed by post-deformation recrystallization.

The less-deformed state of the plutonic rocks on the outer islands may indicate these are relatively later intrusions, that were perhaps subjected only to weak stress during the waning stages of the regional extensional regime (e.g., the foliated margin to the Dog Island ferrodiorite, the foliated anorthosite zone on Noazunakaluk Island). The gneisses into which these plutonic rocks are emplaced similarly appear to have escaped any profound Middle Proterozoic deformation; however, the basic dykes have been preferentially affected. Their deformation in shear zones and development of sigmoidal foliations and lineations is again suggestive of the influence of a regional shear regime. The geometry of the foliation in the dykes of the Sandy Island—Dog Island area noted earlier suggests that in this area a component of extensional shear was oriented northwest—southeast.

The preservation of original garnet and sillimanite shapes in the paragneisses, despite obvious contact metamorphic replacement by secondary minerals, and the lack of regional fold patterns that can be attributed to pluton emplacement, suggest a subordinate role for compressive stress during igneous activity. This is counter to what would be expected in the local area if forceful diapirism was active. Similarly, the vast majority of dykes oriented normal to pluton margins in the area are not anomalously affected by folding or deformation near the plutons; in a diapiric regime one would expect such dykes to be tightly folded and disrupted in proximity to the plutons.

It is perhaps of interest to note that on a regional scale the gneisses have retained their pre-Middle Proterozoic trends in spite of their setting as a narrow septum between batholithic masses of anorthositic and granitic rocks of the NPS. This relationship may also be used to argue against diapiric emplacement of the plutonic rocks, for in this model it is difficult to see how such a narrow gneissic zone could have escaped being drawn into conformability with the margins of the plutonic rocks. Instead the plutons plainly transect, without disturbing, the original fold patterns in the gneissic envelope. Therefore, it implies passive emplacement of the plutonic rocks, a mechanism also implied by the large dykes of granite on northern Dog Island and nearby islands, which appear to have been emplaced as a result of extensional fracturing of the gneisses.

Therefore, it seems that some of the deformed and metamorphosed mafic dykes of the outer islands, and the deformed rocks of the NPS west and north of Nain, are products of the same dynamic process. Dykes, intruded into a hot and ductile crust of gneisses as a result of leaking from a subcrustal magma pond, may have been subsequently deformed and metamorphosed in shear zones associated with the emplacement of the magmas that produced the regional NPS. Mafic dykes episodically penetrated the earliest plutons, and the whole complex was then deformed by subsequent shear-related deformation, with the strongest fabrics appearing to have developed along the original interface between the plutons and the gneisses, perhaps in a tectonic regime not unlike that of core complexes. Repeated intrusion, deformation, and recrystallization is indicated; part of the deformation and recrystallization occurred under conditions conducive to the development of hydrous phases in the plutons themselves. The episodic emplacement and deformation/recrystallization of the plutonic rocks can explain deformed plutons crosscut by undeformed ones and account for fragments of older deformed and recrystallized rocks entrained in younger plutons (cf. Wiebe, 1976; Davies, 1975). A mechanism of this type also predicts that some deformed plutons should contain fragments of even older deformed plutonic rocks, as a result of the repetitive intrusion and deformation.

The proposal of post-emplacement deformation outlined above overcomes some of the problems associated with the diapiric model. For instance, if anorogenic plutons are characteristically emplaced as diapirs—why do all such rocks of the NPS not display foliate margins? Similarly, in areas where two plutonic rocks are of different relative age, why do they carry a common fabric? The simplest explanation is that at time of emplacement, none of the plutonic rocks displayed such features; the foliations were imposed later. Post-crystallization shear-zone-type deformation in the interior of the anorthosite terrane could also account for extensive areas of such rocks described in NAP reports, for instance, the Suzie Brook slab (Morse, 1983b) and foliated anorthosite in the Port Manvers Run area (Berg, 1974), and for zones of 'granulite of uncertain origin' shown on E.P. Wheelers manuscript maps in the area between Kingurutik Lake and Anaktalik Brook. The youngest plutons of the NPS, that is those emplaced during the final stages of crustal extension, still show their primary intrusive discordant contacts because they have not been subsequently modified by the deformational processes related to crustal movement that had affected the older members.

SUMMARY

The 1990 field investigations of the Nain area have suggested a re-evaluation of existing models for the geological evolution of this part of Labrador. In particular, the work has documented a regional swarm of metamorphosed and foliated mafic dykes, and prompted the proposal that some of these dykes are in fact representatives of the basic magmatism that is manifested on a more obvious regional scale as the anorthositic and related rocks of the NPS. The work has shown also that significant areas of the NPS have been subjected to post-crystallization deformation and recrystallization. It is suggested that the deformed/metamorphosed mafic dykes and the foliated plutonic rocks are products of the same process, both being generated by limited, episodic extensional shear during the Middle Proterozoic when the NPS was emplaced.

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