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THE GEOLOGY OF THE AREA AROUND NUKASUSUTOK ISLAND, SOUTHEAST OF NAIN (INCLUDING PAUL ISLAND AND SANDY ISLAND)

K.R. Royse[1], R.G. Park[1] and A. Cadman[2]
[1]Keele University, Keele, Staffordshire, ST5 5BT
[2]University of Leicester, Leicester, LE1 7RH

ABSTRACT

During the summer of 1993, fieldwork was carried out in the Nukasusutok Island area near Nain, Labrador. The area consists of Archean quartzofeldspathic gneiss, intercalated with mafic banded gneiss and paragneiss, which have been intruded by the Middle Proterozoic Nain Plutonic Suite (NPS). The objective of the 1993 fieldwork was to evaluate the deformational effects on the Archean country-rock caused by the intrusion of the Nain plutons. Present models for the emplacement of the NPS do not account for all the features seen in the intrusions and the surrounding rocks. It has been determined that the trend of layering in the quartzofeldspathic gneiss has been re-oriented adjacent to the plutons, and that gabbros marginal to some of the intrusions have been foliated and subjected to an oblate strain.

INTRODUCTION

This report outlines the preliminary findings of fieldwork carried out for six weeks near Nain, Labrador. An area of 100 km² was mapped around Nukasusutok, Sandy, and Paul islands (Figure 1) at 1:10 000 and 1:50 000 scale.

The area consists mostly of (a) Archean quartzofeldspathic gneiss intercalated with earlier metasedimentary and mafic gneiss and (b) the Middle Proterozoic Nain Plutonic Suite (NPS) consisting of anorthosite, anorthositic gabbro and gabbro–anorthosite. These two units are, locally, spatially separated by rocks herein referred to as marginal gabbros; the origin of these gabbros is still to be determined. The Archean gneisses have previously been referred to as the Ford Harbour Formation (de Waard, 1971), but this nomenclature is not used here because of its stratigraphic connotations. The area was first studied in detail by E.P. Wheeler (1948-1974), whose pioneering work provided the basis for surveys by S.A. Morse and colleagues (cf. Morse, 1971-1983) under the Nain Anorthosite Project (NAP; 1971-1981), which focussed on the genesis of anorthosite. Wheeler's work and the NAP revealed the diverse nature of the NPS showing it to comprise anorthosite, norite, troctolite, diorite and granite. The NPS is cited by Morse (1982) as a classic example of Middle Proterozoic anorogenic magmatism. The gneissic country-rock has received considerably less attention. Wheeler's original mapping provided the first descriptions; later this was followed by Taylor (1979), de Waard (1971), Bridgwater *et al.* (1990) and Ryan (1991a, 1992).

This report takes the form of brief field descriptions of each of the main rock subdivisions and a summary of the structural geology. The rock names used in this report are field designations because no petrological data are available at this time.

ROCK UNIT DESCRIPTIONS

MAFIC GNEISS

Mafic gneiss generally forms small layers between 2 and 3 m across, within the quartzofeldspathic gneiss; larger units are located on the northern tip of Nukasusutok Island (Figure 1), on the small islands to the east of Nukasusutok Island and on an island off the southern coast of Nukasusutok Island. The mafic gneiss forms 0.5 percent of the area mapped. It weathers to grey black, in places with a greenish hue, and contains lighter migmatitic bands of granite and later discordant granitic pegmatites (Figure 2).

Its relationship with the surrounding quartzofeldspathic gneiss is complex. The boundaries are generally straight and parallel but in places there is a discordant contact between the layering in the mafic and felsic rock. The margin at some localities is diffuse, with eye structures and boudinaged banding close to the boundary with the quartzofeldspathic gneiss (Plate 1). At some discordant margins, apophyses of the quartzofeldspathic gneiss have invaded the mafic gneiss suggesting that the mafic gneiss is the oldest rock unit in the area. Quartzofeldspathic gneiss locally occurs as lenses within the mafic gneiss.

QUARTZOFELDSPATHIC GNEISS

Quartzofeldspathic gneiss covers 50 percent of the map area and is the dominant rock type on the northeast peninsula of Nukasusutok Island, the small islands to the east of

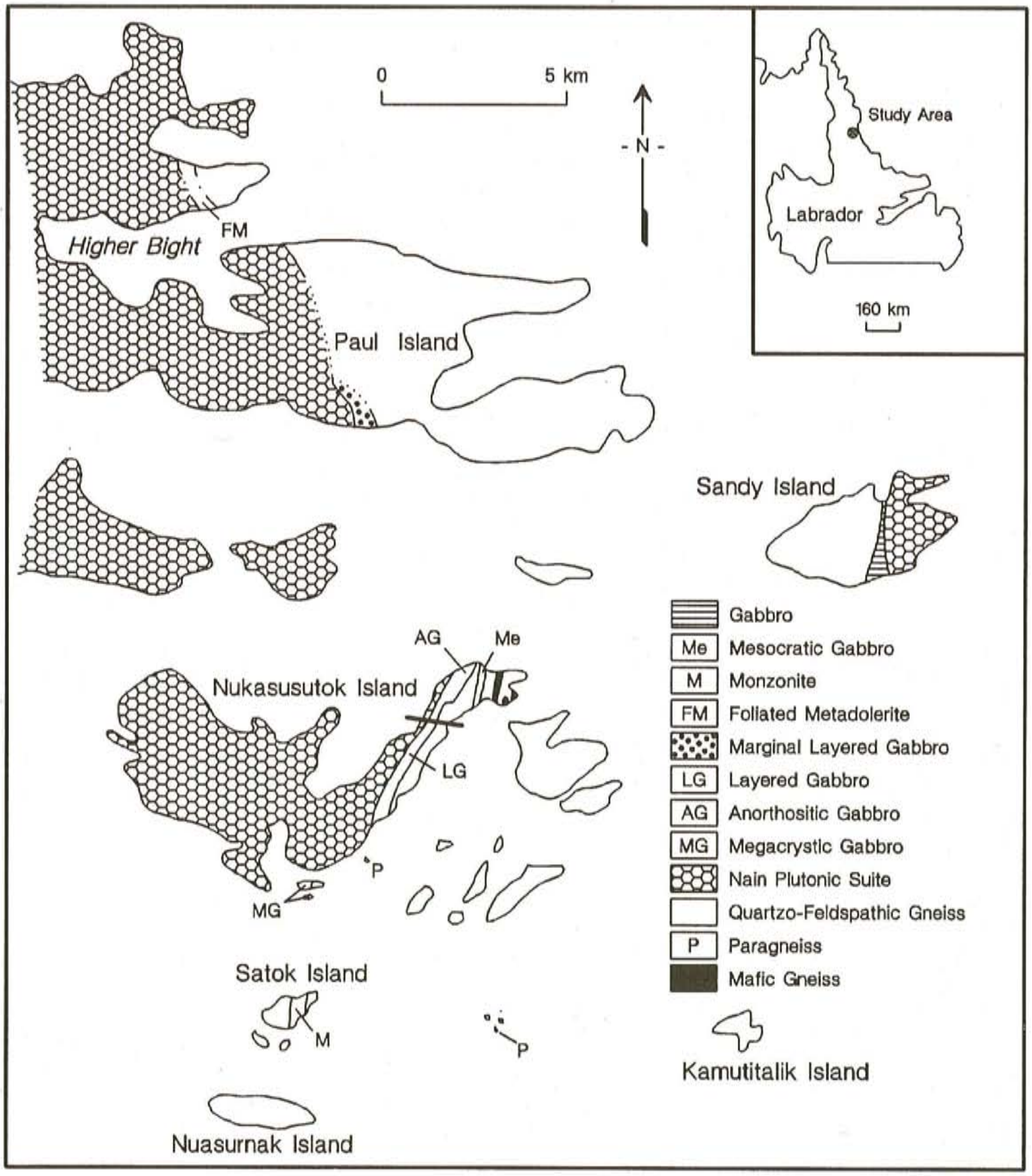

Figure 1. *Geological map of the area around Nukasusutok, Paul and Sandy islands.*

Nukasusutok Island, the west side of Sandy Island and the east side of Paul Island.

The gneisses vary in composition from tonalitic to granodioritic, and in form, from well-layered to augen gneisses. Several generations of mafic dykes and granitic pegmatitic sheets crosscut the quartzofeldspathic gneiss. There are, however, few mafic dykes on Sandy Island and the most eastern of the small islands near Nukasusutok Island.

The gneiss weathers to pinkish white, but yellow and grey varieties also exist. It consists of feldspar (40 to 60 percent), quartz (10 to 20 percent) and minor amounts of pyroxene (probably orthopyroxene) indicating granulite-facies metamorphism. The foliation generally trends northeast–southwest, although distal from the Nain plutons, the trend of the gneissic foliation changes (see below).

There are numerous shear zones within the gneiss; e.g., small shear zones can be seen along pegmatitic sheets. Shear zones trending north-northeast–south-southwest are sites where retrogression has occurred. The presence of a red colouration caused by dusty hematite, the green alteration typical of epidote, and the presence of biotite indicate that

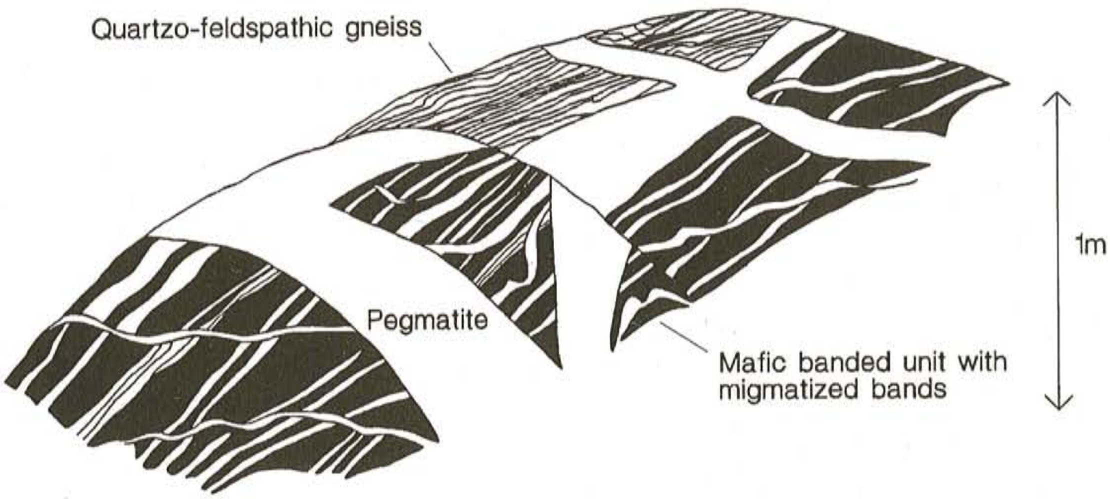

Figure 2. *Field sketch illustrating the field character of some of the mafic gneisses in the area.*

Plate 1. *Eye-folds and migmatization along the margin between a mafic gneiss and the quartzofeldspathic granulites; south side of Mt. Pickle Harbour, Nukasusutok Island.*

retrogression occurred at greenschist facies. There are numerous small folds and a few interference structures suggesting more than one period of deformation.

The gneiss contains a few green-coloured ultramafic pods consisting of 80 to 90 percent pyroxene. There are also bands of mafic gneiss some of which are 200 to 300 m across.

The nature of the contact between the quartzofeldspathic gneisses and the anorthosite plutons varies. In places, it is a sharp undulating intrusive one; at other contacts, there is evidence of some remobilization of the country-rock, especially on Paul Island, where mingling between the anorthosite and rheomorphic granite seems to have occurred.

PARAGNEISS

Discrete belts of paragneiss occur on a small island 750 m east of Nukasusutok Island and on an island 5.5 km east of Satok Island. Paragneiss is also found as small lenses within the other gneisses elsewhere in the area. It is well banded, with rusty-weathering, distinct from the pinkish-weathering of the quartzofeldspathic gneiss. It forms less than 0.25 percent of the study area.

Boundaries between the paragneiss and quartzofeldspathic gneiss are not easily distinguishable and no sharp contacts were found. Contacts between paragneiss and mafic gneiss are generally sharp. The most abundant paragneiss consists of quartz (60 to 70 percent), feldspar (35 percent) and mafic rocks (5 percent), and is therefore probably predominantly derived from an arkosic quartzite. Metasedimentary gneiss found on a small cluster of three islands in the far southeast of the area, contains corundum and biotite, indicating that these rocks are more aluminous.

THE NAIN PLUTONIC SUITE

The NPS consists of anorthosite, anorthositic gabbro, gabbro–anorthosite and leucocratic gabbro. These rocks are typically coarse to medium grained and make up 30 percent of the map area. They weather to grey-white and typically form blocky exposures.

Rocks of the NPS occur on Nukasusutok, Paul and Sandy islands. Pyroxenes are locally found as clusters within the anorthosites. They are unevenly distributed and are regularly found as coarse-grained pod-like xenocrysts containing minor amounts of plagioclase; Wiebe (1990) and others term these pyroxenes 'megacrysts'. These pods have diffuse boundaries and are predominantly found toward the margins of the plutonic bodies.

The anorthositic rocks on Nukasusutok Island have a cumulate texture and vary from 90 percent plagioclase in the anorthosite, to about 20 to 30 percent pyroxene and 70 to 80 percent plagioclase in the anorthositic gabbros. The anorthosite is generally medium to fine grained, and contains east–west fractures, unroofing joints, and a northeast–southwest-striking foliation. A few dykes having compositions similar to the anorthositic gabbros crosscut the intrusion. One gabbro anorthosite + anorthositic gabbro composite dyke was seen on Nukasusutok; it is folded and has an axial-planar foliation trending northeast–southwest.

A steep mineral lineation is developed in anorthositic rocks toward the margin with the country-rock on the eastern side of Nukasusutok Island. The composition of the igneous rocks here is variable, and diffuse boundaries occur between the different rock types. There are pyroxenite bands (80 percent pyroxene) generally greater than 1 m wide. There are areas of fine-grained leucocratic material that show a strong mineral alignment, and there are also very coarse zones with megacrysts 2.5 to 4 cm across. Cognate xenoliths close to the margin probably result from slumping of material from the walls and roof of the intrusion. The nature of the contact with a layered gabbro (Figure 1) on the east side of Nukasusutok Island is difficult to interpret, although locally an intrusive contact against medium-grained anorthosite indicates the latter is older. The contact is undulating, the layered gabbro becoming fine grained and having a steeper dip against the anorthosite.

On Sandy Island, the NPS pluton is a coarse-grained, grey-weathering anorthositic gabbro containing 70 to 80 percent plagioclase. The plagioclase here is markedly iridescent. There are also many black plagioclase xenocrysts. Within the anorthosite, there are diffuse patches of coarser or finer grained anorthosite that are probably cognate xenoliths. The intercumulus pyroxene content of these xenoliths can be variable.

Eastern Paul Island is underlain in part by a medium- to fine-grained norite containing 60 percent plagioclase and 40 percent pyroxene. Locally, it contains coarse-grained mafic pods having 60 to 70 percent pyroxene. This intrusion is crosscut by dykes containing plagioclase (60 to 70 percent), clinopyroxene (30 to 40 percent) and orthopyroxene (1 to 2 percent). These dykes contain xenoliths of quartzofeldspathic gneiss, paragneiss (quartzite) and anorthositic gabbro; some of the anorthositic-gabbro inclusions are deformed (Figure 3). The anorthosite suite must have been solid before the intrusion of these late dykes, which presumably relate to late-stage magmatism within the pluton.

Toward its margin with a foliated dolerite (see below) the leuconorite pluton on eastern Paul Island becomes foliated (Plate 2). On the southern side of the island (Figure 1), a marginal layered gabbro (see below) becomes finer grained and strained toward its margin, where large xenolithic pods contain mafic minerals (mostly pyroxenes). The contact between the anorthositic rocks and the gneisses to the southeast of the dolerite is diffuse, a result of mixing between the intrusion and melts from the country-rock. Migmatization within the country-rocks in the vicinity of the anorthositic pluton may be related to the intrusion.

THE GABBROS MARGINAL TO THE NAIN PLUTONIC SUITE

The gabbros occur at the boundary between the anorthositic rocks of the NPS and the host gneiss; they are interpreted to have intruded along that interface after anorthosite emplacement. The gabbros vary from massive to foliated and are, in many cases, banded. Based on their field appearance, the mineralogy of these gabbros is likely to be variable, and they probably include rocks of more than one origin.

The Megacrystic Gabbro[1]

The megacrystic gabbro [referred to by Davies (1973) as a pyroxene monzonite] outcrops on two islands 100 m from the southern shore of Nukasusutok Island. The boundary between the gneisses and gabbro is sharp in some places but in others it is diffuse. Close to the margin, the gabbro contains many xenoliths; some are cognate and others are exotic. The gabbro weathers to a milky orange, and contains megacrysts of feldspar orientated northwest–southeast, and parallel to the trend of the contact. It is otherwise a homogeneous rock having a blocky, interlocking assemblage of 60 percent feldspar, a brown mineral [possibly pyroxene (35 percent)] and a small, black metallic mineral (1 to 2 percent).

The megacrystic character of the southern part of the gabbro may indicate that it had a two-stage cooling history or that the crystals were accidentally incorporated into the magma from a foreign source.

The Anorthositic Gabbro

This unit is found on the northwest side of the northeast peninsula of Nukasusutok Island; it is exposed for approximately 500 m along the boundary between the anorthosite and the quartzofeldspathic gneiss.

[1] Gabbro is used here purely as a field term. However, the authors note that other students of anorthosites have referred to these rocks as diorites based on the plagioclase composition.

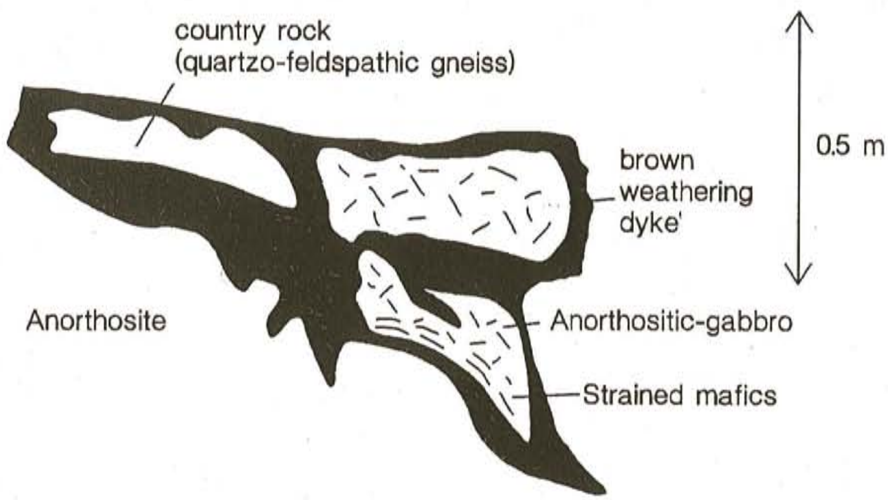

Figure 3. *Field sketch illustrating the variety of xenoliths within dykes that crosscut the anorthosites on Paul Island.*

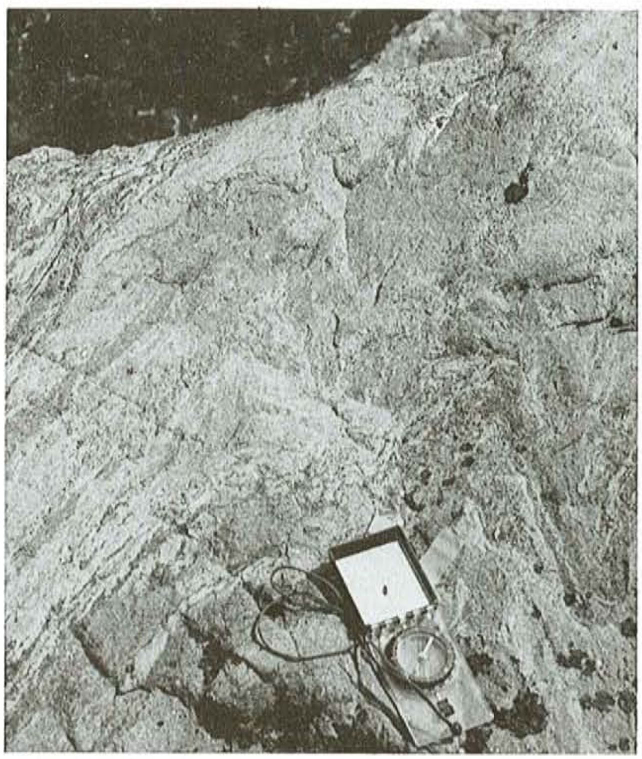

Plate 2. *Foliated leuconorite; north shore of Higher Bight, Paul Island.*

It is a fine-grained leucogabbro that weathers a greenish colour near the coast but is more iron-stained inland. Its margin with the anorthosite proper is gradational and diffuse. However, its margins with the country-rock are sharp and undulating. In some areas, considerable remobilization has occurred and granitic migmatite is associated with the layered gabbro. The gabbro itself is foliated distal from the anorthosite and contains lenses and rafts of anorthosite and gneiss. Pegmatitic granitic sheets crosscut the gabbro, but no mafic dykes were found.

The Layered Gabbro

This unit forms about 3 percent of the map area and is exposed along the eastern side of Nukasusutok Island (Figure 1) and on a small island just to the east. The unit can be traced northeastward across Nukasusutok Island until it is truncated by an east–west fault. It was previously mapped as two separate units by Davies (1973).

The gabbro is layered and massive, weathering to an orange-brown. Leucocratic to mesocratic phases contain plagioclase (30 to 40 percent), pyroxene (20 percent) and a brown-orange mineral (possibly olivine). The darker orange-stained units are sulphide-bearing, containing black amphibole and a gold coloured mica (phlogopite). Most of the unit has a well-developed foliation; some coarse-grained gabbros have large augen of pyroxene.

Near the contact with the anorthositic pluton the gabbro becomes finer grained. The dip of the foliation decreases as the strain decreases until a more granular texture develops (Figure 4). The boundary undulates suggesting that some plastic deformation may have occurred in the anorthosite or the gabbro. Toward the east–west fault mentioned above, the gabbro appears to becomes less strained and layering is not as distinct.

Recrystallized mafic dykes locally crosscut the gabbro. They have a strong lineation indicating that emplacement occurred before deformation (Plate 3). The dykes are discordant to the primary igneous layering, and both are subsequently overprinted by the same penetrative foliation.

Foliated Metadolerite

This metadolerite outcrops on the northern part of Paul Island. Both Wiebe (1981) and Ryan (1991) considered this unit to be a mafic granulite belonging to the country-rock assemblage. It is 200 m wide and can be found at the

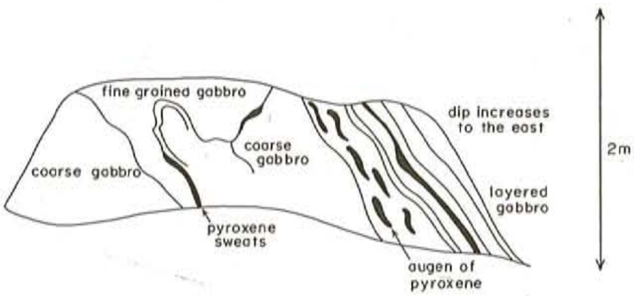

Figure 4. *Photo and labeled sketch of the contact between the layered gabbro and the anorthosites on Nukasusutok Island.*

Plate 3. *Mafic dyke slightly oblique to original layering within the layered gabbro unit; both the gabbro and the dyke carry the same fabric.*

boundary between anorthosite and the quartzofeldspathic gneiss. The dolerite is fine grained, weathers to an orange-brown, and contains pyroxene (30 percent), plagioclase (40 percent), and megacrysts of hornblende, and is locally characterized by pyroxene sweats. The dolerite is well foliated, showing the greatest amount of strain in the centre, in a zone parallel to the margin. A faint, strain-induced, compositional banding is parallel to the foliation.

The contact with the gneiss to the east is sharp, and apophyses of the dolerite intrude the gneiss. The boundary with the anorthosite is diffuse, the anorthosite becoming strained toward the margin. This implies that the intrusion of the dolerite took place penecontemporaneously or shortly after that of the anorthosite. The foliations within the two bodies are parallel and their mutual contact is diffuse, suggesting that deformation must have taken place simultaneously in both.

The Marginal Layered Gabbro

This north-trending, 600-m-wide unit is located between the gneiss and the anorthosite on the southern coast of Paul Island. Textural and compositional variations suggest that it is not a southward extension of the dolerite described above.

Contacts between the layered gabbro and adjacent rocks are not well-established because exposure is poor in this area. The gabbro varies from leucocratic to melanocratic. It contains pyroxenite bands and is locally mica-rich; the grain size is also variable. There is a slight elongation of the minerals in a north–south orientation. Proximal to the gneisses to the east it is less banded and more homogeneous.

Gabbro

This gabbro is a poorly exposed, 200-m-wide, fine- to medium-grained, non-foliated intrusion along the boundary between the anorthosite pluton and the country-rock gneiss through central Sandy Island. It consists of plagioclase (50 percent) and two mafic minerals–black hornblende (15 percent) and a green pyroxene (35 percent). On a fresh surface, the gabbro can appear green but its weathered surface is orange-brown.

The contact with the anorthosite pluton is exposed on the northeastern side of the island where it is sharp, undulating and clearly discordant. The gabbro is finer grained toward the margin, implying intrusion and chilling after the emplacement of the anorthosite. The sinuous boundary suggests that some plastic deformation has taken place, and that the anorthosite must have been capable of ductile behavior at the time the gabbro was emplaced. Granitic pegmatitic sheets and aplite veins crosscut both units.

The contact with the gneiss to the west is less well-exposed. Layering in the gneiss is diffuse toward the contact; this is likely to be caused by the intrusion, but may possibly be an original feature. The gneiss–gabbro interface is sharp but undulating, and the gabbro contains lenses of the gneiss.

INTRUSIONS OF UNCERTAIN AFFINITY

A number of igneous bodies were mapped, whose age in relation to the anorthositic rocks is unknown, because no relevant field relationships were observed.

Mesocratic Gabbro

This brown-orange-weathering gabbro body covers 0.1 percent of the area mapped. It underlies Mount Pickle at the northern end of the northeastern coastline of Nukasusutok Island.

This sheet-like gabbro has strongly discordant margins, and undulates across Mount Pickle harbour. Ophitic texture is well displayed, but in some outcrops it has a granular appearance. It contains pyroxene (30 to 40 percent), plagioclase (30 to 40 percent) and minor amounts of olivine (2 to 5 percent).

The gabbro is not layered, but at some locations a faint foliation is developed oblique to the margins. Close to its margins with the enclosing gneiss it contains lenses of the country-rock.

The Monzonite

Monzonite underlies the eastern part of Satok Island 3 km south of Nukasusutok Island (Ryan, 1991a, 1992); it forms less than 0.1 percent of the area mapped. It weathers a light orange-brown and consists predominantly of feldspar (60 to 70 percent), clinopyroxene and olivine (30 to 40 percent total mafics) with minor amounts of quartz (1 to 5 percent). The mafic content is less near the margins than in the interior part of the pluton. The monzonite contains a very faint foliation but is otherwise undeformed.

The body crosscuts the quartzofeldspathic gneiss and also cuts a north–south-trending shear zone on the south side of the island. The contact on the eastern side is difficult to establish as the gneiss loses its banding toward the contact, becoming more granitic in character; in places there is a dyke between the two units. The northern contact between the country-rock and the monzonite is marked by a megacrystic basic dyke, which shows a strong foliation parallel to its margins. The gneiss to the west of the dyke is granitic and lacks distinct layering.

The western contact between the gneiss and the monzonite through the central and southern part of the island is marked by a basic dyke, 3 to 5 m across, consisting of 30 percent plagioclase and 70 percent mafic minerals. This dyke dips away from the monzonite and is strongly foliated oblique to its margins.

DYKES

The gneisses of the Nain region are host to a complex assemblage of mafic dykes. Although mentioned in early reports of the Nain Anorthosite Project (e.g., Upton, 1974), their importance in the regional history of the area was not emphasized until recent remapping of the Nain area (Ryan, 1990, 1991a,b, Cadman *et al.*, 1993). The dykes exhibit diversity in metamorphic grade, mineral content and trend. Although crosscutting relationships are common, there is no readily apparent consistency between relative dyke chronology and trend. Hence, at present, the dyke assemblage cannot be confidently subdivided into distinct swarms on the basis of field criteria. Nevertheless, a number of apparently distinct types can be recognized.

1. Mafic Banded Dykes. These are the earliest dykes in the area. Their high competency has resulted in many of them being boudinaged and migmatized during regional deformation (Plate 4). The best-preserved dykes have apophyses, which intrude into the adjacent gneiss, and they have sharp, slightly discordant, margins. These latter features distinguish them from the mafic gneisses of presumed supracrustal origin.

2. Biotite-Bearing Dykes. These are found in great profusion on the small island to the east of Mount Pickle. Their margins are straight and slightly discordant with the country-rock. They are regionally parallel to layering in a 'straight belt' in the gneisses on the west coast of the island. In other places,

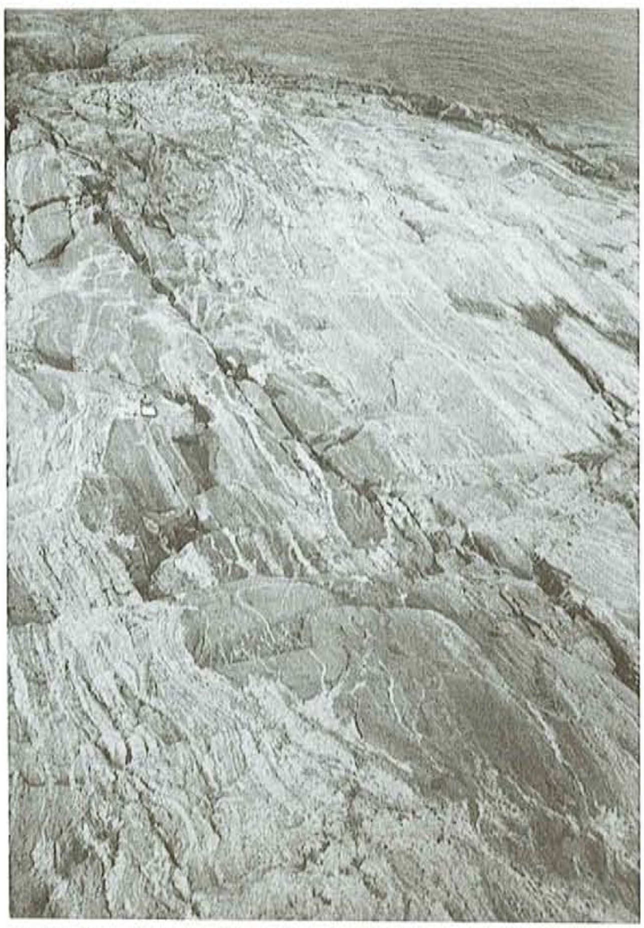

Plate 4. *Mafic layer in the gneisses on Satok Island, interpreted to be derived from an early mafic dyke.*

they crosscut shear zones in the gneisses, but at some locations shear has taken place along the dykes. Some of the biotite-bearing dykes have been contaminated by back-veining of melts from the country-rocks; diffuse nodules of partially assimilated country-rock are found within some of the dykes, up to 20 cm from the dyke margins. Many of the dykes contain lobe-and-cusp features, which point into the country-rock, implying that the dyke has a higher viscosity than its host. Because no axial-planar fabrics were found in the cusps, these are interpreted as primary features (Ryan, 1990) suggesting that emplacement was at greenschist to amphibolite facies.

The biotite-bearing dykes locally show evidence of dilational emplacement and often contain xenoliths of the host (Plate 5).

Plate 5. *Mafic dyke intruded into quartzofeldspathic granulite, demonstrating dilational emplacement under brittle conditions.*

3. Fine-Grained Black Dykes. These dykes are found throughout the region, and because they are fine grained, their mineralogy could not be accurately determined in the field. They are in places folded.

4. Two-Pyroxene–Hornblende Dykes. These dykes are medium- to fine-grained rocks that contain felsic and pyroxene segregations. At several locations, lobe-and-cusp features seen on the margins of the dykes show that the dykes were more competent than their surroundings; however, in other places, they show the reverse relationship. The margins of some dykes are characterized by rheomorphism of the adjacent gneiss. The dykes have undergone boudinage within most large shear zones, but they show syn-shear emplacement features within some minor shear zones. They contain a foliation that is oblique to their margins. A few of these dykes are folded, and have a well-developed axial-planar foliation.

5. Lamprophyres. These dykes weather black and are biotite bearing. They are found only on Nuasurnak and Satok islands. On Nuasurnak Island, some are emplaced along a northeast–southwest shear (Figure 5). On Satok Island, they are also associated with a shear zone, but the relationship between shearing and dyke emplacement has not been established.

6. Intraplutonic Dykes. Several intraplutonic mafic dykes were observed within the NPS, one on Nukasusutok Island and a few on Paul Island. On Nukasusutok Island, the dyke is a composite intrusion of anorthositic gabbro and gabbroic anorthosite, having an undulating margin against its host. The dyke is folded, and displays an axial-planar foliation trending north-northeast–south-southwest. The dykes on Paul Island are medium grained and have a granular texture. They contain many xenoliths, some related to the anorthositic host and others similar in composition to the quartzofeldspathic gneisses to the east (Plate 6). The anorthositic xenoliths display elongate mafic minerals on their edges close to the margin of the dyke, suggesting that deformation of the xenoliths occurred during dyke emplacement.

7. Other Dykes. On Kamutiktalik Island, there is a north-northeast-trending brownish-orange dyke containing megacrysts of black plagioclase. The distribution of the megacrysts suggests deposition by crystal segregation. Also, on Kamutiktalik Island are numerous grey-weathering dykes, which are emplaced in an *en-echelon* manner. These latter dykes contain a foliation, which is locally folded.

8. Granitic Pegmatitic Dykes. These intrusions crosscut all the mafic dykes in the area, except the late east–west-trending set. Many pegmatites appear to be related to minor shear zones and were probably emplaced both before and penecontemporaneously with shear-zone deformation. Others are fracture-filling bodies related to granites of the NPS.

9. Brownish-Orange-Weathering Unmetamorphosed Dykes. These have a well-developed ophitic texture and straight chilled margins implying brittle emplacement into cool crust. They have an east–west trend, unlike the previous dykes, and they do not contain xenoliths. These dykes crosscut all previous dyke types.

10. Dyke Chronology. Several localities in the Nukasusutok area can be used to establish the relative chronology between

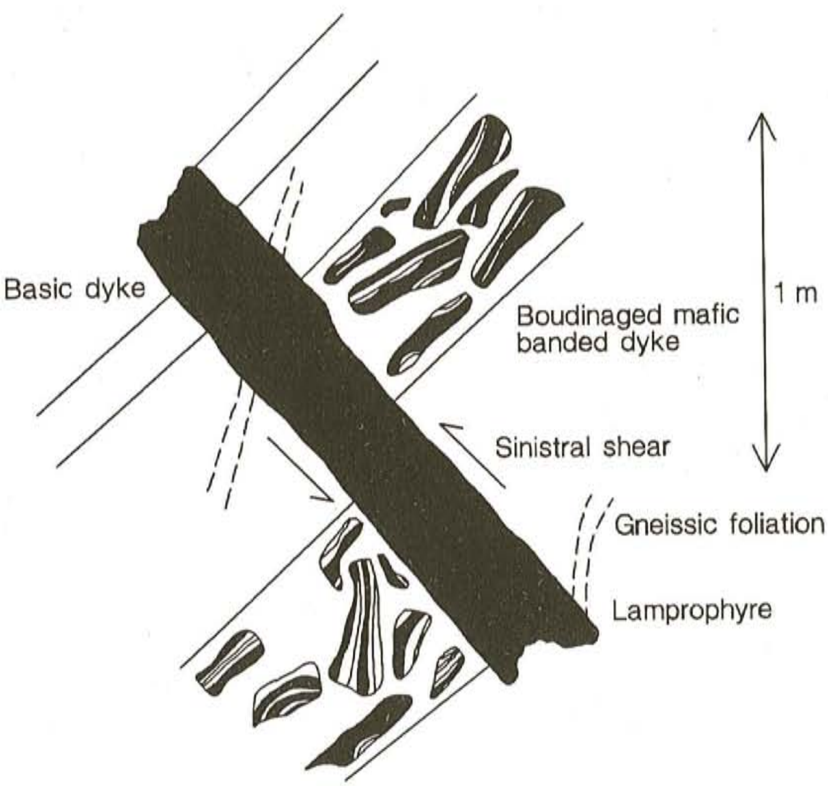

Figure 5. *Sketch illustrating a lamprophyre dyke interpreted to have been emplaced coevally with the formation of the shear it occupies; Nuasurnak Island.*

Plate 6. *Deformed and brecciated xenoliths in a dyke crosscutting anorthosite on Paul Island.*

different dyke types, and regional metamorphic and deformational events. One such locality is on a small island east of Nukasusutok Island. At least three dyke types are present here, two of which are affected by shear-zone deformation. A 5.5-m-wide two-pyroxene + hornblende-bearing 060°-trending dyke, is reorientated into parallelism with the layering in a north–south-trending shear zone. The dyke contains a foliation parallel to the shear-zone margin and therefore is pre- or syn-deformation.

The two-pyroxene + hornblende-bearing dyke described above is crosscut by thin (0.3–0.7 m wide) black dykes, which show well-developed cusp-and-lobe structures on their margins. Similar black dykes are folded around northeast–southwest-trending axes on the north coast of an adjacent island to the south. The black dykes show evidence of anticlockwise reorientation and attenuation when crosscutting the shear-parallel intrusion. The folding of the black dykes suggests that these dykes may have been intruded in the stress regime associated with a later stage of the shear deformation. The fact that these dykes have not been completely reorientated in the shear zone would seem to argue that they were intruded in waning stages of this deformation episode. A late, unmetamorphosed, east–west-trending diabase dyke crosscuts a two-pyroxene + hornblende-bearing dyke on another nearby island. This late dyke is likely to be related to the mid-Proterozoic Nain LP or HP dykes (e.g., Wiebe, 1985), and provides a minimum age of the deformed dyke assemblage.

The association between dyke injection and north–south-trending sinistral shear deformation is also apparent on the south coast of an island east of Mount Pickle Harbour. Anastomosing, biotite-bearing dykes are intruded sub-parallel to the Archean foliation. A shear-parallel segment of the dyke contains a foliation in the appropriate orientation for sinistral shear. Hence, the field relationships at this locality suggest that the dyke was intruded synchronously with shear deformation. A few metres to the west, several more north–south-trending biotite-bearing dykes are present. One of these dykes contains white plagioclase phenocrysts, whereas another shows clear evidence of country-rock assimilation–the only intrusion observed to do so in the field.

A further example of dykes affected by shear deformation occurs on Satok Island, south of Nukasusutok Island. Here, several lamprophyre dykes crosscut the east–west-trending Archean foliation but are reorientated anticlockwise and attenuated in a major 006° shear zone, giving a sinistral movement sense for the shear zone. In common with many other dykes in the Nukasusutok area, these dykes are biotite-bearing in the shear zone.

In summary, the localities noted above show that intrusion of most of the dyke types observed in the Nukasusutok area appear to predate or be synchronous with north–south sinistral shear deformation. On balance, the lamprophyre dykes and the two-pyroxene + hornblende dykes would appear to predate shear deformation. However, it must be restated that the evidence from individual localities cannot be extrapolated to a regional framework at present. It is possible that petrologically similar dykes could be intruded at different times during the evolution of the Nain region, or that more than one episode of shear deformation has occurred.

The relationship between shear deformation and biotite growth in dykes is worth further consideration. Although the biotite is possibly associated with low-grade retrogression, there is also evidence that the growth of hydrous minerals occurred during static recrystallization of some Nain dykes after intrusion (see Cadman and Ryan, *this volume*). It is hoped that future geochemical and geochronological studies will help to further constrain the relationship between dyke emplacement and the structural evolution of the Nain area.

STRUCTURAL GEOLOGY

GNEISS

The gneissic foliation (S_0) is folded by isoclinal intrafolial F_1 folds. The gneissic foliation, therefore, contains a composite S_0-S_1 fabric. Adjacent to the NPS intrusions, the F_1 folds are refolded by F_2 folds accompanied by a faint S_2 foliation. Hook-shaped interference structures imply that the F_2 folds are steeper than the F_1 folds; several dome-and-basin type interference patterns have been observed in areas of multiple folding. However, interference structures are rare in the area as a whole. Many of the F_2 folds have well-formed parasitic s-, z-, and m-folds, as well as boudinaged limbs. F_2 folds may be related to the emplacement of the NPS as their axial trends are parallel to the margins of the plutons and they appear to die out distal from the NPS (Figure 6).

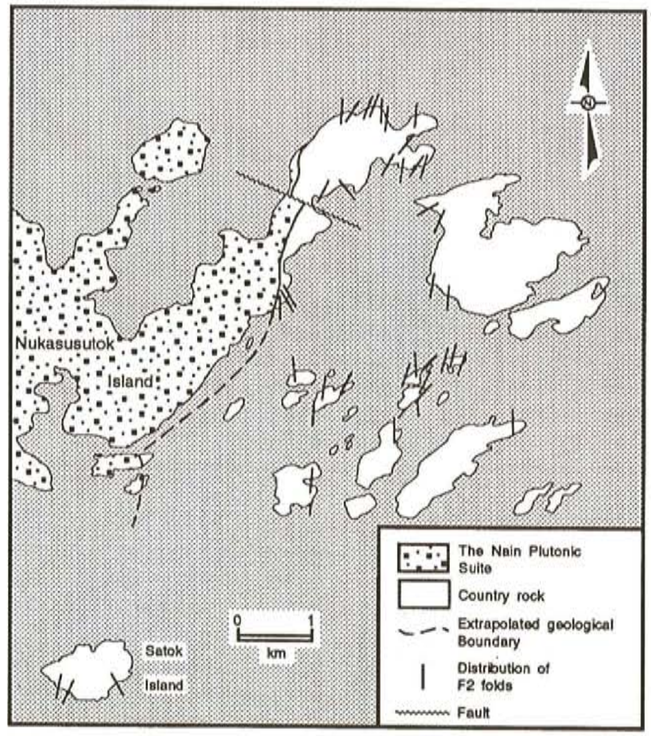

Figure 6. *Sketch map showing the distribution of F_2 folds in the Nukasusutok Island area.*

The general trend of the gneissic foliation in the area is northeast–southwest. However, the foliation close to the NPS on Nukasusutok Island has a north-northeast trend; 3 km away, the trend becomes northeast–southwest (Figure 7). On Satok Island and on Nuasurnak Island, the gneissic foliation is orientated west-northwest–east-southeast except where rotated within small shear zones. On Sandy Island, the gneissic foliation near the pluton trends north-northeast–south-southwest; 600 m away from the intrusion this changes to northeast–southwest. On Paul Island, where the margin of the pluton has a slightly different angle, the foliation reflects this. Therefore, superficially at least, the plutonic rocks in this area appear to control the trend of the gneissic foliation.

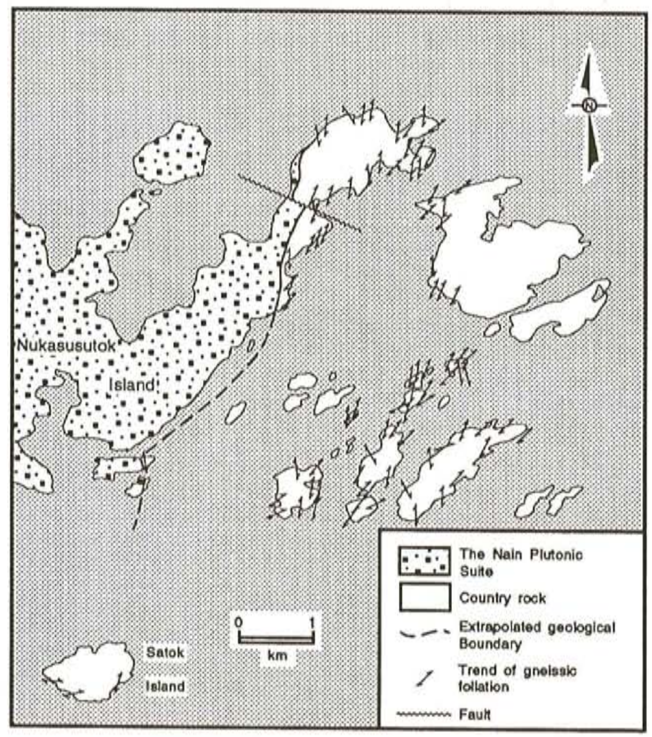

Figure 7. *Sketch map showing the trend of the gneissic foliation in the Nukasusutok Island area.*

SHEAR ZONES

There are 5 north-northeast–south-southwest-trending ductile shear zones. At outcrop scale these all show apparent sinistral displacement. However, using the techniques described by Wheeler (1987) for the determination of true shear sense, the shear zones were found to be dextral normal on Satok Island and on the island east of Mount Pickle Harbour, but sinistral reverse on the small islands to the east of Nukasusutok Island. Retrogression to greenschist facies can be seen within the centre and on the western margin of several shear zones.

Some of the mafic dykes within the shear zones have been retrogressed to amphibolite and greenschist facies. Many are rotated into parallelism with the shear zones. The dykes were intruded before, during, and after shear, giving good evidence of either several periods of dyke emplacement or repeated movement along the shear zones.

Although the quartzofeldspathic gneiss in this area is generally at granulite or amphibolite facies, there are a number of shear zones in which the higher grade assemblage is overprinted by a greenschist-facies assemblage as indicated by the presence of hematite, biotite and epidote. This indicates that there has been two stages of movement along the shear zones (see also Ryan, 1992). The later movement must postdate peak metamorphic conditions and therefore the movement along the shear zones must have continued after the emplacement of the plutons.

DEFORMATION AND METAMORPHISM ASSOCIATED WITH THE NAIN PLUTONIC SUITE IN THE AREA

It is important to determine the degree of deformation within the country-rock that can be attributed to the Nain plutons in order to constrain an emplacement model. The reorientation of the gneisses referred to above is likely to be progressive. Therefore, it is probable that all the gneissic foliation within the area has been re-orientated to varying degrees.

The dykes close to the margins of the largest plutonic masses have been affected more by metamorphism than those further from the plutons' margins. The metamorphism of the dykes may, thus, in part, be related to pluton emplacement.

The gneisses are locally migmatized close to the plutons, especially on the east side of Paul Island. Along the margin of the pluton, back-veining has taken place, indicating that the pluton remobilized the country-rock during its emplacement. The gneissic foliation close to the margins of the anorthosite is parallel to the trace of the margin. In this area the margin of the pluton is, in places, occupied by gabbros; these are typically banded and foliated parallel to the margin. K values for strain within the gabbros approach 0 and therefore oblate strain is dominant. Oblate strain is a characteristic feature of the edges of plutons that have undergone either ballooning or diapiric emplacement (England, 1990).

The Paul Island anorthosite is locally foliated toward its margins. This foliation could be either the result of diapirism or ballooning of the pluton in the solid state or, alternatively, be due to a later deformational event. However, from the evidence provided by the presence of deformed anorthositic xenoliths in anorthositic gabbro dykes on Paul Island, it is likely that the main pluton was solid before the intrusion of the dykes; the latter are likely to have been intruded shortly after the final solidification of the Paul Island pluton. This evidence, together with the foliation development at the edge of the pluton, indicates that the marginal deformation was likely related to emplacement rather than to a later event.

Evidence for the emplacement mechanism of the NPS plutons is inconclusive. The relatively low intensity of deformation seen in the country-rocks could be used as evidence against a forceful emplacement model. However, at the depth required for granulite-facies metamorphism, temperatures would be between 750-800°. At this temperature, the viscosity contrast between the surrounding rocks and the pluton would be low and both would be ductile, which, according to Ramberg (1963), considerably affects the expression of deformation.

Some of the deformation of the NPS is certainly post-emplacement and post-crystallization in age. This is supported by (i) the presence of folds within a dyke crosscutting a pluton on Nukasusutok Island where an axial-planar foliation has developed in a north-northeast—south-southwest orientation and (ii) by the formation of a foliation elsewhere within the plutons implying that they must have been solid at the time of deformation.

FURTHER WORK

Further work will include:

1) A detailed study of the metamorphic history of the area in order to determine the relationship between the metamorphic events and the emplacement of the NPS.

2) Modelling of liquid, solid, passive and diapiric modes of emplacement for the NPS, to determine the likely structures that would develop in each case.

3) Geochemical analysis to determine the petrogenesis of the Nain anorthosites and related rocks.

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REFERENCES

Bridgwater, D., Mengel, F., Schiøtte, L. and Winter, J.
1990: Research on the Archean rocks of northern Labrador, progress report, 1989. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 90-1, pages 227-236.

Cadman, A.C., Harris, D. and Ryan, B.
1993: An investigation of some metamorphosed mafic dykes of the Nain area, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 93-1, pages 1-15.

Cadman, A.C. and Ryan, B.
This volume: An investigation of some metamorphosed dykes of the Nain area, Labrador: Part 2—Geochemistry of the Akkuneq dykes of the Dog Island region.

Davies, H.M.
1973: Geology of Nukasorsuktokh Island. *In* The Nain Anorthosite Project Labrador: Field Report 1972. *Edited by* S.A. Morse. Contribution Number 13, Geology Department, University of Massachusetts, Amherst, Massachusetts, pages 81-97.

De Waard, D.
1971: Country-rock of the anorthosite massif and anorthosite contacts in the Ford Harbour region. *In* The Nain Anorthosite Project, Field Report 1971. *Edited by* S.A. Morse. Contribution No. 9, Geology Department, University of Massachusetts, Amherst, Massachusetts, pages 15-26.

England, R.W.
1990: The identification of granitic diapirs. Journal of the Geological Society, London, Volume 147, pages 931-933.

Morse, S.A. (Editor)
1971-1983: The Nain Anorthosite Project, Labrador, field reports. Department of Geology, University of Massachusetts, Amherst, Massachusetts, Contributions 9, 11, 13, 17, 26, 29, 38, 40.

1982: A partisan review of Proterozoic anorthosites. American Mineralogist, Volume 67, pages 1087-1100.

Ramberg, H.
1963: Experimental study of gravity tectonics by means of centrifuged models. Bulletin of the Geological Institutions of the University of Uppsala, Volume 62, pages 1-97.

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

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

1991b: Nain—Nutak area: a new 1:500 000-scale colour compilation. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 91-1, pages 229-230.

1992: Nain area geology: observations on selected islands, and the area south of Nain Bay. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 92-1, pages 381-398.

Upton, B.G.J.
1974: Basic dykes in the Nain-Kiglapait region. *In* The Nain Anorthosite Project, Labrador, Field Report, 1973. *Edited by* S.A. Morse. Geology Department, University of Massachusetts, Contribution No. 13, pages 133-143.

Wheeler, J.
1987: The determination of true shear senses from the deflection of passive markers in shear zones. Journal of the Geological Society, London, Volume 144, pages 73-77.

Wiebe, R.A.
1981: Eastern margin of an anorthosite pluton on Paul Island. *In* The Nain Anorthosite Project, Labrador: Field Report 1980. *Edited by* S.A. Morse. Department of Geology, University of Massachusetts, Amherst, Massachusetts, Contribution No. 38, pages 35-40.

1985: Proterozoic basalt dykes in the Nain anorthosite complex, Labrador. Canadian Journal of Earth Sciences, Volume 22, pages 1149-1157.

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