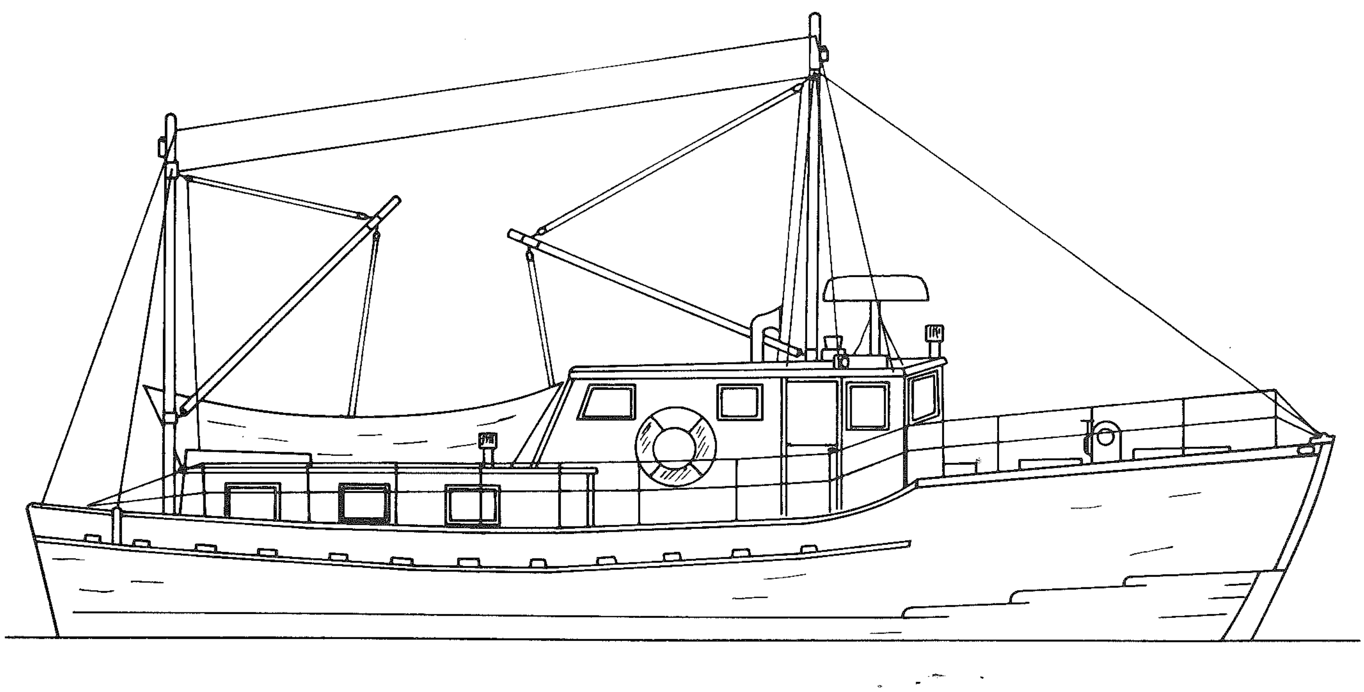
THE NAIN ANORTHOSITE PROJECT, LABRADOR: FIELD REPORT 1981

S. A. MORSE, EDITOR



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THE NAIN ANORTHOSITE PROJECT, LABRADOR: FIELD REPORT 1981

S. A. Morse, Editor

Final Report under NSF Grant EAR-8011385,

"Mantle and Crustal Evolution as Reflected in the Anorthositic Nain Complex, Labrador"

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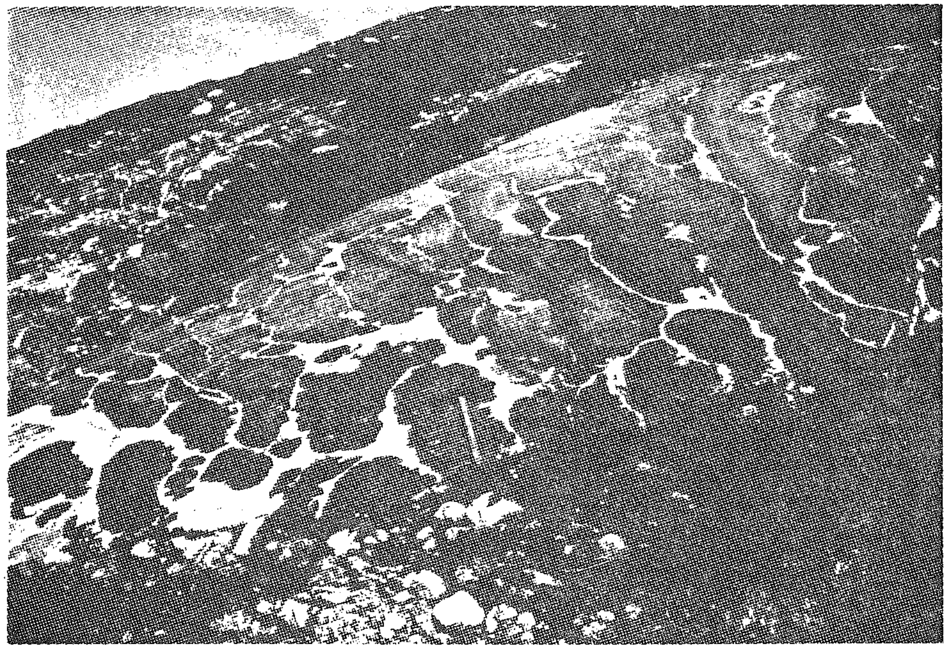

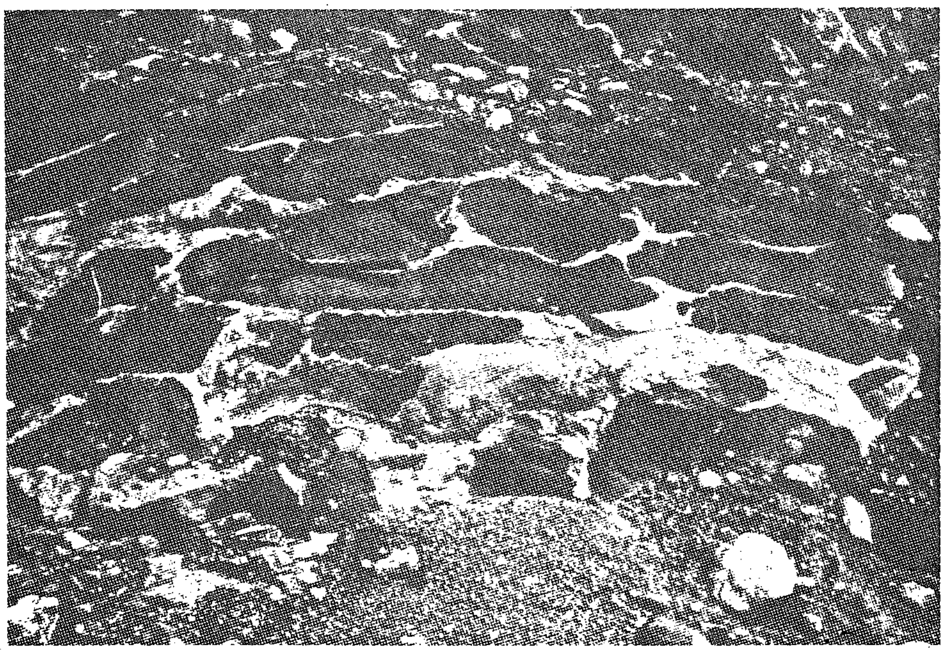

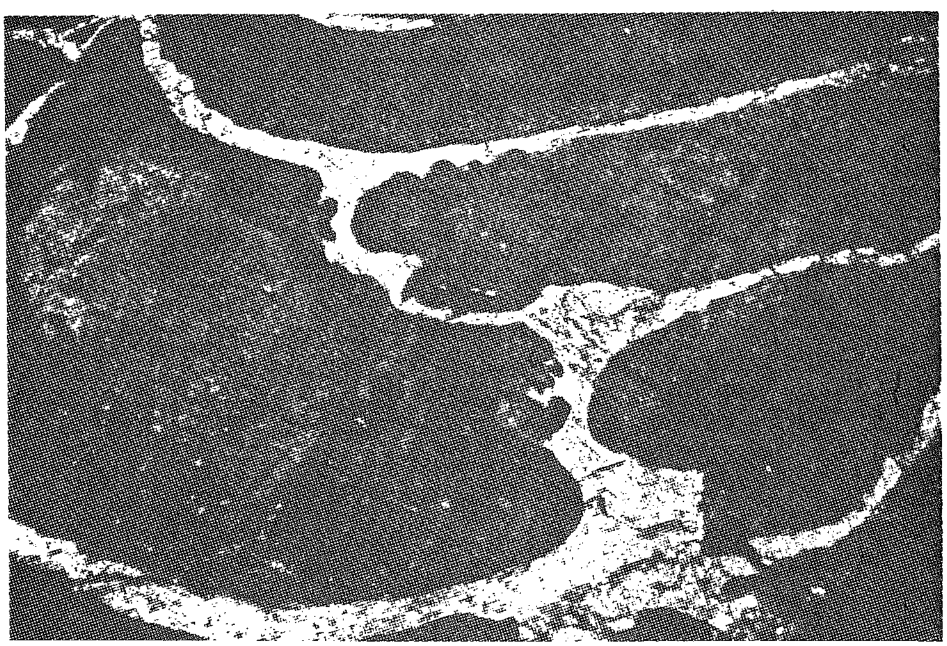

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← Frontispiece. Pillows of chilled troctolite (dark) in granite matrix (light), Newark Island Layered Intrusion. Photos by R. A. Wiebe; see page 65.

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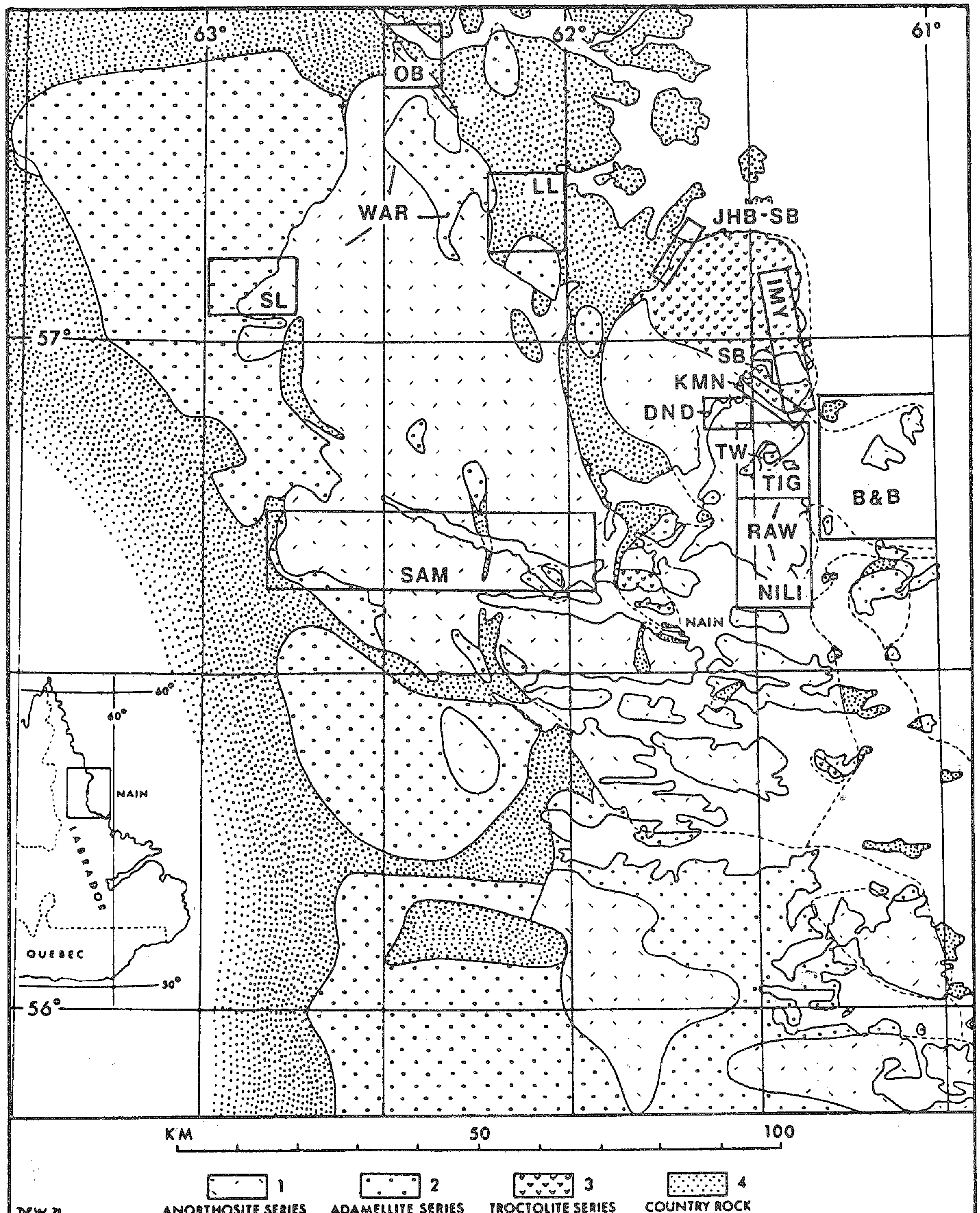

Fig. 1. Regional geology of the Nain area, after Wheeler (1968), showing locations of 1981 field areas. KEY, north to south: OB Ranson (Okhakh Bay); LL Ranson (Laura Lake); JHB-SB Berg (Snyder Bay); SL Ranson (Staghorn Lake); IMY Young (Kiglapait); SB Ball (Partridge Point); KMN Nolan (Basal Lower Zone); DND Dickey (Hettasch); TW Wild (Tigalak); TIG Wiebe (Tigalak); B & B Berg and Briegel (Jonathon); NILI Wiebe (Newark); SAM Morse (Bird Lake).

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INTRODUCTION AND REVIEW

With this Report we bring to a close a decade of field research in the birthplace of one of the oldest outstanding problems of geology. People have been worrying about labradorite and anorthosite since the Moravian missionary Wolfe, about 1770, took home to Europe some labradorite from Paul Island near Nain (de Waard, 1968). Many of us are still worrying about anorthosite, but our concerns are not quite the same as they were in 1971 at the inception of this Project. Then we noted a superabundance of bright ideas not seriously encumbered by hard factual foundations. Now we have facts and insights that help greatly to redefine the whole problem of anorthosites and related rocks, their geologic setting, and their potential for shedding light on the geochemical evolution of the earth. At very least, we have helped to lay to rest some of the more tenacious mythology of anorthosites, such as great depth of emplacement, water-rich magmas, and orogenic setting, and at best we have demonstrated some distinctive magma types, examples of plutonic supercooling and magma dynamics, spectacular examples of coexisting basic and acidic liquids (see Frontispiece), and some tentative ideas about how these specific phenomena arose.

By no means all of the Nain Complex has yet been mapped or even seen, except by E. P. Wheeler, who saw most of it and mapped it at small scale (1968) and large scale (manuscript maps in the Wheeler Collection, University of Massachusetts). But we have at least characterized the plagioclase composition range (FR 1976, p. 41) and the En-An relations (Morse, 1982), and demonstrated the multiplicity of intrusions that make up the Complex. With the addition of four newly established layered intrusions in this Report (Newark, Jonathon, Slambang, and Port Manvers Run) our catalog of layered intrusions (FR 1976, p. 47) now contains 24 entries, and it is to be presumed that these represent only the minimum number of discrete intrusive events. The above examples only begin to characterize the results of a decade of research, many of which are yet to appear, as laboratory studies proceed.

This bare preamble should not close without a salute to those who have done the real work. Pep Wheeler made it all possible by his 48 years' single-handed devotion to what he recognized as a singularly important problem. Then Dirk de Waard joined us to make this Project a reality, and together Pep and Dick coached a whole generation of students in how to see and how to thrive in the field. In later years, Bob Wiebe and Jon Berg joined on as Associate Investigators and brought to bear their own superb talents for seeing and thriving, as well as a new host of lively students. The Project has involved, over the years, 73 students and staff members from 30 institutions. To paraphrase Churchill, I was the one lucky enough to be allowed to give the roar; I would be remiss indeed if I did not, in Brian Skinner's felicitous phrase, give credit to those "who built the cairns on which we stand to see."

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The 1981 season saw concentrated activity on and around South Aulatsivik (Newark) Island, where no fewer than seven layered intrusions occur in close proximity (Hettasch, Kiglapait, Jonathon, Tigalak, Slambang, Port Manvers Run, and Newark). The great variety of internal and contact relations found in these intrusions, including two mutually perpendicular planes of plagioclase lamination in Jonathon, troctolite pillows in a matrix of leucogranite in Newark, and xenoliths in the Kiglapait, form the centerpiece of this Report. As customary, however, we set the stage with a regional overview and a look at the geologic setting, which we have always considered integral to our understanding of anorthosites as a record of crustal evolution.

With trepidation but with hopes of stimulating hard-nosed inquiry, Morse essays an emplacement history of the entire Nain Complex. Three major basic intrusive events (older anorthosite, main anorthosite, and troctolite) are distinguished, and an attempt is made to assign all major units to one or another of these events. Deformation, shearing, and veining by pink granite are among the criteria used to assign relative ages. The tentative chronology should prove useful as a guide in future geochronology, which is badly needed because we do not know within 400 million years the duration of the emplacement episode!

Elevating the Aphebian Falls Brook Group to full status alongside the Snyder Group, Berg undertook a comparison of these contiguous units with the Mugford Group, and concluded that, on balance, the correlation proposed by previous workers is not presently justified. Ranson investigated the presumably Archean rocks near Laura Lake and Okhakh Bay and found lithologies ranging from ultramafic through basaltic and anorthositic to the tonalitic composition usually associated with these rocks. At Okhakh Bay, however, garnet-cordierite granulites of probable supracrustal origin occur which, according to one informant, may be correlative with the well-known Upernavik Supracrustals 125 km to the north. In a separate note, Ranson reports further evidence that monzonitic rocks in several localities are younger than and intrusive into anorthosite and that the two rock types stem from separate, distinct parent magmas. A study by Morse of the Bird Lake Anorthosite Massif showed that the western contact rocks are garnet-biotite paragneiss and that biotite-bearing anorthosite occurs locally within the Massif; this is the first substantial evidence of a "wet" contact known from the Nain Complex, which elsewhere has dry granulite contact rocks. Such a finding is welcome, not only for its refreshing variety but, more importantly, for showing that hydrous assemblages are capable of surviving locally in anorthosite contact zones, and that their more general absence reflects an initial paucity of water rather than later dehydration.

Even in our tenth year of research, the Nain Complex has not lost its capacity to surprise. Berg and Briegel have discovered a major layered intrusion, the Jonathon Intrusion, that may underlie an area as large as 400 km^2, according to my interpretation of Wheeler's manuscript maps. This important anorthositic body comes complete with a well-exposed outer contact zone against country rocks composed of granitic to tonalitic gneisses, supracrustals, and mafic granulites. A chilled margin and a border zone are present, and the latter contains enormous (up to 1/2-meter) olivine crystals containing boxworks of skeletal plagioclase. The main zone of the intrusion contains both troctolitic and noritic lithologies, and the two mutually perpendicular laminations of plagioclase crystals mentioned earlier. With such a rich variety of nucleation features and mineralogy combined with a promising chilled margin, the Jonathon Intrusion seems destined to become a major source of understanding about plutonic crystallization and anorthosites, despite the fact that much of it now lies under water.

New work by D. N. Dickey shows that the Hettasch Intrusion extends across Port Manvers Run and tapers out within about 3 km of the Run. Its unusual and complex synclinal form and stratigraphy are retained, tightly compressed, and an extensive anorthosite block zone -- a megabreccia or stockwork of troctolite invading anorthosite -- also continues across the Run. Numerous smaller troctolite and melatroctolite bodies occur within and near the Hettasch Intrusion, as well as dioritic bodies that are plausible candidates for a late-stage fractionated residuum.

The Newark Island Layered Intrusion, earlier suspected by me (FR 1976, p. 47) to be part of the Tigalak Intrusion, is now confirmed by Wiebe's work as a separate body of great interest. Like the Jonathon, it has both troctolitic and noritic lithologies, but it also has a main sequence containing large sheets of hybrid rocks which are essentially mixtures of troctolite and granite. In the basal parts of these sheets occur spectacular troctolite pillows chilled against a matrix of once-liquid granite (Frontispiece). The hybrid sheets grade upward to veined and then homogeneous troctolite. Hybrid dikes also occur, showing the high mobility of the troctolite-granite suspension. As Wiebe remarks, the Newark Intrusion provides an excellent setting for geochemical studies of concurrent multiple injections, contamination, and fractional crystallization within a magma chamber.

New work on the Tigalak Intrusion included an examination of the geologic setting by Wiebe and detailed mapping by Wild. Wiebe successfully unravelled the age and structural relations among Port Manvers Run anorthosite, Slambang leuconorite, the Newark Island Layered Intrusion, and Tigalak. Wild studied in detail two areas of hybrid rocks in which diorite is intermingled with quartz monzonite. He distinguishes as many as seven mappable lithologies in the spectrum between the two end members, including diorite containing blocks (autoliths) of finer-grained diorite, diorite with leuconorite inclusions, and hybrid diorite-quartz monzonite with blocks of finer-grained diorite. His maps and sampling will furnish the basis for a detailed petrographic, chemical, and isotopic study of these remarkable mixtures.

The 1981 field season saw a burst of activity in the Kiglapait intrusion, leading to important discoveries and new insights. Xenoliths in profusion have been found at three stratigraphic levels, in the basal Lower Zone, near the top of the Lower Zone, and in the Upper Zone. A description and catalog of these xenoliths is presented by Morse, Young, and Ball, who discuss their possible significance to contamination of the Kiglapait magma during crystallization. Ball shows that the Partridge Point xenoliths just below the Upper Zone are basic plagioclase-augite granulities with compositions distinct from those of the Layered Group. Young discusses two breccias, one xenolithic and the other autolithic, and their implications for magma dynamics. He then goes on to report the first purposeful study of layering styles in the Kiglapait intrusion. Most layers (except major phase layers like the Main Ore Band) are probably lenses, with lateral extents ranging from several hundred meters for macrorhythmic layers to tens of meters for graded and lenticular layers. His genetic interpretation of the various types of layering emphasizes that unconformable varieties are likely candidates for current deposition, whereas the strikingly parallel 2-cm and macrorhythmic layers are likely candidates for an in situ origin. Young's report is strikingly illustrated with detailed sketches from field photos.

In the original study (Morse, 1969) the southern contact of the Kiglapait intrusion was hastily located and examined. A re-examination was long overdue, particularly to search for a chilled margin and for earliest cumulus crystal compositions. Nolan undertook this task, located the contact more accurately, and found both the prime targets: a finer-grained, relatively chilled margin that is modally similar (Dei gratia) to the calculated intrusion average, and basal mineral compositions that broadly conform to a familiar reverse trend up stratigraphy. Nolan also describes a remarkable variety of lithologies, coarseness, and cross-cutting relations in the basal 30 meters of the intrusion. Augite compositions of the Inner Border Zone and basal Lower Zone are shown to be similar to each other but distinct from the first cumulus augites of the Upper Zone in being both more calcic and more magnesian. Her detailed mapping and sampling furnish a sound baseline for a continued study of the basal Lower Zone.

As a coda to the Kiglapait field studies, Morse and Hart report a strontium-isotope study of a separated feldspar mixture from the uppermost Kiglapait Layered Group. This study was conceived as a test of an outrageous hypothesis by Morse (1981b) that involved passive strontium isotope fractionation during fractional crystallization, with radiogenic strontium being carried preferentially by sanidine-like structural units in the melt. Ironically, the test was ambiguous but distinctly unfavorable to sanidine as the carrier. If the feldspar pair was not reset well after the original crystallization, isotopic disequilibrium does in fact exist and plagioclase, not sanidine, carries the high abundance of radiogenic strontium. However, the case for possible resetting awaits further examination. The question of strontium isotope fractionation, apparent or real, is fundamental to the interpretation of late-stage residua, immiscible liquids, and the whole matter of crustal contamination in plutonic magmas in general and the Nain Complex in particular. Since the isotopic variation is so regular and extreme in the Kiglapait intrusion (Simmons and Lambert, FR 1980), it appears likely that this question can (and must) be resolved in that body if anywhere.

If layered intrusions seem to play a big role in this Project, it is because they form volumetrically important and genetically telling parts of the anorthosite kindred. This is true of every major regional subdivision of the Nain Complex and every major anorthosite complex in Labrador, notably the Harp Lake, Michikamau, and Mealy Mountains bodies so diligently studied by Emslie. Far from being the trackless wastes of plagioclase they first appeared to be, the great massif anorthosites are full of tracks leading to their mode of origin, and the layered complexes with their derivative liquids are foremost among these imprints.

As a perspective on the anorthosite problem and a decade of field studies in the Nain Complex, the abstract of a recent review article is reproduced nearby. It is the conclusion of that article, and of the present Introduction and Review, that the "Anorthosite Problem" is now resolved into specific questions of tectonics, magma genesis, emplacement, and crystallization that center around mantle-derived magma, and that the time has come to use these rocks intelligently to ask fundamental questions about the Proterozoic mantle. In parallel, the associated granitic rocks can be regarded as windows on the nature of the Proterozoic deep crust. "The anorthosite problem becomes, potentially, the anorthosite solution."

-- S.A. Morse

American Mineralogist, Volume 67, pages 1087–1100, 1982

A partisan review of Proterozoic anorthosites[1]

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Abstract

Most anorthosites of the massif type crystallized in the episode 1.7–1.2 Gyr, with a pronounced peak of the age distribution near 1.4 Gyr. They were emplaced anorogenically at depths as shallow as 7 km, where the ambient temperature of country rocks was probably less than 250°C. Depths of emplacement may have been as great as 25 km or more in rare cases; the greater depths of equilibration estimated from granulite facies metamorphism may be incorrectly interpreted as emplacement depths, but in any case they are demonstrably not required or characteristic of anorthosite emplacement. Penetrative deformation and metamorphism of anorthosites are post-emplacement accidents of the local geologic history, and are not directly caused by the presence of anorthosites.

Granitic rocks (mangerite–charnockite suite) associated with anorthosite are in general later or contemporaneous products of crustal anatexis, with chemical and isotopic signatures distinct from the anorthosites and their residua. Such granitic rocks should not, therefore, be summed with the anorthositic rocks to obtain bulk compositions.

The magmas that produced most anorthosites were dry, as shown by high-temperature mineralogy and anhydrous mineral assemblages in contact aureoles. Residua from their crystallization are ferrodiorites to ferrosyenites typical of closed-system fractionation. These residua were locally and frequently ejected into contemporaneously molten granite, where they formed pillows and cooled rapidly.

The overall chemistry of anorthosites and residua is broadly tholeiitic and consistent with derivation from the mantle. Olivine-bearing magmas locally ranged from leucotroctolite (anorthosite) to later but coexisting picrite or melatroctolite in the same pluton, confirming a wide spectrum of magma types. A signal feature of troctolitic and noritic magmas is their low augite content, implying high content of spinel component. Large anorthosite complexes such as Nain and Harp Lake consist of many plutons representing repeated injections of separate magma batches with varying chemistry.

The abundant true anorthosites, richer in plagioclase than magmas cosaturated with a mafic phase, must represent plagioclase enrichment by either mechanical or chemical processes or both. The role of kinetics in nucleation and solidification of such rocks may be centrally important. It is proposed that hyperfeldspathic (plagioclase-supersaturated) liquids were generated by quasi-isothermal extraction of mafic minerals from tholeiitic magma enroute to and at the site of emplacement, and that such a kinetic process was uniquely permitted in an environment of aborted continental rifting. Anorthositic rocks may have much to say about the episodic versus continuous geochemical evolution of the earth's mantle.

[1]Dedicated on behalf of all students of anorthosite to the memories of A. F. Buddington and E. P. Wheeler, who sustained us all so long by their marvelous example and enthusiastic support.

OVERVIEW AND REGIONAL GEOLOGY

EMPLACEMENT HISTORY OF THE NAIN COMPLEX

S. A. Morse
University of Massachusetts[1]

Introduction

The Nain Complex is known to consist of many dozens of individual basic plutons whose combined volume probably approaches $10^5 km^3$, comparable to the estimated volumes of some large flood basalts. It would be of great interest to know the time span over which these plutons were emplaced, but radiometric data (see Fig. 2 of FR 1980) are as yet too scarce to furnish useful constraints. Knowledge of the relative ages of emplacement would aid greatly in the efficient search for an isotopic chronology. Because intrusive contacts between plutons tend to be scarce and ill-defined, a comprehensive chronology of emplacement is elusive. However, at the close of a decade of research it seems appropriate and worthwhile to attempt such a relative chronology. The present account is intended as a statement of present knowledge and educated guesses, and hence as a working hypothesis for further testing and revision. I have relied heavily, in its preparation, on the advice and experience of J. H. Berg and R. A. Wiebe, but they should not be held responsible for any shortcomings of the interpretation.

Major Divisions

Three classes of the ANT suite (Anorthosite-Norite-Troctolite, including leuco members) of the Nain Complex present themselves immediately as candidates for grouping according to relative age. The oldest of these is a class of steeply-dipping layered bodies with either foliation or stretched texture implying deformation during or after solidification. Of these bodies, the Susie Brook Slab (Morse and Wheeler, FR 1973; see also this Report) is a notable example. Objects belonging to this class are here assigned to an Older Anorthosite Event (OAE). Another class consists of flat to moderately-dipping or unlayered anorthosite and leuconorite, rarely with olivine-bearing or other mafic basal layers, without stretched texture or significant foliation. These bodies are assigned to a Main Anorthosite Event (MAE). The third class consists mainly of troctolitic bodies which typically cut one or more

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[1] Authors' full addresses are given at the back of this volume.

of the other two classes and are here assigned to a youngest Troctolite Intrusive Event (TIE).

Problems arise immediately. The deformation shown by members of "OAE" does not, of course, guarantee that the units were deformed contemporaneously or by the same forces, and there may have been deformations of various ages that we cannot distinguish. The groupings therefore contain most of the weaknesses of any lithologic correlation. Nevertheless, they are testable in principle, and they conform broadly to the available evidence.

Shearing, Granitic Diking, and Hydrothermal Alteration

Topographic maps at any scale reveal a profusion of linears that strike roughly E-W (to about 110°) in the Nain area. Where displacement is observed, as in the Barth Intrusion (de Waard, 1976), it is left-lateral but short, a few km at most. Parallel to the major linears, and particularly along Nain Bay and Tikkoatokhakh Bay, are numerous shear zones containing pink to red granite material. In and near these shear zones, the normally gray feldspar of anorthosite has become waxy white or pale gray, and pyroxenes have been altered to actinolite. An excellent example of this pervasive greenschist hydrothermal alteration may be seen in the quarry off the end of the runway on Northern Point in Nain. In the Bird Lake Massif (Morse, this Report), it was noted that the pink granite veins tend to have conjugate dips north and south, suggesting an origin by N-S extension.

Similar pink granite veins are well developed in sheared anorthosite at Hare Point, Port Manvers Run, just below the basal contact of the Kiglapait intrusion. Layered troctolites, dikes, and apophyses of the Kiglapait intrusion are not similarly sheared or veined. White or rarely pink Manvers granite dikes which do cut the Kiglapait intrusion typically reside in joints unrelated to shearing, and have sharp contacts with only short-range influence on the host troctolites and olivine gabbros. They are therefore distinctively different in field aspect from the "pink shearing." From these observations it is inferred that at least one event of shearing associated with pink granitic material occurred in anorthosites before the emplacement of the Kiglapait intrusion. Fresh specimens and memory of the outcrops also suggest that the Barth intrusion (de Waard, 1976) is unaffected by the pink shearing, although it is offset by left-lateral faulting.

There may, of course, have been more than one event that produced pink shears. The strongest suggestion of a second event occurs in the Jonathan Intrusion (Berg and Briegel, this Report), which is undeformed (hence assigned to MAE) but affected by extensive hydrothermal alteration.

Red granitic material is generally isotopically heavy in $^{18}O/^{16}O$ (Taylor, 1968), perhaps denoting interaction with multiply-exchanged and altered source material. The source of the pink vein material was presumably subanorthositic in location and distinct from the crustal source of dry granitic melts of the adamellite series. The shearing and veining may therefore reflect a distinctive event or events in the emplacement of the Nain Complex, perhaps a prolonged pause separating major stages in the evolution of the Complex. From the conjugate dips observed in the Bird Lake Massif, one would suppose this event to be N-S extension, possibly preceded or accompanied by some uplift. From such considerations, the pink shearing event is assigned a position at the end of OAE.

Very clearly, an attempt should be made to date the pink granite in shear zones throughout the Nain Complex, in order to investigate the validity of the above conclusions and to shed further light on the tectono-magmatic history of the Complex.

Detailed Intrusive Stratigraphy

A summary of the tentative chronology, based on the considerations noted above and elaborated slightly below, is given in Table 1 . References to radiometric ages are contained in Fig. 2 of FR 1980, and in Morse (1979a).

Older anorthosite event (OAE). The relative positions of the different units is unknown except that Bird Lake presumably engulfs Susie Brook (Morse, this Report). For the rest, the order given is arbitrary.

Main anorthosite event (MAE). No order within the group is known, and the list is surely incomplete. Future assignments to the group should be made on the basis of lack of foliation. The undeformed Jonathon intrusion is assigned to MAE but, because of its olivine content, could as well be assigned to TIE. Berg and Briegel (this Report) cite the presence of numerous pink granite dikes, as well as extensive shearing and hydrothermal alteration, suggesting that the pink shearing event may have overlapped with MAE, or been repeated.

TABLE 1. TENTATIVE CHRONOLOGY OF THE NAIN COMPLEX

UNIT OR EVENT	AGE, Gyr
MANVERS GRANITE	1.25 Rb-Sr
- - - -	
Unloading and vertical release jointing (Kiglapait)	
BASALT DIKES (Upton, FR 1973; Wiebe, FR 1980)	Various
Left-lateral faulting (Nain Bay, Barth Intrusion)	
- - - -	
TROCTOLITE INTRUSIVE EVENT (TIE)	
(Includes differentiation to leuconorite or ferrodiorite and some coeval diorite and granite. Asterisk indicates those bodies whose relative age is known with some confidence.)	
* Kiglapait Intrusion (Morse, 1969)	1.41 Sm-Nd
* Tigalak Intrusion (Wiebe, FR 1981)	
= Barth Intrusion? (de Waard, 1976)	
* Slambang leuconorite (Wiebe, FR 1981) (Assumed equivalent to leuconorite south of Kiglapait; Nolan, FR 1981; and to leuconorite cutting Hettasch Intrusion; Berg, FR 1975)	
* Various melatroctolites (Berg and Pencak, FR 1980)	
? * { Hettasch Intrusion (Berg and Briegel, FR 1981)	
{ Newark Intrusion (Wiebe, FR 1981)	
North Ridge Gabbro? (Berg, FR 1975)	
MAIN ANORTHOSITE EVENT (MAE)	1.39 Rb-Sr
[Anorthosite, leuconorite, and leucotroctolite, locally with mafic basal portions. Granitic crustal melts coeval and younger (main Adamellite series of Wheeler, 1960).]	
Younger anorthosite of Tunungayualok (Wiebe, 1978).	
Puttuaaluk Lake (Ranson, 1981)	
Khikkertavak I.	
Paul I.	
Jonathon Intrusion (Berg and Briegel, FR 1981)	
- - - -	
Arching with N-S extension, shearing and diking with red to pink granite.	
- - - -	
OLDER ANORTHOSITE EVENT (OAE)	
(Steeply dipping or stretched anorthosite and leuconorite.)	
Port Manvers Run = Foliated anorthosite (Wiebe, FR 1981; Berg, FR 1975).	
Bird Lake and Lister massifs (Morse, FR 1981)	
Older anorthosite of Tunungayualok I. (Wiebe, 1978).	
Bridges Intrusion (Planansky, 1977).	
Susie Brook Slab (Morse, 1975; FR 1981).	
Calcic and deformed anorthosite of block structures.	
- - - -	
Burial of supracrustals to 8-10 km (possibly continuous with OAE)	
Deposition of supracrustals	≥1.8 Rb-Sr
- - - -	
KENORAN OROGENY	2.4-2.7 K-Ar

Troctolite intrusive event (TIE). Here the order of events is the most secure of all the groups, due mainly to the efforts of Wiebe and Berg in and around South Aulatsivik (Newark) Island. One lithologically anomalous unit (Slambang leuconorite) occurs among the troctolitic units, serving as a warning that other noritic units could be misassigned to MAE on purely lithologic criteria. As indicated by queries, the ages of the North Ridge Gabbro (NRG) and the Barth Intrusion are unknown. NRG is assigned its lowermost position to indicate that it may, in fact, belong to MAE. Barth is located close to Tigalak because both intrusions contain hybrid rocks. The relative ages of the Newark and Hettasch intrusions are also unknown.

Other members of TIE are more confidently known to have the relative ages indicated by their order in Table 1 , as indicated by asterisks.

Discussion

It will be readily appreciated, from the nature of the exercise itself as much as from the uncertainties expressed above, that the proposed chronology is tenuous in places and perhaps even sadly wrong in others. Not the least of the causes of our insecurity is the fact that most of the exercise was undertaken retrospectively, when it belatedly became apparent that there were sound reasons for attempting such a chronology. Had such an outline as Table 1 been constructed early in the season, and discussed on the outcrop, it might now be appreciably more secure. At all events, the present attempt should provide a useful focus for future investigations, both in the field and in the laboratory.

With trepidation, then,but with emphasis on the strongest information, I offer the following tentative summary of the history of emplacement of the Nain Complex.

Summary. Accepting as sound the arguments of Berg (e.g. 1977 and recent Field Reports) for a rifting environment of emplacement, and based upon the principle that younger fracture systems are likely to represent reactivation of previous ones, it is probable that rifting with N-S extension inaugurated the emplacement of basic plutons some time after 1.8 Gyr, probably much nearer to 1.5 Gyr, and continued intermittently thereafter. Calcic, very leucocratic anorthosite was formed in sufficient quantity to appear commonly as xenoliths in block structure; this event may have occurred repeatedly. The sodic Susie Brook Slab and perhaps the calcic Bridges intrusion were emplaced and then deformed by the advent of later intrusions, particularly the sodic Bird Lake Massif. Because the Susie Brook Slab is some 9 km thick and is tilted or folded to 70° dips, its deformation required considerable room and must represent the access of a very large batch of magma. Other anorthositic bodies were also crystallized and deformed while hot, perhaps contemporaneously with Susie Brook. It is possible that one or more major granitic magmas were generated and introduced alongside anorthosite during OAE, judging from the 1.45 Gyr age found by Brand (1976).

At least one period of flexuring with N-S extension and shearing accompanied by pink granitic alteraton ensued.

Major anorthosite and leuconorite bodies, largely with labradorite feldspar, were then emplaced, along with or followed by relatively dry, mesoperthite-bearing granitic bodies.

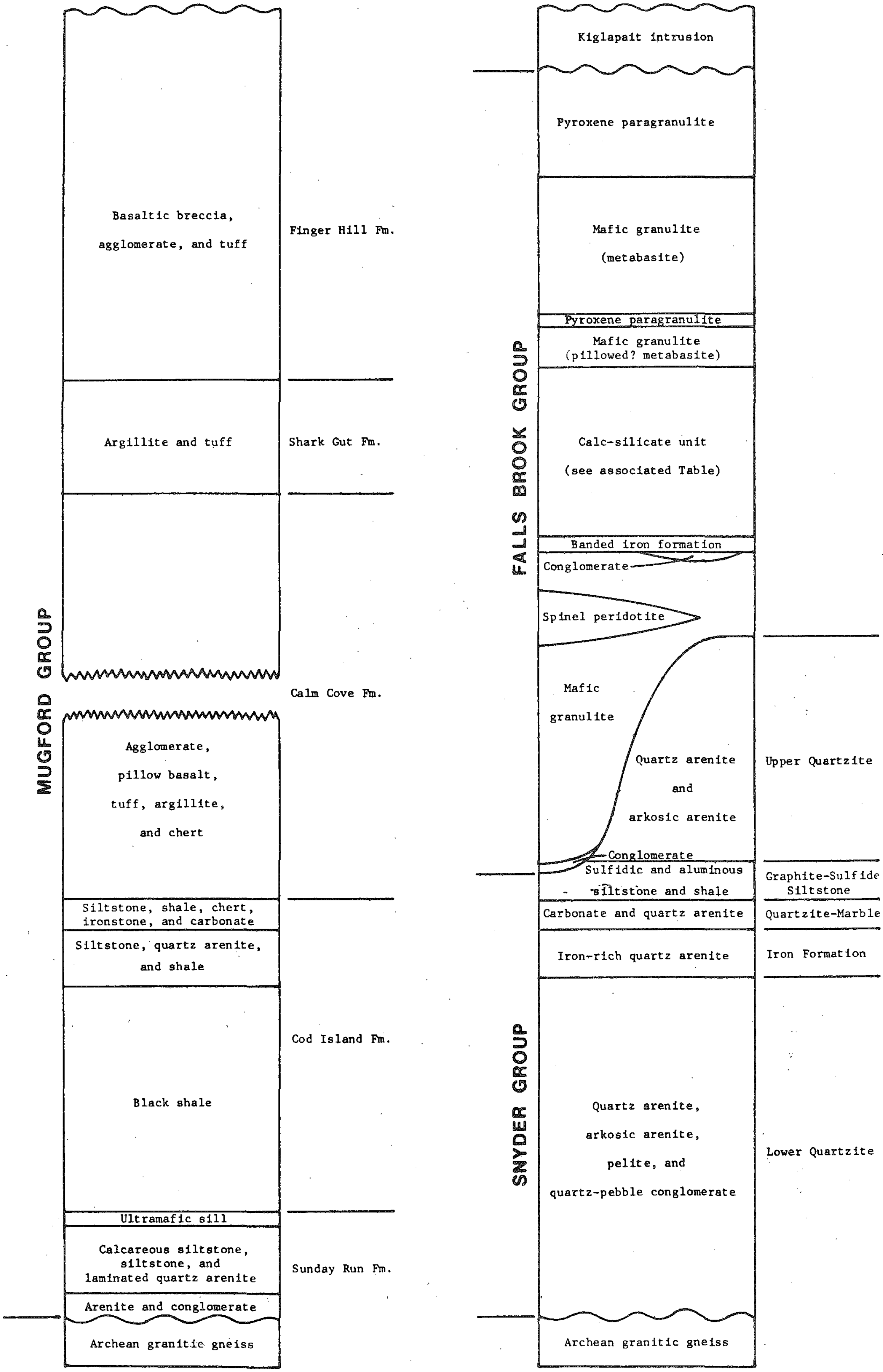
An array of troctolitic and lesser melatroctolitic bodies was emplaced in the final intrusive event, along with at least one leuconorite body. If separate dry granitic intrusions also occurred during this event, they were minor or at least are not well recognized from field evidence, although a zircon age as young as 1.29 Gyr is well established (Krogh and Davis, 1973). Lesser amounts of granite magma did, however, coexist and mingle with troctolitic magmas, as in the Newark intrusion (Wiebe, this Report and Frontispiece).

Renewed N-S extension, accompanied by some left-lateral motion, occurred after the emplacement of troctolitic bodies. Some large basaltic dikes (e.g. at Khaukh Harbour) occupy roughly E-W fractures and are probably related to the *en echelon* E-W linears that dominate the Nain area both on land and under water. Other sets of basaltic dikes have northerly to northeasterly trends (Wiebe, FR 1980), denoting a (probably subsequent) period of E-W extension.

Unloading leading to vertical release jointing then occurred, allowing the emplacement of high-level, subsolvus, largely white, and fluid-rich Manvers granite about 1.25 Gyr ago. No younger igneous activity is known, but some basaltic diking may have occurred later than this.

The time span for all of the basic igneous emplacement was certainly less than 400 Myr but is otherwise essentially unconstrained. The two direct dates, 1.41 and 1.39 Gyr, are probably the same within sampling error. No radiometric determinations have as yet been attempted on likely candidates for a maximum age, such as the Susie Brook Slab.

Despite uncertainties, our present understanding of the emplacement chronology appears to be at least as comprehensive as that available for any other anorthosite complex, and it serves well to illustrate the wide variety of events that occurred in the evolution of the Nain Complex. The resemblance of this complicated history to that of large orogenic granitic batholiths will not be lost on students of those rocks, despite the clear contrast between the anorogenic, tensional setting of the Nain Complex and the orogenic setting of granite batholiths.


MUGFORD GROUP
Basaltic breccia, agglomerate, and tuff
Finger Hill Fm.
Argillite and tuff
Shark Gut Fm.
Calm Cove Fm.
Agglomerate, pillow basalt, tuff, argillite, and chert
Siltstone, shale, chert, ironstone, and carbonate
Siltstone, quartz arenite, and shale
Black shale
Cod Island Fm.
Ultramafic sill
Calcareous siltstone, siltstone, and laminated quartz arenite
Sunday Run Fm.
Arenite and conglomerate
Archean granitic gneiss
Kiglapait intrusion
FALLS BROOK GROUP
Pyroxene paragranulite
Mafic granulite (metabasite)
Pyroxene paragranulite
Mafic granulite (pillowed? metabasite)
Calc-silicate unit (see associated Table)
Banded iron formation
Conglomerate
Spinel peridotite
Mafic granulite
Quartz arenite and arkosic arenite
Upper Quartzite
Conglomerate
Sulfidic and aluminous siltstone and shale
Graphite-Sulfide Siltstone
SNYDER GROUP
Carbonate and quartz arenite
Quartzite-Marble
Iron-rich quartz arenite
Iron Formation
Quartz arenite, arkosic arenite, pelite, and quartz-pebble conglomerate
Lower Quartzite
Archean granitic gneiss

STRATIGRAPHIC COMPARISON OF THE SNYDER AND FALLS BROOK GROUPS WITH THE MUGFORD GROUP

J.H. Berg
Northern Illinois University[1]

Introduction

In an attempt to compare the lithologies of the Aphebian Snyder and Falls Brook Groups (Speer, FR 1972, 1978; Berg FR 1974, FR 1975; Docka, FR 1980; Schuh, FR 1980) with those of the Mugford Group (Smyth, 1976; Smyth and Knight, 1978), the latter Group was examined briefly for the first time by this author and the former Groups were re-examined. Smyth and Knight (1978) have suggested that the Mugford and Snyder Groups are correlative, but they were unaware of the Falls Brook Group which overlies the Snyder Group. Thus I present here a summary of my present understanding of the Aphebian stratigraphy in the Snyder Bay-Avakutakh Bay region, as well as a summary of my observations on the Aphebian stratigraphy in the Kaumajet Mountains.

Snyder Group and Falls Brook Group

Speer (1978) has reported on the stratigraphy of the Snyder Group, and the following description combines his conclusions with recent observations by my students and me. The lower quartzite (120 m thick) consists of interbedded quartz arenite, arkosic arenite, pelite, and quartz-pebble conglomerate (Fig. 2). Overlying the lower quartzite is a banded or laminated quartz-rich metasedimentary rock which contains locally abundant iron- and manganese-rich silicates and recently discovered iron oxides, either interstitially or in layers. This 15 m thick unit has been called the iron formation by Speer (1978).

Overlying the iron formation is a calcareous unit called the quartzite-marble (Speer, 1978). This unit is 10 m thick and consists predominantly of carbonate-rich quartzite and interlayered carbonate and quartzite. Above this unit is the 14 m thick graphite-sulfide siltstone. In addition to being graphite- and sulfide-rich, this unit is quite aluminous. Locally this formation contains conglomerates up to cobble and boulder size (Schuh, FR 1980) and either cobbles, nodules, or lenses of metamorphosed chert.

[1]Authors' full addresses are given at the back of this volume.

← Fig. 2. Stratigraphy of the Mugford Group compared to that of the Snyder and Falls Brook Groups.

The graphite-sulfide siltstone is overlain by a brown to white quartzite called the upper quartzite (Speer, 1978). This unit is 80 m thick and is dominated by quartz arenites, although locally it consists of feldspathic arenites. Near its base it consists of regularly alternating layers of quartzite and cordierite-rich rock, interlayered on an approximately 1-cm scale. The lower part of the upper quartzite is thus assumed to have been deposited as interlayered arenites and lutites.

At the top of the Snyder Group an unconformity is apparently present, resulting in the local removal of all of the upper quartzite and some of the graphite-sulfide siltstone. Nevertheless, an area that was a topographic high during deposition of the Snyder Group persisted as such during deposition of at least some of the Falls Brook Group (Schuh, FR 1980). This and the nearly conformable relationship between the two groups suggest that the unconformity was not of great duration, nor was it punctuated by any significant tectonism.[2]

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[2] Note Added in Proof-- Recent petrographic study has resulted in the identification of cobbles of the Snyder Group iron Formation (B formation of Speer, 1978) in the conglomerate at the unconformity between the Snyder Group and Falls Brook Group. Thus the erosional surface must have locally cut down at least as far as the iron formation. It is difficult to determine whether the many quartzite cobbles are upper or lower quartzite, but the presence of large cobbles of granite may indicate that erosion locally penetrated through the Snyder Group to the Archean rocks.

The detailed nature of the unconformity has been obscured because of the ever-present intrusive (?) mafic granulite (metabasite) which separates the Snyder Group from the Falls Brook Group (Fig. 2). In addition, this portion of the section is nowhere well-exposed. However, in areas where the upper quartzite is missing, there are some poorly exposed pebble- to cobble-size sulfide-rich conglomerates either at the top of the graphite-sulfide siltstone or at the base of the Falls Brook Group.

In addition to mafic granulite, a Cr-rich spinel peridotite up to 20 m in thickness is present between the two groups where exposures are good. Whether it is continuous at this horizon has not been established. The chemistry (unpubl. data) and lateral extent of this unit suggest that it may have originated as a komatiitic sill.

The lowest meta-sedimentary unit of the informally named Falls Brook Group is a bonafide banded iron formation which typically is only 4-5 m thick (Schuh, FR 1980; 1981). This unit consists of interlayered quartzite, iron-silicate-rich quartzite, and magnetite. Locally there are thin layers or lenses rich in apatite.

Overlying the banded iron formation is a unit of variable meta-sedimentary lithologies whose protoliths were probably dominated by calcareous/argillaceous sediments. This unit has been informally named the calc-silicate unit (Berg, FR 1975) because of the abundance of green and black para-amphibolites and other calc-silicate assemblages. Table 2 lists a rudimentary description of the highly metamorphosed rock sequence in this unit, which is approximately 60 m thick.

Above the calc-silicate unit are about 15 m of alternating foliated mafic granulite and mafic granulite possessing possible relict pillow structures. Each individual layer is about 3 m thick. This sequence is overlain by about 3 m of pyroxene paragranulite and biotite schist. The next 40-50 m consist of moderately foliated mafic granulite. The highest unit recognized before the sequence is truncated by the Kiglapait intrusion is a pyroxene paragranulite which locally contains minor amounts of cordierite.

Throughout the two groups mafic granulite layers are common (Berg, FR 1974, FR 1975). Although the mafic granulites mentioned in the previous paragraph may have originally been flows, most of the mafic granulites probably originated as sills or dikes. The stratigraphic relationships described above are shown graphically in Fig. 2 .

Mugford Group

Observations on the Mugford Group are of reconnaissance nature and do not differ substantially from those reported by Smyth (1976) and Smyth and Knight (1978). Although the upper units of the Mugford Group were examined briefly, most of my observations concern the lower sedimentary unit of Smyth (1976).

The lowest unit of the Mugford Group, exposed in the Sunday Run area, is a gray to black sandstone which contains layers and lenses of conglomerate, black chert, and black siltstone. Locally the sandstone is cross-bedded, and it has a dark (graphite-rich) laminated chert cement. This unit passes upward into a laminated sandstone and siltstone unit which is capped by a calcareous siltstone which locally contains abundant cobbles and fragments of chert and quartzite.

Table 2. Sequence of lithologies in calc-silicate unit from Falls Brook (in stratigraphic order).

Thickness (m)	Rock Type
4	Calc-silicate and laminated amphibolite (top)
4	Pyroxene granulite and biotite schist
6	Mafic granulite
2	Calc-silicate and black amphibolite
2	Laminated green amphibolite
2	Biotite granulite
3	Biotite schist and pyroxene granulite
1	Fe-silicate-rich quartzite and granulite
3	Not exposed
2	Biotite schist and pyroxene granulite
2	Fe-silicate-rich quartzite
5	Calcite-diopside-wollastonite-amphibole-scapolite gneiss
5	Not exposed
1	Calcite-diopside-wollastonite-amphibole-scapolite gneiss
3	Biotite-cordierite-garnet schist
15	Green laminated amphibolite (bottom)

This entire unit, the Sunday Run formation of Smyth and Knight (1978), is somewhat greater than 30 m thick.

Between the calcareous siltstone and the overlying black slate is a talc-serpentine-carbonate-brucite(?) rock which contains pseudomorphs of olivine. This 5 m thick unit is either a flow or sill of ultramafic composition. Very fine-grained basaltic sills occur within the calcareous siltstone and between the ultramafic sill and the overlying black slate.

The black slate is relatively homogeneous and is approximately 80 m thick. Near its base are rare lenses of carbonate, 10-20 cm thick. Above the black slate is a 20 m thick unit of interlayered siltstone, fine sandstone, and shale. Most of these rocks are either green or buff, although some of the thin shale layers are black.

The siltstone-shale unit becomes richer in carbonate matrix or cement toward the top and grades into the overlying unit which consists of alternating layers of carbonate-rich siltstone or shale, chert, and carbonate. This unit is about 5 m thick, but the middle 1-1 1/2 m consists of a massive chert layer. This chert layer is locally an ironstone having magnetite laminae alternating with chert laminae which are rich in greenalite(?) and minnesotaite(?).

The next highest unit is a 1/2 m thick black slate or shale which is fairly massive. It is overlain by a 2 m thick laminated green and black slate or shale. Above this are what appear to be greenish breccias or agglomerates of the Calm Cove formation (Smyth and Knight, 1978).

From the upper part of the thick black slate unit to the base of the Calm Cove formation, debris flows or intraformational breccias or conglomerates are present locally.

The Calm Cove, Shark Gut, and Finger Hill formations were examined only very briefly; for reconnaissance descriptions see Smyth (1976) and Smyth and Knight (1978).

Comparisons

Fig. 2 compares the stratigraphic columns of the two Aphebian sequences. Smyth and Knight (1978) emphasized the similarity in position of the calcareous rocks (quartzite-marble and top of Sunday Run formation) between sandstones and black shales as evidence for correlating the two sequences. However the interlayered siltstone-shale unit in the Cod Island formation does not correlate with the white quartzite (upper quartzite) of the Snyder Group. If the calcareous rocks, chert, and ironstone in the upper part of the Cod Island formation correlate with the banded iron formation near the base of the Falls Brook Group, then why is there no unconformity in the Cod Island formation? If, on the other hand, the Mugford Group correlates only with the Snyder Group, where are the Snyder Group equivalents to those calcareous and cherty rocks at the top of the Cod Island formation?

In addition to the correlations emphasized by Smyth and Knight (1978), other tenuous correlations can be made, such as that of chert and ironstone with banded iron formation as mentioned above. Some of the sandstones in the upper part of the Sunday Run formation have abundant limonite and other iron-bearing minerals and may correlate with the iron formation of the Snyder Group. The thick mafic granulite unit in the Falls Brock Group has pillow-like structures near its base and may be correlative with the Calm Cove formation of the Mugford Group. In this case, the overlying pyroxene paragranulite of the Falls Brook Group might correlate with the Shark Gut formation.

Despite these possible correlations, the stratigraphic columns offer at least as much contradictory evidence as they do supportive. As described above, correlation of the Mugford Group strictly with the Snyder Group results in unlikely correlations with the upper part of the Snyder Group. By including the Falls Brook Group, new possibilities emerge, but so do severe problems. The rocks of the Snyder Group and especially those of the Falls Brook have been strongly metamorphosed, and in some cases the determination of protoliths is difficult. The Mugford Group, while only weakly metamorphosed, has been studied in only reconnaissance fashion. Undoubtedly the stratigraphy of each sequence is imperfectly understood. With these limitations in mind, it becomes obvious that correlations between the Mugford Group and the Snyder/Falls Brook Groups are not justified at present. Given the fallability of lithologic correlations in general and some of the inconsistencies mentioned above, it seems unlikely that correlations between these Groups, based solely on lithology, will ever be very satisfactory.

BASEMENT ROCKS AND THEIR RELATIONSHIP TO THE NAIN COMPLEX NEAR LAURA LAKE AND OKHAKH BAY

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Introduction

Interest in the basement rocks from this part of the Nain complex (Fig. 1) stems from the discovery by this author in 1975 (FR 1975) of pyroxene granulites south of Laura Lake. One purpose of the 1981 field season was to map the extent of these granulites, to investigate their compositional variation, and to characterize their relationship with the anorthositic and monzonitic rocks of the Nain complex. To this end, mapping and sampling proceeded in 1981 in the vicinity of Laura Lake and then northward to Okhakh Bay (Fig. 1). These areas provided good exposure of basement lithologies, anorthositic and monzonitic rocks, and their contact relations.

Laura Lake

Basement rocks, inferred to be of Archean age, are the predominant rock type in the vicinity of Laura Lake, which lies west of Tessiuyakh Bay. The relationships of these basement rocks with anorthositic and monzonitic rocks of the Nain complex are shown in the geologic map of Fig. 3. This geologic map is contiguous with the geologic map of the Ighlokhsoakhtaliksoakh Lake area presented in FR 1975.

Basement Lithologies

In outcrop appearance basement rocks at Laura Lake are well layered gneisses and granulites of fine to medium grain size and a color varying from dark gray to green to tan. The orientation of the layering (Fig. 3) is very uniform throughout the area, with northerly strikes and steep dips to either the west or the east. Isoclinal folds, which were not commonly observed, have axial

[1]Authors' full addresses are given at the back of this volume.

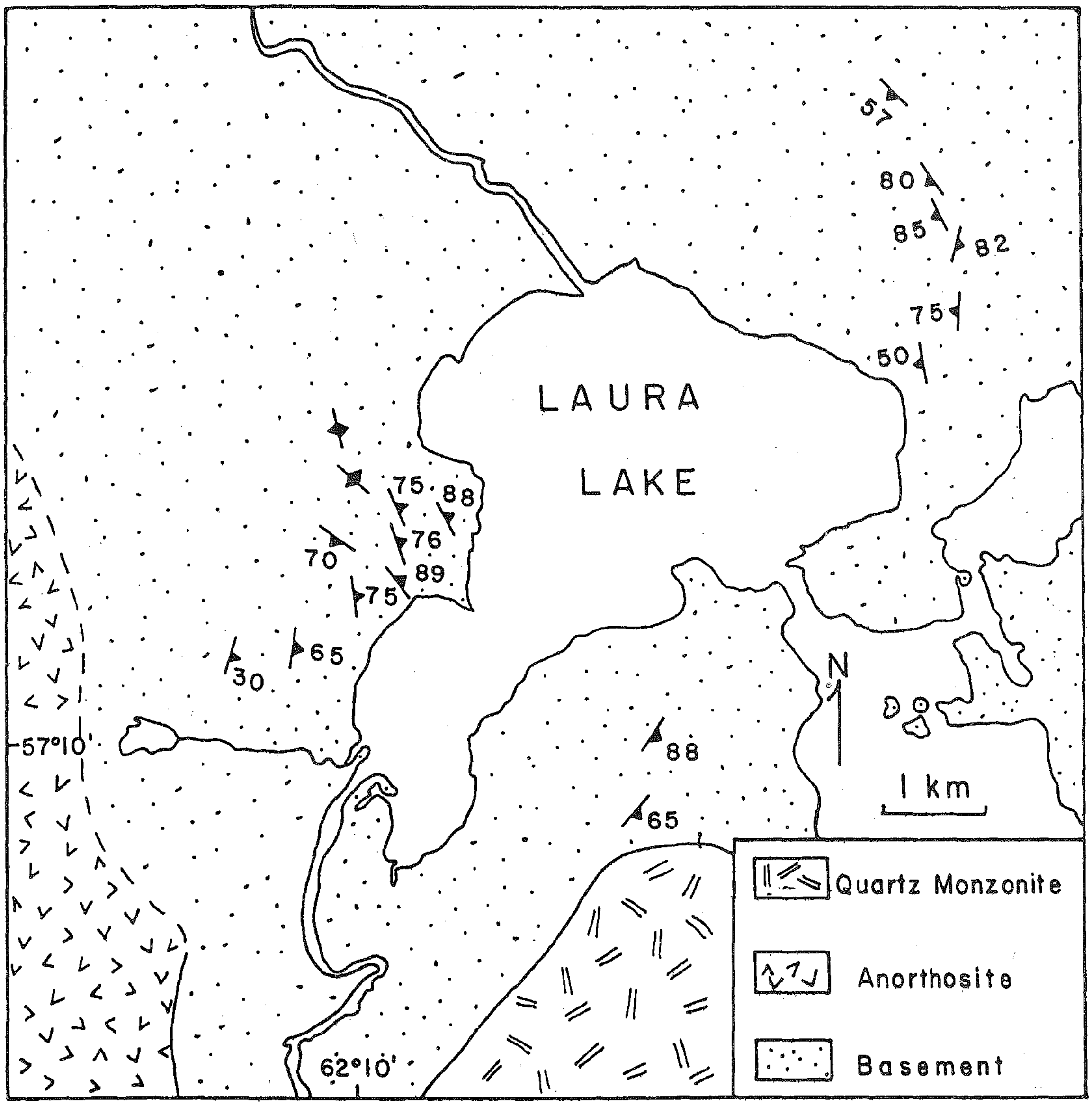


Fig. 3. Geologic map of the Laura Lake area; symbols refer to layering.

planes with strike and dip consistent with that of the layering.

Although the layering is a common feature of the basement observed on the scale of an outcrop, many hand specimens are composed of equidimensional, equigranular minerals and do not exhibit layering or other foliation. The layering is chiefly the result of alternating bands of light and dark minerals, the different bands commonly having quite different composition. It is difficult to make generalizations about the composition of the basement near Laura Lake because of the variety of basement rock types. The gray, fine- to medium-grained, two-pyroxene granulites mapped in the Ighlokhsoakhtaliksoakh Lake area (FR 1975) reappear along strike on the western shore of Laura Lake. However, these two-pyroxene granulites appear to be just a single variety of basement rock in this region and are limited to the region west and southwest of Laura Lake. Perhaps the most common basement composition type is a gray to tan colored granodioritic to tonalitic gneiss or granulite. This light-colored basement rock type (CI 5-20) is generally composed of plagioclase, pyroxene, quartz, usually minor but variable amounts of K-feldspar, plus accessory minerals, notably biotite and cordierite. Some of these rocks are so rich in plagioclase and depleted in mafics that they are anorthositic in composition. It should be emphasized that these granodioritic to tonalitic basement rocks commonly contain lenses and layers of much more mafic material and may also be interlayered with extensive sequences of mafic rocks.

Mafic basement rocks are dark gray (CI 25-50), fine- to medium-grained, dense granulites which generally lack foliation in hand specimen. Average specific gravity for mafic (CI 25-50) basement rock is 3.20 compared with an average specific gravity of 2.79 for less mafic (CI 10-20) basement rocks from Laura Lake. A few ultramafic layers were observed among mafic granulites, and these appear to be peridotitic. The mineralogy of the mafic granulites is dominated by gray plagioclase and pyroxene. Preliminary oil immersion studies show that both clinopyroxene and orthopyroxene are locally present and that other mafic silicates include amphibole, garnet, and olivine. Accessory minerals are oxides, sulfides, and biotite.

In summary, basement rocks around Laura Lake may be described as gneisses or granulites of composition ranging from granodioritic and anorthositic to to basaltic and peridotitic.

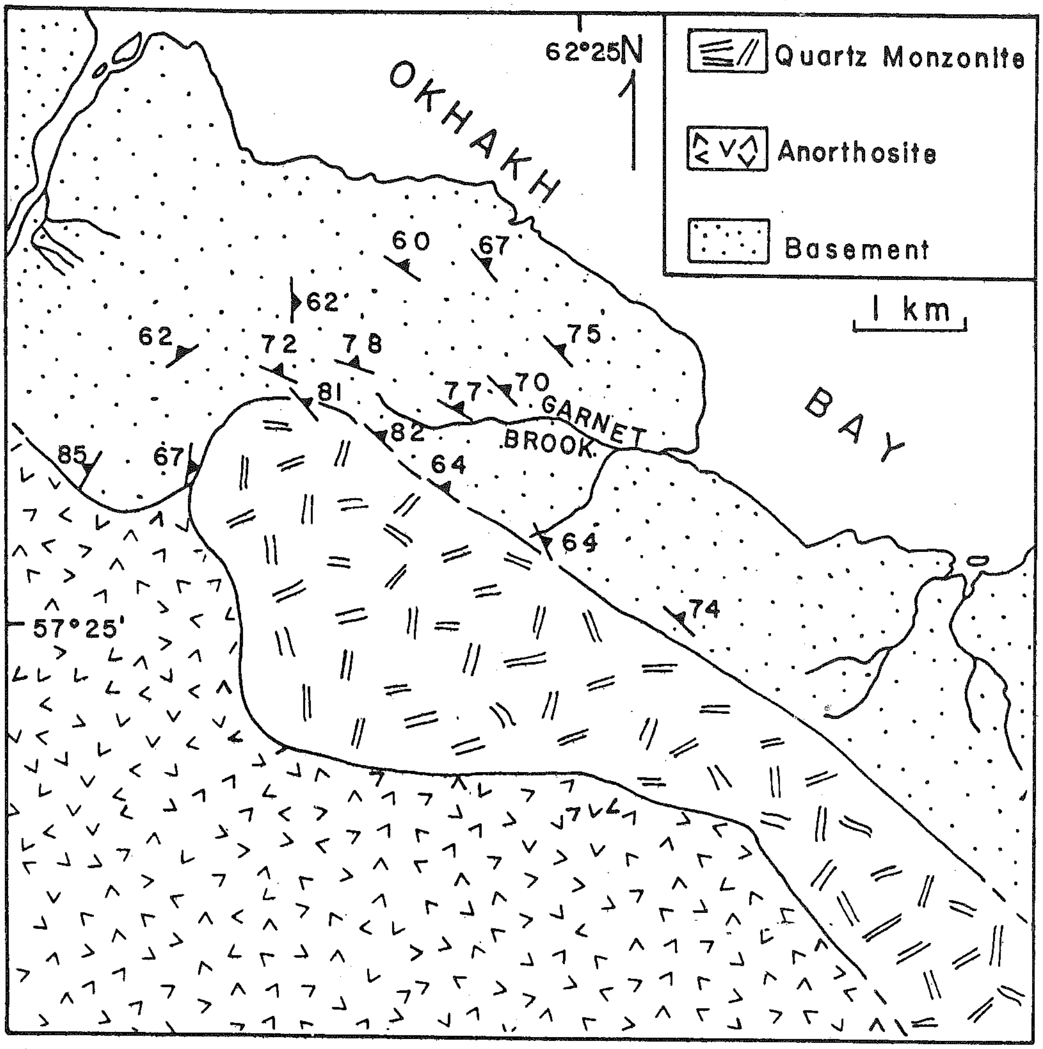


Fig. 4. Geologic map of the Okhakh Bay area; symbols refer to layering.

Contact Relations

Contact relations among anorthositic and monzonitic rocks of the Nain complex and the ancient basement rocks which they intrude are highly confusing in this area. One major reason for the confusion is that the basement rocks are pervasively cut by dikes and veins ranging in type from anorthositic to granitic to aplitic. Dikes of anorthosite are common, and plugs or small isolated stocks of leuconorite and anorthosite intrude the basement and sharply truncate foliation. These features become more common as contacts with Nain complex rocks are approached. The picture is further confused by layered mafic sequences within the basement that commonly occur as isolated outcrops lacking visible contacts with other basement rocks. Presumably these large layered sequences of mafic rocks are isolated by more intense weathering along contacts with the tonalitic rocks. It is perhaps for these reasons that Wheeler, on his 1975 geologic map of the Nain complex, has mapped a narrow belt of rocks termed "layered bodies and granulites of uncertain origin."

Okhakh Bay

From Laura Lake the contact between basement and Nain complex trends northwesterly toward the termination of Okhakh Bay (Fig. 1), where the mapping of basement rocks was continued. The exposure south of Okhakh Bay is fresher and more continuous than that at Laura Lake, and this area provided an excellent opportunity to establish a metamorphic stratigraphy for the basement and to observe contact relations with the Nain complex anorthositic and monzonitic rocks.

Basement Lithologies

Many of the less common basement rocks studied in the Laura Lake area were later determined to be units within the basement stratigraphy mapped along E-W trending brooks in the Okhakh Bay area. One such brook, shown in Fig. 4 as Garnet Brook, has nearly continuous rock exposure, interrupted only by short covered zones and occasional snow fields, for nearly 1000 feet of relief. To take advantage of this excellent exposure, a pace and compass map was made, and on this base the metamorphic stratigraphy was mapped and is presented in Fig. 5. Although the detailed stratigraphy could not be mapped very far beyond the confines

MAP LEGEND

IGNEOUS UNIT

GRANITE

METAMORPHIC UNITS

PLAGIOCLASE-PYROXENE GNEISS

BIOTITE-PLAGIOCLASE GNEISS OR GRANULITE

QUARTZ-PLAGIOCLASE GRANULITE

QUARTZ-PLAGIOCLASE-SULFIDE GRANULITE

GARNET-CORDIERITE-HYPERSTHENE GNEISS

CONTACT

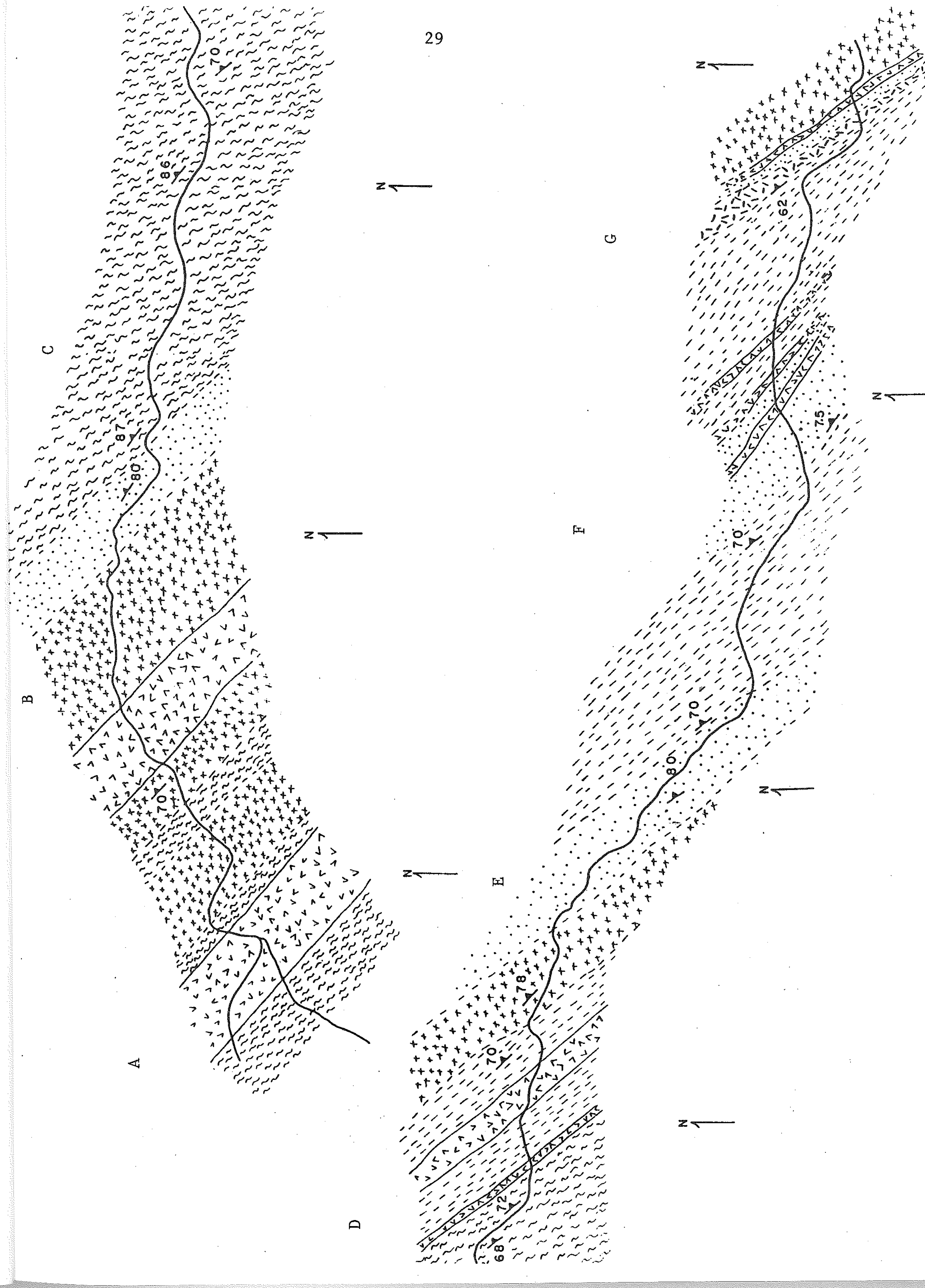
GRADATIONAL CONTACT

METAMORPHIC FOLIATION

0 50

FEET

Fig. 5. Geologic map of Garnet Brook based on a pace and compass map. Sheets A through G progress from west to east with A at high elevation and G at low elevation. Rock units are discussed in the text as encountered in a traverse from east to west.


A
B
C
D
E
F
G
N
70
86
87
80
70
68
72
70
78
80
70
70
75
62

of the brook's deep channel, many of the rock units were observed elsewhere within the map area, usually along strike.

Five distinct rock types or units were observed in Garnet Brook, and these units of the metamorphic stratigraphy merit detailed description based on field observation and preliminary oil immersion studies. The first rock type encountered at the lower east end of Garnet Brook (Fig. 5) is a fine- to medium-grained, blue and tan striped gneiss that appears to have undergone significant shearing. The major minerals composing this first unit are blue cordierite, tan hypersthene, and plagioclase. Further upstream in the stratigraphy, this unit is repeated at least four more times, and the rock contains large, rolled garnets. Here at its first appearance garnet is absent. The thickness of the cordierite-hypersthene gneiss is approximately 13 meters, and its upper contact is marked by a coarse-grained granitic intrusion. This intrusion or sill, only about 2 m in width, intrudes the basement rocks essentially concordantly and is similar in appearance to the monzonitic rocks of the Nain complex. Granitic sills and dikes commonly intrude the basement stratigraphy along Garnet Brook, and all are composed essentially of blue quartz, pink K-feldspar, and minor green amphibole. It seems likely that these tabular granitic intrusions are emanations from the main body of Nain quartz monzonite, which crops out not far to the southwest (Fig. 4).

Beyond the small granite sill, a second metamorphic unit occurs, distinctive because of its red, iron-stained appearance on the weathered surface. A fresh specimen has a blue-gray color and is composed of quartz, plagioclase, and 5 to 10% dispersed iron sulfides. This second unit is about 10 feet thick, and it grades into a third unit, a blue plagioclase-quartz granulite containing minor amounts of hypersthene and sulfides. The plagioclase-quartz granulite is approximately 10 feet thick where it was first encountered and can be distinguished from the previous unit by the lack of iron staining on the weathered surface.

The fourth unit encountered is a weakly foliated, medium-grained biotite granulite. The major minerals are plagioclase and biotite with orthopyroxene and cordierite being less abundant. This rock is the most mafic (CI=50) of any unit seen in Garnet Brook.

The only additional rock unit observed in Garnet Brook is the most extensive of the five units mapped. The rock is a medium-grained, pinkish gneiss composed of plagioclase, greenish orthopyroxene, and cordierite.

Four of the five units described above are repeated, the exception being the blue, plagioclase-quartz granulite, which occurs only once (Fig. 5). The thickness and order of repetition of the 4 repeated units are not consistent. This variability is in contrast to the uniformity of the northwesterly strike and steep easterly dip of the metamorphic foliation. Minor folds in the cordierite-garnet-hypersthene gneiss are isoclinal with axial planes parallel to the foliation. Many of these isoclinal folds have fishhook shapes and appear to represent isoclinal folds that have been refolded isoclinally.

Contact Relations

Contact relationships among the members of the Garnet Brook stratigraphy are commonly gradational as noted in Fig. 5 . Intervening granitic intrusions, covered zones, and snowfields obscure some of the contact relations.

Basement-Nain anorthosite contacts are typically sharp, with the anorthositic rock truncating the layering of the basement. Basement-quartz monzonite contacts appear to be equally sharp, although the contact zone is commonly deeply weathered.

Discussion

The stratigraphy established along Garnet Brook provides the most complete picture to date of the basement lithologies for the Okhakh Bay-Laura Lake area. Any firm conclusions regarding the origin of the metamorphic units without the benefit of laboratory studies would be premature. No relict sedimentary structures were observed in the Garnet Brook rocks. However, the lack of sedimentary features is not surprising in light of the evidence for multiple metamorphism and deformation found in the rocks. This evidence includes uniformity of orientation of foliation, isoclinal folding and possibly refolding of isoclinal folds, equigranular texture, and generally anhydrous mineral assemblages of the granulite facies. The alternative to a clastic parentage for these basement rocks is one involving volcanic flows of basaltic to andesitic composition. The repetition of units observed in Garnet Brook may be the result of folding, or may represent repetition of the original parent rocks, be they sedimentary or igneous in origin.

It is clear that the composition of the basement in the study area varies considerably. Mafic pods, lenses, and layered sequences, too numerous to map, occur within the more common grandioritic to tonalitic gneisses and may represent mafic igneous intrusions into an older lithology, both having been deformed by subsequent orogenesis. Wheeler called these layered rocks "layered bodies and granulities of uncertain origin." Although their origin is still unclear, as is that of their less mafic host rocks, it is clear that they are a not so uncommon part of the basement lithology in this area.

Acknowledgement

The author gratefully acknowledges support for field work in 1981 from the Research Corporation. Assistance in the field from J. E. Gillespie is also greatly appreciated.

Editor's note

It has been suggested by I. F. Ermanovics of the Geological Survey of Canada (conversation, 30 Nov. 1981) that the lithologies described above along Garnet Brook have some similarities to the Upernavik Supracrustals of Bridgwater et al (1975) at Saglek (Saeglekh), some 125 km to the north. Moreover, Dr. Ermanovics suggests that these lithologies might well be traceable from Upernavik Island in Saglek Fjord to Okhakh Bay and thence southeastward out past the Jonathon Intrusion (Berg and Briegel, this Report); they are absent in the Hopedale Block to the south.

--S.A.M.

CONTACT RELATIONS OF ANORTHOSITIC AND MONZONITIC ROCKS AT STAGHORN LAKE AND OKHAKH BAY

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Introduction

In earlier studies (Ranson, FR 1975, FR 1976), I sought to map and sample in detail an area which extended across the Nain Complex and included both anorthositic and monzonitic (adamellitic of Wheeler's terminology) rock types. At the end of the 1975 and 1976 field seasons the contact relationship between these two rock types was still unclear, largely because of poor exposure in critical areas and variation of rock composition near the contact. Hence, one of the purposes of mapping at Okhakh Bay and Staghorn Lake (Fig. 1) was to study again the contact relations of the anorthosite and monzonite and the compositions of the rocks in the vicinity of that contact. Elsewhere (Ranson, 1979), I have reported laboratory studies that indicate that the anorthosite and monzonite are mineralogically distinct and are not the products of a single, fractionating magma. New contact relations seen in the field at Staghorn Lake and Ohhakh Bay lend support to this conclusion and refute the theory that there is a continuous gradation from anorthosite to monzonite.

Okhakh Bay

A geologic map of the Okhakh Bay area, which shows the contact mapped between the Nain anorthosite and quartz monzonite, has already been presented in this volume (Fig. 4). In most instances the transition from typical Nain quartz monzonite to typical Nain anorthosite or leuconorite can be measured in meters where exposure is good. The term transition is appropriate for describing the contact zone, because a sharp contact between the anorthosite and quartz monzonite was not seen in this area.

Before discussing the appearance of the rocks within the contact zone, it is useful to review their typical appearance away from the contact.

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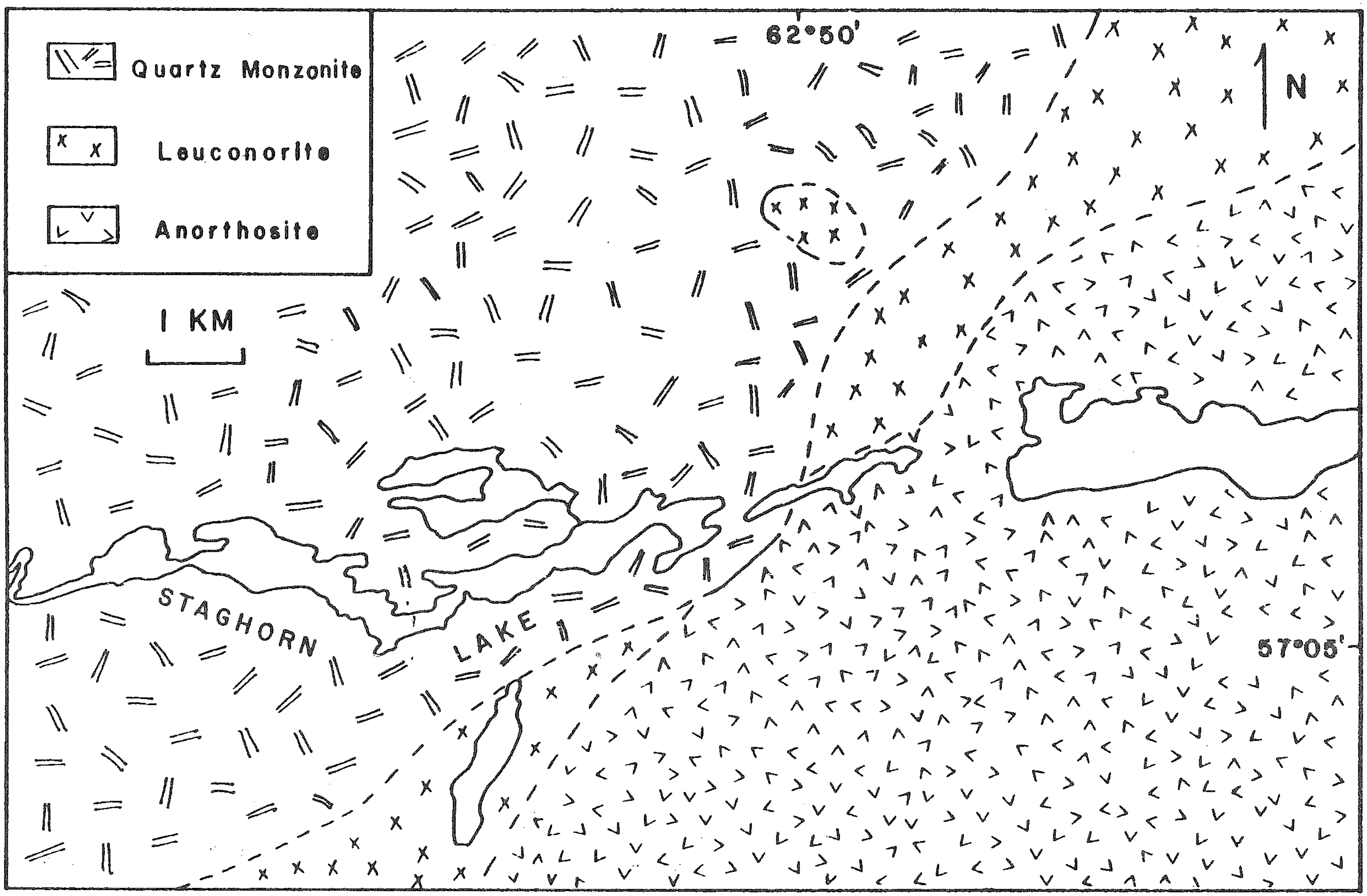
[1]Authors' full addresses are given at the back of this volume.

Fig. 6. Geologic map of the Staghorn Lake area.



The quartz monzonite is a medium- to coarse-grained (2 to 10 mm), light gray rock composed of orthoclase, sodic plagioclase, blue-gray quartz, and green amphibole, with accessory biotite, fayalite, and magnetite. The percentage of quartz varies and the rock name changes in accordance with that variation from granite to quartz monzonite to monzonite. Quartz monzonite appears to be the most abundant in the Okhakh Bay area.

The typical Nain anorthosite at Okhakh Bay varies in composition from anorthosite to leuconorite. Anorthosite (CI<10) consists of medium- to coarse-grained (5 to 20 mm) plagioclase, minor pyroxene, and accessory Fe-Ti oxides. Leuconorite (CI 10-25) always contains orthopyroxene in addition to plagioclase and accessory Fe-Ti oxides.

Within the narrow zone of contact observed between quartz monzonite and anorthosite, changes in the rocks appear to be restricted to the quartz monzonite. The first change noted as the contact was approached was the presence of purple crystals of plagioclase 1 to 2 cm in length set in a matrix of monzonitic rock. Concurrently, there is a reduction in amount of quartz present, and the rock is more appropriately called a monzonite. Finally, within a few meters of the contact with anorthosite, the grain size of the monzonite is reduced to 0.5 to 1 mm for the matrix. Isolated in this matrix are larger crystals (5 to 8 mm) of gray plagioclase and pink K feldspar.

Staghorn Lake

The anorthosite-monzonite contact relations at Staghorn Lake are shown in the geologic map of Fig. 6, which is contiguous to the north with the geologic map of the Puttuaaluk Lake area (FR 1976). The rocks at Staghorn Lake are more deeply weathered than those at Okhakh Bay, but the characteristics of the rocks are the same as those described in the previous section. Although the anorthosite-monzonite contact was more difficult to map, detailed mapping has revealed that in areas of good exposure the contact zone is commonly only 2 to 3 meters in width. As at Okhakh Bay, a sharp intrusive contact was not observed, but neither was there the subtle, gradual transition from anorthosite to monzonite that was seen to the north in the Puttuaaluk Lake area (FR 1976). The chief changes that occur near the contact are within the monzonite, which shows a decrease in quartz and grain size adjacent to the anorthosite. Both anorthosite and leuconorite are present in the contact zone and neither were seen to undergo changes in mineralogy or texture near the contact with monzonite.

Discussion

Presumably the large purple plagioclase crystals observed in monzonite matrix in the vicinity of the contact at Okhakh Bay have their origin in the anorthosite and were incorporated into the monzonite as it intruded anorthosite. Hence, these xenocrysts of plagioclase suggest a nearly solid anorthositic body at the time of monzonite intrusion. In both areas the monzonite is finer grained and apparently lower in free silica adjacent to the anorthosite. These field observations suggest that the anorthosite was fully crystallized and cool enough to chill the monzonitic magma as it intruded, thereby producing a fine-grained matrix surrounding early-formed K feldspar phenocrysts and plagioclase xenocrysts. The apparent scarcity of quartz in the contact monzonites may simply mean that it is hidden in the matrix or that near the margins of the intrusion quartz was not a liquidus phase.

Although a sharp intrusive contact remains elusive, the field observations made at Staghorn Lake and Okhakh Bay refute the idea of a continuous gradation of anorthosite to monzonite. Furthermore, these observations suggest that the anorthosite is older than the monzonite and that it was substantially cooled at the time of monzonite intrusion. Certainly, an intrusive rather than a gradational contact is more harmonious with the model that anorthosite and monzonite are derived from genetically distinct parent magmas, a model based on their very different mineralogies (Ranson, 1979).

Acknowledgement

Support for field work from the Research Corporation is again gratefully acknowledged, as is assistance from J. E. Gillespie.

RECONNAISSANCE GEOLOGY OF THE BIRD LAKE ANORTHOSITE MASSIF, LABRADOR

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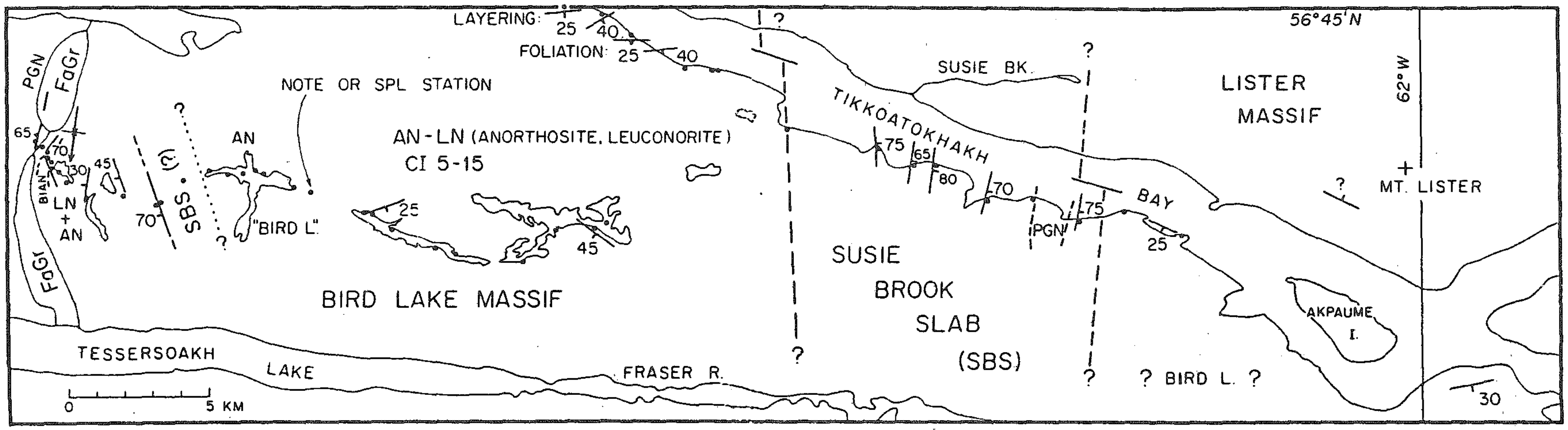
Introduction

Three major anorthositic massifs--Bird Lake, Susie Brook Slab, and Lister--are exposed along the shores of Tikkoatokhakh Bay (Morse and Wheeler, FR 1973). They contain generally sodic plagioclase (An 40's; Morse, FR 1976) and orthopyroxene, which, in Susie Brook and locally elsewhere, contains exsolution lamellae of plagioclase (Morse, 1975). The Susie Brook Slab is notable for its steep easterly dip of 70°, indicating at least one episode of large-scale deformation during the emplacement of anorthosite. The Bird Lake Massif, previously examined only along the shore of Tikkoatokhakh Bay, was examined along an upland traverse during the 1981 field season from its western margin with country rocks to within 6 km of the western edge of the Susie Brook Slab. Findings include the recognition of a biotite-garnet zone at the western margin, and a possible western limb of the Susie Brook Slab.

Western Contact Zone

The anorthosite contact is exposed in a narrow gap between two bodies of younger fayalite granite (Wheeler, 1968), as shown in Fig. 7. The Aphebian (?) country rocks include mafic and ultramafic opx + plag ± cpx ± biot gneisses and garnetiferous qz + fsp + biot gneisses showing at least two stages of deformation. Foliation dips 65° W. Anorthosite and leuconorite near the contact are also strongly foliated with the same attitude. The outward dip of this apparently conformable contact suggests the proximity of a roof. However, the conformability disappears within a few hundred meters, and a steep easterly dip is

[1] Authors' full addresses are given at the back of this volume.



PGN, paragneiss; FaGr, fayalite granite; BIAN, biotite anorthosite

Fig. 7. Geologic map of the Bird Lake Massif, Susie Brook Slab, and Lister Massif.

succeeded eastward by a shallow westerly dip, suggesting the presence of a syncline in the anorthositic rocks (Fig. 7).

The foliated 1-cm anorthosites and leuconorites of the contact zone are succeeded eastward by a 200-m wide zone of fine-grained, white, biotite anorthosite with CI∿10. This unit is succeeded by unfoliated anorthosite and leuconorite, locally with layers up to CI=35. Plagioclase megacrysts 1 x 8 cm occur locally in seriate-textured anorthosite. Widespread shearing involving rotation of plagioclase megacrysts suggests deformation before the end of crystallization. A locally intense E-W jointing is occupied by pink granitic material, near which the normally pale gray plagioclase becomes waxy white.

Western Limb of Susie Brook Slab

Beginning 2 km west of Bird Lake, the rock is relatively fresh leuconorite with distinctive black, stretched orthopyroxene megacrysts up to 20 cm long, in places clearly subophitic to plagioclase, and locally forming layers with CI∿15. Exsolution lamellae of plagioclase occur in at least some of the pyroxene megacrysts. The distinctive stretched-subophitic texture of high-Al orthopyroxene megacrysts is identical to that of the Susie Brook Slab (Morse, 1975), and on this basis the rocks are correlated with that unit. This lithology either merges with or is in contact with leucocratic structureless anorthosite to the east, as far as the middle of Bird Lake. Where observed, the dip of the stretched-layered unit is 70°W, symmetrical with the 70°E dip of the Susie Brook Slab. Taken together, the two limbs suggest an upright anticline plunging gently to the south for the Susie Brook unit as a whole, or else widely separated non-parallel intrusions.

Bird Lake Massif

The rocks from the middle of Bird Lake to the end of the traverse are all coarse anorthosite to leuconorite with CI 5-15. The orthopyroxene locally contains exsolution lamellae of plagioclase but is not stretched. Rare layering occurs with southerly dips (25° and 45°). The rocks are sheared and altered by numerous brick-red to pink granite dikes and veins striking roughly 110° with conjugate dips

45^{o} N and S.

Discussion

Bird Lake Massif. The region of moderate southerly dips extends at least from the south shore of Tikkoatokhakh Bay to the present traverse and continues east of the Susie Brook Slab at least as far as Tikkoatokhakh Rattle at the eastern end of Fig. 7. For want of a better criterion, all the rocks showing southerly dips are here considered part of the Bird Lake Massif. Westerly dipping rocks west of the west limb of the Susie Brook Slab may also belong to the same massif. Ignoring the interruption of the Susie Brook Slab, the Bird Lake Massif extends for some 50 km in an east-west direction and for an unknown distance north and south of the present map area. It is therefore one of the largest anorthositic massifs of the Nain Complex.

Wet contact aureole. The garnet-biotite paragneiss at the anorthosite margin and the biotite anorthosite zone inside the contact are highly unusual for the Nain Complex, which commonly shows dry granulite assemblages at the contact (Berg, 1977). If the biotite is due to later metamorphism, that event would have to be peculiarly localized to the paragneisses and a small zone within the noritic anorthosites. The fayalite granites occupying most of the contact zone are essentially anhydrous and an improbable source of water; moreover, they are not themselves metamorphosed insofar as can be determined from the descriptions of Wheeler (1968). The biotite is therefore likely to be an original feature of the contact aureole where the partial pressure of aqueous vapor was fortuitously high.

Emplacement history. Intrusive relations between the Susie Brook Slab (SBS) and Bird Lake Massif (BLM) are unknown. The presence of a screen of paragneiss near the eastern limit of SBS suggests the foundering and tilting of this 9-km thick unit from a higher level. The gentle to moderate southerly dips of BLM are permissive of a primary origin and are inconsistent with later deformation of the whole block to produce the rotation (or folding) of SBS. The SBS is therefore considered the earliest anorthositic unit in the area, which was then deformed by rotation and hot plastic stretching of layers and megacrysts due to its engulfment by magma which produced BLM.

Post-crystallization history. Abundant diking of BLM (and SBS?) by pink to brick-red granite in conjugate shears which strike parallel to the main fracture pattern of the Nain Complex suggests an event of N-S extension long enough after the crystallization of anorthosite to permit brittle fracture and low-grade hydrothermal alteration. It is possible that this extension was a reactivation or a prolongation of an earlier extension that permitted access of the anorthosite-producing magmas to the crust (Berg, 1977).

Acknowledgments

The capable and cheerful assistance of George Marshall is gratefully acknowledged, as is the diverting but stimulating presence of several thousand milling caribou.

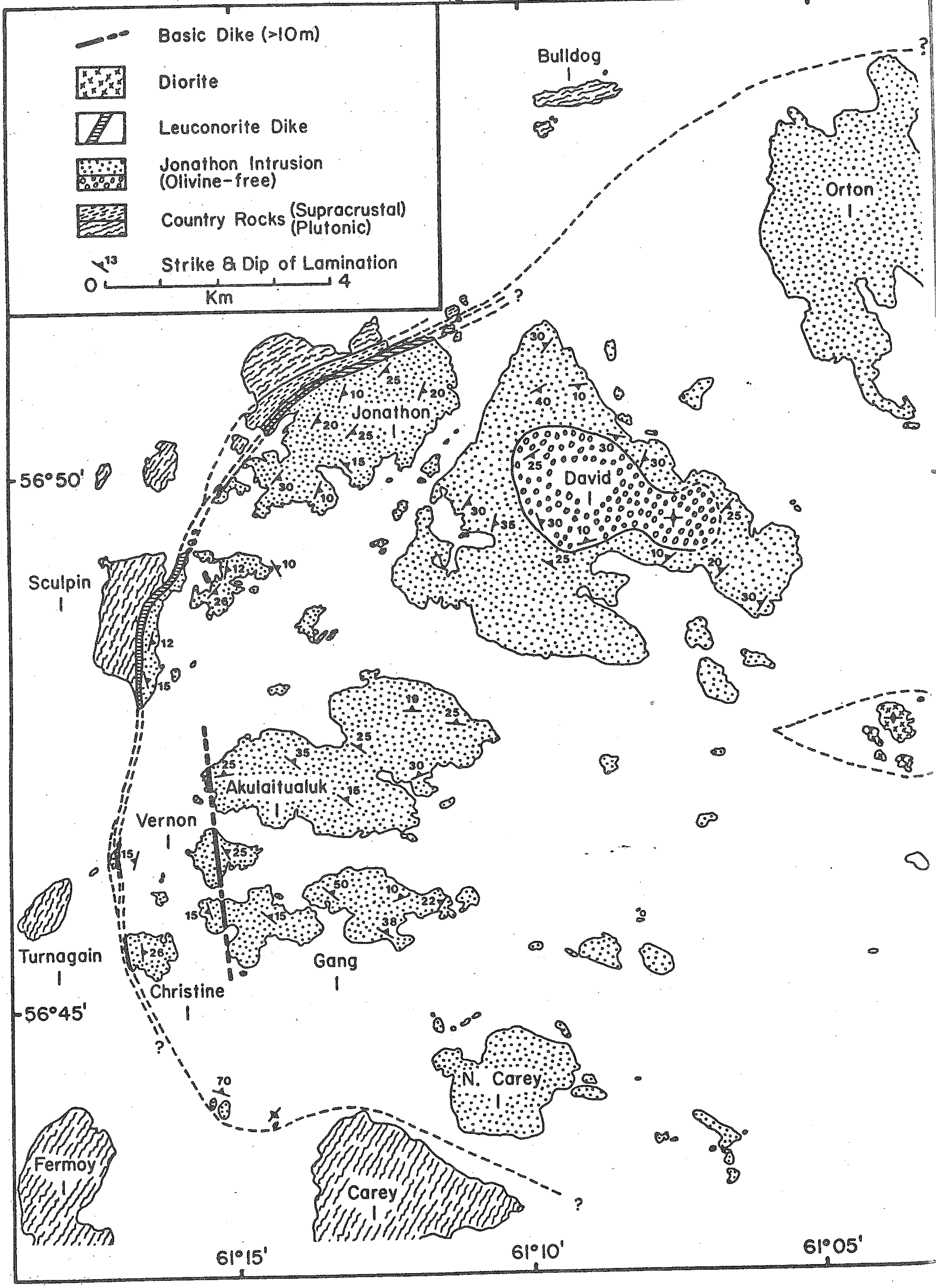


Fig. 8. Geologic map of the Jonathon intrusion.

LAYERED INTRUSIONS EAST OF PORT MANVERS RUN

GEOLOGY OF THE JONATHON INTRUSION AND ASSOCIATED ROCKS

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Introduction

Seeking to explore further the contact relations between anorthositic rocks and metamorphic country rocks, and also hoping to find more examples of melatroctolitic intrusions (Berg and Pencak, FR 1980), we conducted field work on the islands located east of Kolotulik Bay on South Aulatsivik Island (see Fig. 1). On Jonathon Island a contact between anorthositic rocks and country rocks is well exposed (Fig. 8), as are most of the characteristic features of the anorthositic intrusion. Thus we have named this intrusive body the Jonathon intrusion, and herein we describe the field aspects of this intrusion and associated rocks.

Country Rocks

The country rocks adjacent to the Jonathon intrusion are exposed on the western sides of Jonathon and Sculpin Islands and some of the islets between them as well as on Carey Island (Fig. 8). These country rocks can be divided into three categories: (1) granitic to tonalitic gneisses and migmatites, (2) rocks of supracrustal origin, and (3) mafic granulities and gneisses.

On Jonathan Island there is a zone about 200-400 m thick, adjacent to the intrusion contact, which is dominated by the rocks of probable supracrustal origin and abundant dikes or sills of fine-grained mafic granulite. The supracrustal rocks consist of quartzites with thin conglomerate lenses, semipelites (biotite + feldspar + quartz), calc-silicate gneisses, spectacular metamorphosed breccias or debris flows, and a peculiar purple rock that appears to be of sedimentary origin but consists predominantly of feldspar and orthopyroxene with locally common quartz and K feldspar. In thin section two feldspars, purple oligoclase/andesine and colorless mesoperthite, are apparent. The rock has an annealed texture. The purple rock is well-layered and commonly interlayered

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with the calc-silicate gneisses. Locally it contains lenses with a conglomeratic texture, and here quartz and K feldspar seem to be more abundant. The purple rock is also the matrix of the breccias whose fragments are rounded, range from about 4 cm to 50 cm in diameter, and consist mainly of anorthosite (?), calc-silicate rock, and mafic granulite. Locally there are sulfide-rich pyroxenite veins in the matrix. The igneous composition of the purple rock combined with its sedimentary appearance suggest that it is of pyroclastic origin.

Farther out from the intrusion contact on Jonathon Island the country rock is dominated by granitic to tonalitic gneisses and migmatites which are locally cut by dikes or small plutons of mafic granulite. The granitic and tonalitic gneisses also appear to dominate the country rocks on Sculpin and Carey Islands, although layers that may be quartzites can be found locally.

Mafic Granulites. The mafic granulities that cut the country rocks are clearly of several generations. On the northwestern side of Sculpin Island mafic granulite dikes which cut granitic gneisses have been broken up and partially invaded by remobilized granitic gneiss. The mafic granulites that are so abundant in the supracrustal rocks near the intrusion contact take the form of dikes and sills that are commonly parallel to the strike of the surrounding rocks, but locally they are at high angles to the strike. The localized nature of these mafic granulites and their typically sharper contacts suggest that they are probably younger than at least some of the mafic granulites which cut the granitic gneisses.

A probable third generation of mafic granulites was found cutting the gneisses on Carey Island. Two parallel mafic granulite dikes, each 3-5 m thick, cut the gneisses at a high angle. The dikes trend approximately E-W, whereas the gneisses trend roughly N30^{o}E. These olivine-bearing dikes are interesting in that although they may be recrystallized and are cut by small dikes of anorthosite, a xenolith of coarse anorthosite is present in one of them. Apparently they were intruded at an early stage the development of the anorthosite complex.

Another mafic granulite dike which trends E-W and sharply cuts across the foliation of basement gneisses and also sharply cuts other mafic granulite was found on the northwest side of Sculpin Island. The minimum relative age of this dike cannot be determined as closely as in the case of the dikes on Carey Island, but we suspect that these E-W mafic granulite dikes are related.

Jonathon Intrusion

The Jonathon intrusion is anorthositic in a very broad sense. The average color index is probably 15, although color indices of 20-25 and 0-10 are not uncommon. The intrusion has been mapped on Christine and North Carey Islands to the south, Sculpin and Jonathon Islands to the west, and David, Akulaitualuk, Vernon, and Gang Islands (Fig. 8). The northern and eastern limits of the intrusion have not been determined because of logistical problems related to ocean swell. Reconnaissance mapping by Wheeler (FR 1972) indicates that the rocks on Orton Island are similar to those on David; thus we infer that the intrusion contact passes north of Orton Island.

Chilled Margin. Where clearly exposed on Jonathon Island, the contact between the intrusion and country rock (mafic granulite) is very sharp. At and near the contact the igneous rock is fine-grained (0.2 - 1.0 mm) and massive, and compositionally it is an orthopyroxene-bearing leucotroctolite. This chilled margin is distinctively finer grained than the main body of the intrusion which has grain sizes ranging from 2 to 8 cm, and it has a color index near 25 with an olivine:orthopyroxene ratio of about 3:1 or higher. Locally the chilled margin contains parallel lenses or stringers of slightly coarser leucotroctolite. These stringers are typically 4-6 cm by 1-2 cm and have grain sizes ranging from 2 to 5 mm. At its thickest the chilled margin is about 15 m thick.

Border Zone. Over a distance of 1-2 m, the chilled margin grades into a zone of coarser leucotroctolite with CI = 20-30. This zone is heterogeneous in texture and grain size and ranges in thickness from a few meters to 70-100 m. Nearer the chilled margin, grain size can change abruptly from less than a centimeter to more than 60-70 cm. Texturally these rocks range from massive to comb layered with the comb layering of plagioclase oriented roughly perpendicular to the intrusion contact.

An unusual texture involving large olivine crystals is most common in, though not confined to, this zone. Large olivine crystals, typically 15-30 cm in diameter but up to 1/2 m, occur in patches and contain an internal boxworklike skeleton of plagioclase or, locally, orthopyroxene. The plagioclase typically makes up no more than about 10% of the volume of an olivine patch, and portions of the plagioclase are commonly in optical continuity with plagioclase crystals adjacent to the patch. This interesting texture has been found locally in the interior of the intrusion but is extremely common in this marginal zone.

Toward the interior of the intrusion this zone becomes less heterogeneous. Grain size becomes more uniform (1-3 cm), and lamination parallel to the intrusion floor occurs locally.

Main Zone. Over a few meters to a few tens of meters the border zone grades rather abruptly into the main part of the intrusion via a decrease in olivine and color index, an increase in plagioclase and orthopyroxene, and a greater degree of plagioclase lamination in the rock. Although plagioclase lamination is relatively common and the color index does vary from 0 to 30, obvious layering in the intrusion is extremely rare.

The structure of the intrusion has been determined primarily on the basis of lamination. This is not a simple matter, inasmuch as there appear to be two types of plagioclase lamination. One type is typically gently-dipping (0° - 30°), and where near the intrusion contact its strike parallels that of the contact. The other type of lamination has steep dips (commonly 70° - 90°) and is characteristically perpendicular in strike to the other lamination where both types occur in different parts of the same outcrop. The strikes and dips of the former type of lamination are plotted in Fig. 8 and are assumed to be parallel to the intrusion floor at various stages of crystallization.

We interpret the steep lamination as representing perpendicular growth of plagioclase from the floor of the intrusion. The relatively common occurrence of the steep lamination would suggest that this process of crystallization was widespread in the intrusion. We have no explanation for why the strikes of the two laminations are typically perpendicular.

The strikes and dips of the gently-dipping lamination are broadly consistent and concentric about the center of David Island (see Fig. 8), indicating that this is the structural center of the basin-like intrusion. Nevertheless, there are numerous, locally incongruous strikes or reversed dips; it seemed especially common to find reversed dips near the marginal zones. On the east end of Gang Island there is a clearly visible broad synclinal or elongate basinal structure, and other such irregularities, though not as obvious, probably are common across the intrusion. These irregularities are more easily understood when one considers the fact that much of this lamination has dips which are near 10^{o} or 15^{o}. Not only could slight undulations on the floor of a magma chamber cause dip reversals, but the measurement uncertainty is comparable to the dip angle in some places.

The most characteristic rock type in the intrusion is olivine leuconorite having considerably more abundant orthopyroxene than olivine. Plagioclase occurs as primocrysts throughout the intrusion, but the mafic minerals appear to be intercumulus or interstitial except locally. This judgment, however, is not always easy to make in the field. It is not uncommon to find orthopyroxene rimming olivine and in rare instances olivine has been found rimming orthopyrozene. The typical grain size is 2-4 cm and plagioclase phenocrysts or megacrysts (5-10 cm) are ubiquitous.

Locally either mafic mineral may dominate, and over hundreds of square meters of area one mafic may occur to the exclusion of the other. On a very local scale (square meters), this appears to be a nucleation phenomenon. In one volume of the plagioclase "pile" only olivine nucleated and in the adjacent volume only orthopyroxene. Locally, boundaries between leucotroctolite and leuconorite cut perpendicularly across the shallow-dipping plagioclase lamination. On a large scale (hundreds of square meters) perhaps inhomogeneities in the magma or injections of new magma into the magma chamber caused the alternations between leuconorite and leucotroctolite.

Near the structural center of the intrusion at the higher elevations on David Island, there is an apparently significant change from olivine leuconorite to olivine-free leuconorite (Fig. 8). Whether this is just a fortuitous occurrence of the inhomogeneities described above or whether the magma had evolved to the point where olivine permanently ceased to crystallize is difficult to assess. However because the center of David Island is about 300-360 m higher than the adjacent islands mapped and because of the concentricity of lamination about David Island, it is reasonable to assume that the center of the island might preserve the stratigraphically highest parts of the intrusion.

Throughout the intrusion anorthosite xenoliths are abundant. They range from angular to rounded and a few centimeters to considerably more than 50 m in diameter. Although there is some variability in the nature of the anorthosite xenoliths, the clearly predominant type has a relatively fine grain-size (1 cm), gray-white color, and granulated texture.

The larger anorthosite xenoliths ($\geq$ 1 m) are typically surrounded by a zone of extremely coarse (pegmatitic) olivine leuconorite. In most instances it appears that the larger the xenolith, the larger the pegmatitic zone. For a 1-2 m xenolith the pegmatitic zone is commonly about 1 m thick. For the largest xenoliths the pegmatitic zone may be tens of meters thick. Also, it is not uncommon for this pegmatitic material to be more olivine-rich than the surrounding average rock. Coarse pegmatitic zones without anorthosite cores are also common in the intrusion, although it is difficult to prove that they are not associated with anorthosite in the third dimension.

Severely altered shear zones are common throughout the intrusion, but especially on David Island. Unfortunately, alteration is not restricted to shear zones and is found in many unsheared rocks of the intrusion. The alteration is made obvious by the partial or complete replacement of mafic minerals by a green amphibole.

Younger Intrusions

Hybrid Leuconorite. The Jonathon intrusion is cut by a variety of younger dikes. Probably the oldest of these and perhaps even genetically related to the Jonathon magma is a hybrid leuconorite dike which has been intruded along the margin of the Jonathon intrusion (Fig. 8). The dike ranges from 15-40 m thick, and it is typically found between the chilled margin and country rock or between the chilled margin and the rest of the intrusion.

The dike ranges from extremely coarse-grained leuconorite with minor olivine, locally, to fine-grained leuconorite and rarely to medium-grained diorite. Xenoliths are abundant and in some cases difficult to distinguish from the host rock. The most common xenoliths are chilled margin and coarser-grained rocks of the Jonathon intrusion, but anorthosite xenoliths (common) and basement xenoliths (rare) occur. A streaky layering, dipping very steeply, and pyroxenite stringers are characteristically present. The range of compositons and grain sizes, the streaky layering and stringers, and the abundant xenoliths combine to give the dike a very heterogeneous appearance.

Pink Granite. Many pink granite dikes cut the Jonathon intrusion. These dikes are commonly pegmatitic, and in one place large (3-4 cm) crystals of molybdenite were found. The most prominent dikes have strikes that are approximately E-W, ranging from N77°E to N60°W. Unfortunately, the orientations of most dikes were not measured, but by analogy with the orientations of pink granite dikes elsewhere in the Nain complex (Morse, this Report) we suspect that E-W is the dominant direction.

Melatroctolite. Two melatroctolite dikes were found in the area. One was intruded between the chilled margin and the basement for a short distance on the north side of Jonathon Island, and the other is a dike $<$ 1 m thick which strikes E-W and is exposed on the small islet west of the big bay on the west side of Akulaitualuk Island. These dikes are fine-grained and homogeneous. By their very mafic nature, they are clearly related to other melatroctolitic rocks found throughout the Nain complex (Berg and Pencak, FR 1981; Berg, 1980).

Diorite. Small diorite dikes, rarely over a meter thick, are found sparsely distributed throughout the area. Locally they form dense parallel swarms with a distinct E-W orientation. Most of the dikes are fine- to medium-grained, and some are layered. An intrusion of apparently similar composition was found on a group of islets east of David and Akulaitualuk Island (Fig. 8). The diorite in this intrusion is coarse-grained and has moderately strong foliation with a steep dip and an E-W strike.

Light-Colored Granitoid Rocks. Although not abundant, several light-colored felsic to intermediate dikes cut the Jonathon intrusion. Although some have an E-W orientation, there does not appear to be one predominant orientation. These dikes are typically $>$ 1 m in thickness. The largest strikes about N40°W, is about 30 m thick, and locally contains numerous angular xenoliths of olivine leuconorite. The dike is probably granodiorite in composition and has a coarse-grained interior but a very fine-grained chilled margin. Most of the other dikes are less mafic and more granitic than this dike.

Basalt. Sharply cross-cutting and very fine-grained basaltic dikes are found throughout the Jonathon intrusion and the surrounding country rocks. These dikes, with one exception, are near vertical, trend E-W, and have extremely fine-grained chlled margins. The one exception is a prominent 10 m thick dike which trends N7°W and is exposed on the western side of Akulaitualuk, Vernon, and Gang Islands. This dike is lighter colored and coarser grained than the other dikes and may not even be basalt. Where it was coarsest, it appeared that it might contain two feldspars. The strike of the E-W dikes is somewhat variable. Only a fraction of the dike attitudes were measured, but they range from at least N77°E to N83°W (077° to 097°).

Conclusions

The large number of anorthosite xenoliths and the fluctuations between orthopyroxene and olivine as the dominant mafic mineral suggest the likelihood that the Jonathon magma chamber was not a closed system. Nevertheless the chilled margin appears homogeneous and, based on modal composition, is likely to yield a chemical composition not far different from the Hettasch chilled margin (Berg, 1980; FR 1973).

The age of the intrusion relative to several other prominent intrusions of the Nain complex can be inferred. The Jonathon intrusion is heavily diked by pink granite and is also intruded by at least two melatroctolite dikes. Pink granite dikes are rare or absent in the Hettasch intrusion (Berg FR 1973), and melatroctolite is contemporaneous with it (Berg, 1980). Pink granite dikes are rare or absent in the Kiglapait intrusion (Morse, this report), and the Hettasch intrusion is apparently cut by the Kiglapait intrusion (Berg, unpublished data). The "foliated anorthosite" of Berg (FR 1973) is intruded by pink granite dikes, has steep foliation, and commonly appears stretched, smeared out, or granulated. Based on the above, it is inferred that the age sequence from oldest to youngest is "foliated anorthosite", Jonathon intrusion, Hettasch intrusion, and Kiglapait intrusion.

Finally, the establishment of evidence for a long history of E-W diking, starting early in the development of the anorthosite complex (mafic granulites) and continuing through to a post-anorthosite phase (fine-grained basalts), strongly suggests that a roughly N-S extensional regime (continental rifting?) was contemporaneous with the anorthosite event, and not just a post-anorthosite event (cf. Emslie, 1978).

Editor's note

Wheeler's manuscript maps suggest that the Jonathon Intrusion may extend southeast as far as St. John I. (UTM 20VPT2685) and Savage Is. (UTM 20VPT2992) as well as north of Orton I. If so, its area could approach or exceed 400 km^2, making it one of the largest intrusions in the Nain Complex, after Bird Lake-Lister (800 km^2?) and Kiglapait (560 km^2).

-- S.A.M.

THE HETTASCH INTRUSION AND SURROUNDING ROCKS IN THE VICINITY OF MILLS HARBOUR, PORT MANVERS RUN, LABRADOR

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Introduction

Field work on South Aulatsivik Island was done during the summer of 1981 with the intention of establishing the presence or absence of the Hettasch Intrusion to the southeast of Port Manvers Run. That the Hettasch Intrusion did in fact cross Port Manvers Run was quickly established; and emphasis changed to the determination of the nature and extent of the Hettasch and its host rocks in that area.

Previous work by Berg (FR 1972, FR 1973) established that the Hettasch Intrusion forms an asymmetric syncline, of arcuate surface expression, extending over some 200 km^2. Between its northernmost extent, where it is cut off by the Kiglapait Intrusion, and Port Manvers Run, the Hettasch is in contact to the west and south with the North Ridge Gabbro, the Webb Valley Metamorphic Complex, and the Foliated Anorthosite, each in turn. To the north and east it is in contact with Massive Leucogabbronorite and Foliated Anorthosite (Berg FR 1973). Of these, Berg has indicated that the Massive Leucogabbronorite is younger than the Hettasch Intrusion.

Southeast of Port Manvers Run, the host rocks for the Hettasch Intrusion are dominantly Foliated Anorthosite although there is at least one troctolitic body of intermediate age in contact with the Hettasch Intrusion on its southern flank. In turn, the Hettasch is intruded by younger troctolite in at least two separate locations. The intrusion maintains its generally synformal structure throughout the area of interest. As noted by Berg (FR 1973), the southern limb of the syncline dips far more steeply than the northern limb. The Hettasch Intrusion appears to end 2 - 3 km east of Port Manvers Run, although this is difficult to establish with certainty since this critical area is well covered with glacial debris (Fig. 9).

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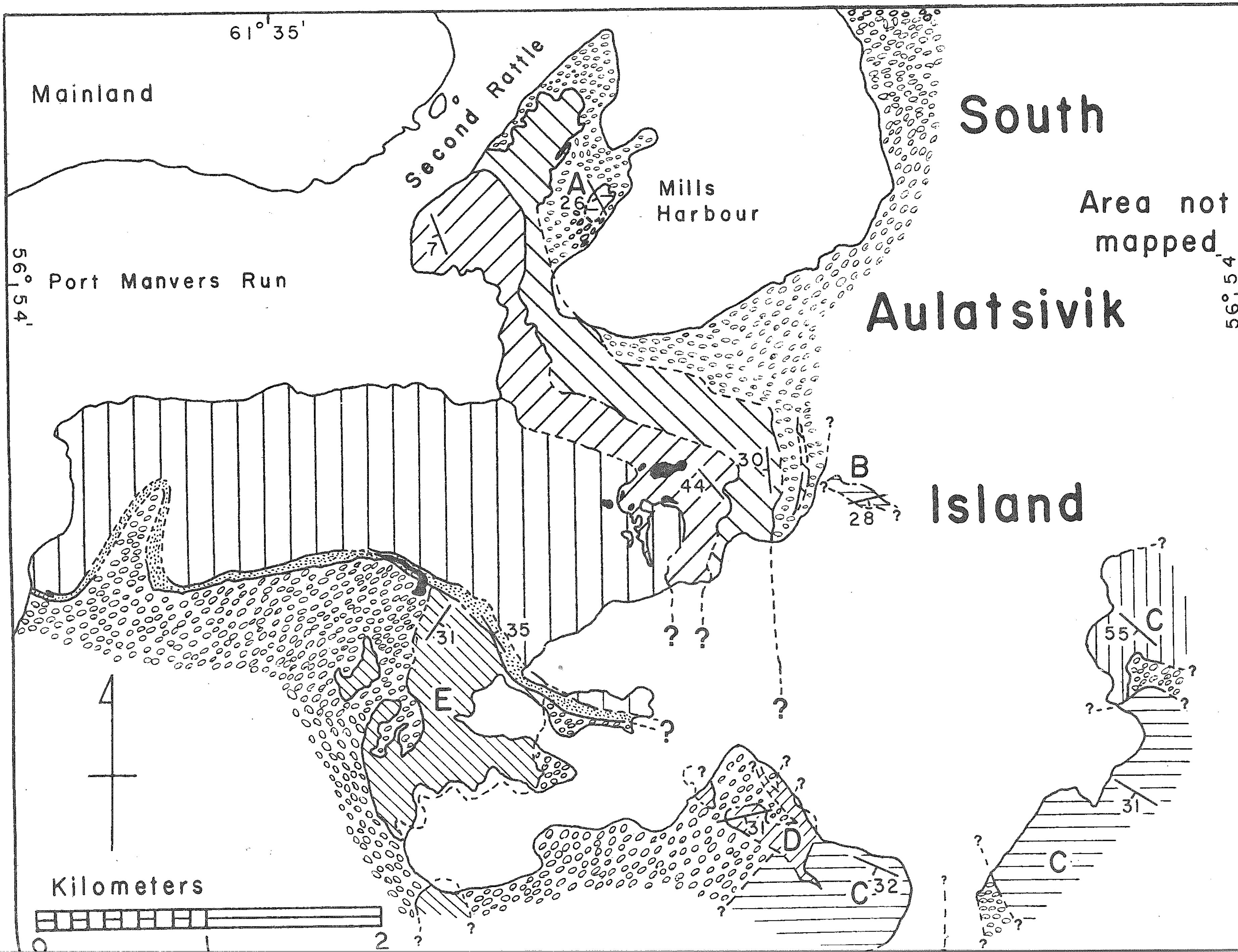
[1] Authors' full addresses are given at the back of this volume.



61°35'
Mainland
Second Rattle
Mills Harbour
South Aulatsivik Island
Area not mapped
56°54'
Port Manvers Run
56°54'
A
B
C
D
E
26
7
30
44
28
55
31
35
31
32
Kilometers
0
1
2

Fig. 9. Geologic map of the Hettasch intrusion and related rocks in the vicinity of Mills Harbour.

KEY

Strike and dip of lamination

Recent glacial sediment deposits, within area mapped only.

Troctolitic bodies younger than the Hettasch Intrusion

Hettasch upper zone

Hettasch inner lower zone

Hettasch outer lower zone

Anorthosite block zone

Intermediate troctolite:

- Troctolite of locality D
- Mafic troctolite of locality E
- Fine-grained troctolite - leucotroctolite
- Coarse-grained troctolite - leucotroctolite

Foliated Anorthosite

Foliated Anorthosite

Rocks mapped as Foliated Anorthosite exhibit highly variable textures, structures, and mineralogic compositions. Generally, the color index is low, less than 5, and there is an absence of any clearly defined foliation, lamination, or layering, though local exceptions to this rule occur. The groundmass consists of gray plagioclase crystals less than 1/2 cm in length. Typically there are megacrysts of plagioclase, 5 - 6 cm long with some up to 8 cm, scattered throughout the groundmass in greater or less amounts. The megacrysts are commonly broken and rounded, as are the crystals of the groundmass, forming a protoclastic texture. The plagioclase is locally stained a pinkish color from iron oxide platelets enclosed by the crystals (J. H. Berg, pers. comm., 1981). The finer grained plagioclase which forms the groundmass is locally surrounded by white alteration rims. This feature is most common on the peninsula at Mills Harbour, where it was found to be confined exclusively to the Foliated Anorthosite. Elsewhere it is much less common, though diagnostic of the Foliated Anorthosite. The color index is locally as high as 15 - 20. Mafic minerals consist predominantly of orthopyroxene, although olivine is not rare. Most commonly, the mafics occur interstitially between the plagioclase laths; however, there are examples of discrete crystals of olivine and orthopyroxene up to 60 cm across.

Intermediate Troctolite

Rocks mapped as intermediate troctolite constitute a suite of rocks, variable in aspect, which are discontinuous spatially and perhaps also temporally. They are referred to as intermediate because they seem to be intermediate in age between the Hettasch Intrusion and the Foliated Anorthosite, as will be discussed below. Five separate occurrences, which were distinguished on the basis of texture or mineralogic composition, are noted. Locations are designated by the appropriate letter on the map (Fig. 9).

Locality A on the southeastern tip of the peninsula bordering Mills Harbour consists of a mass of medium-grained leucotroctolite which grades to a coarse-grained leuconorite in the southern corner of the exposure. In the leucotroctolite the plagioclase crystals are 4 - 5 cm in length, the color index is 20 (olivine 15, orthopyroxene 5), and some of the olivines are rimmed by orthopyroxene. Within the leucotrocolite are layers of fine-grained anorthosite, oriented subparallel to the lamination. As the leucotroctolite grades into the leuconorite, olivine disappears, oxides become common (3 - 5% of the rock), the color index drops to 10 - 15, and plagioclase increases in length to 6 - 8 cm. The leucotroctolite - leuconorite mass is well laminated and is in sharp contact with the Foliated Anorthosite which it appears to intrude.

Locality B on the highlands to the south of Mills Harbour is composed of material similar in many respects to that at locality A. The rock is coarse-grained, with plagioclase crystals from 6 - 8 cm in length, and well laminated. The mafic minerals are interstitial to the plagioclase, and consist of olivine and orthopyroxene in roughly equal amounts. The color index is 20.

At the eastern and northern ends of the exposure at locality B the coarse-grained material is in seemingly conformable contact with finer-grained material which dips beneath it. This finer-grained material includes blocks of anorthosite of irregular shape. Lamination in the finer material seems locally to parallel the edges of the blocks. Plagioclase tablets are present up to 1.5 cm in length in a finer-grained groundmass while the odd plagioclase megacryst is typically up to 8 cm in length. The mafics are present as discrete grains, rather than being interstitial, and are mostly olivine. The color index of the finer material is 20. The contacts of this body with the Foliated Anorthosite were lost under sedimentary material to the east and west.

Locality C is actually a very large area which was mapped and sampled in reconnaissance fashion towards the end of the field season. This was done when it became apparent that the southern terminus of the Hettasch Intrusion was covered by glacial debris; however, time constraints prevented an exhaustive effort. Generally, the descriptions given are of the closest outcrop of bedrock to the last known exposure of the Hettasch Intrusion.

The northeast end of locality C consists of a fine-grained leucotroctolite. The plagioclase grains are up to 1.5 cm in length, some equant and some tabular, in about equal proportions. Most of the plagioclase is much less than 0.5 cm in length, forming a saccharoidal groundmass; however there are rare battered megacrysts of plagioclase, up to 5 cm in length, present also. A weak lamination is observed in the plagioclase grains, and the color index is 15 - 20. Lenses and irregular blocks of anorthositic material (color index less than 5) occur within the leucotroctolite. These lenses increase in abundance in the direction of the contact with the easternmost of the two anorthositic bodies of locality C (see Fig. 9). The anorthosite which forms the lenses and blocks, as well as that of the anorthositic body, is indistinguishable from the Foliated Anorthosite described above.

In contact with both the eastern anorthosite and the fine-grained troctolite described above, and overlying the fine-grained unit, is a coarser-grained troctolite. This material has strongly laminated plagioclase tablets 4 - 5 cm in length. The color index is 15, of which 10 is olivine and 5 orthopyroxene. Though interrupted by the westernmost anorthositic body of locality C (see Fig. 9), this body of rock may originally have been continuous all the way to its termination against the troctolitic rocks of locality D. In that direction, several mineralogic and textural changes are observed: The plagioclase tablets decrease in size to 1 - 1.5 cm or less; the color index first rises to 20, and then decreases to 5 at the contact with the troctolitic rocks of locality D; orthopyroxene attains an abundance approximately equal to that of olivine; and both show progressive chloritization, which becomes complete at the locality D contact. In the vicinity of the western anorthositic body, a small amount of clinopyroxene was observed in the rock.

The western anorthosite body has the appearance of Foliated Anorthosite, which has already been described. Near its contact with the surrounding troctolite is a cataclastic zone.

The rock at locality D is easily distinguished from that of the southwest end of locality C in that the mafic minerals associated with this body are more abundant and essentially unaltered. Plagioclase grains are variable in size, but are commonly up to 1.5 cm in length, have a lathlike habit, and exhibit lamination. Many are smaller, with a granulated appearance. The color index varies from 10 to 40, with local excursions as high as 70. The mafic mineral is dominantly olivine. It is not known whether this body is in contact with the Hettasch Intrusion or not; the possible contact area is covered by glacial debris.

The final body mapped as intermediate troctolite is exposed at locality E. This rock unit overlies the Foliated Anorthosite, and occupies hilltops, for the most part, throughout its area of outcrop. The contact between the two rock types is essentially flat lying in the west, becoming steeper and dipping to the west at the eastern edge of the body. The color index ranges from 40 to 70, with olivine the dominant mafic mineral. The plagioclase is typically 2 - 3 cm in length, though locally near contacts it may be less than 0.5 cm. Lamination is common, and near the contacts it seems to parallel the contact. In the interior of the body, however, it assumes a steeper southeast dip (see Fig. 9). Blocks of anorthosite of varying size are present, particularly near the contacts with the Foliated Anorthosite. This intermediate troctolite unit is in contact along its northern edge with the Hettasch Intrusion, which truncates its lamination.

The Hettasch Intrusion

Preliminary statement. Following the nomenclature of Berg (FR 1972, FR 1973), the Hettasch Intrusion is divided into upper and lower zones, and the lower zone is further subdivided into inner and outer limbs. The intrusion is synformal and asymmetric. On the mainland west of Port Manvers Run, the outer lower zones lies along the southern border of the intrusion and its inner counterpart lies along the northern border, hence the terms "outer" and "inner" refer to limbs lying near the external (basement complex) margin and the internal (anorthosite) margin of the intrusion, respectively. The two limbs of the outer lower zone are considered to represent petrographically distinct as well as geometrically separated facies of the same unit. The petrographic differences are mainly those of texture and grain size.

Approaching Port Manvers Run from the west, the outer lower zone (OLZ) becomes detached from the upper zone (UZ) by the intervention of a large block of older anorthosite, hence the OLZ becomes a dike at the present exposure level. The same relationship continues across the Run into the map area. The block of anorthosite is so heavily invaded by a network of troctolitic material that it is mapped as a separate unit, the Anorthosite Block Zone (ABZ). Retention of the name OLZ for the dike is justified by its continuity into the main western body of the Hettasch Intrusion, where the gradational relationship of the OLZ to the UZ is demonstrable (Berg, FR 1972, FR 1973). The field relationships now to be described thus contain a measure of interpretation, reflected in the nomenclature, carried in from the previous mapping by Berg on the mainland.

Outer lower zone. The OLZ is a narrow (50 m) dike separating Foliated Anorthosite from the Anorthosite Block Zone (Fig. 9). Lamination dips subparallel to the contact with Foliated Anorthosite, and is steeper than the lamination of the inner lower zone (ILZ) on the northern limb of the Hettasch intrusion. The OLZ is also coarser grained than the ILZ. The contact with Foliated Anorthosite is normally sharp, distinct, and straight, whereas that with the ABZ is more irregular, as discussed below in connection with the ABZ.

Rocks of the outer lower zone are extremely variable in character. To the west, near Port Manvers Run, the rock is a layered troctolite, having a color index of 60 to 80 in the melanocratic layers and 20 to 30 in the more leucocratic layers. The mafic mineral is dominantly olivine, locally altered to serpentine. Plagioclase is 2 - 3 cm in length and minor orthopyroxene is present. At least one block of layered material seems to have been rotated relative to its matrix of similar layered material.

To the east, the outer lower zone changes character. There is a layered zone richer in orthopyroxene adjacent to the south contact. The rock has an overall color index of 30, mostly orthopyroxene, and ranges from an olivine leuconorite to an olivine norite. Layering occurs on a scale of a few centimeters to 0.5 meters and is marked by variations in the percentage of mafic minerals. A leucocratic layer grades upward into more mafic and more coarsely crystalline material, which terminates sharply in an undulatory contact against more leucocratic rock. Mafic minerals in this rhythmically layered material are from 1 mm to 3 cm in length. Away from the contact zone, the rock becomes an orthopyroxene-bearing leucotroctolite, which is well laminated and has plagioclase from 2 to 4 cm long. The color index of this material is lower, around 15, and the mafic minerals are interstitial. Oxide minerals are present in small amounts.

Blocks up to two meters across and layers of anorthositic material are locally present in the outer lower zone. The plagioclase in the anorthosite is fine grained, less than 0.5 cm in length.

Inner lower zone. The inner lower zone of the Hettasch Intrusion constitutes a generally finer-grained suite of rocks than those of the outer lower zone. The larger plagioclase laths are between 1 and 2 cm in length, with much finer-grained interstitial plagioclase less than 0.5 cm in length. Modal layering is typically prominent. The color index is typically close to 15, most of which is represented by olivine with minor orthopyroxene. Locally, it may be as high as 20 or as low as zero in the more anorthositic layers. Subophitic texture was observed in one location in the inner lower zone. Local areas of outcrop, up to 30 cm or more across, are diffusely poikilitic with one crystallographically continuous mafic grain exposed as small interstitial bits between the plagioclase laths. This was noted particularly for orthopyroxene in which reflections from a single continuous cleavage were seen. Oxide minerals are locally present, commonly less than 1%. Lamination of the plagioclase laths is a prominent feature. The contact of the inner lower zone with older rocks is locally distinct, more commonly gradational and indistinct, and everywhere undulatory.

A notable feature of the inner lower zone is the presence of anorthosite having a color index typcially less than 5. Locally, it may constitute as much as 50% of the rock mass or more. This material exists as irregular blocks, pods, lenses, and layers of varying thickness and extent. Locally the lamination of the inner lower zone is interrupted by the anorthosite body, especially in the case of irregular blocks and pods. Typically, however, within a few centimeters of the contact, the lamination is subparallel to the outer edge of the block or pod. In the vicinity of locality A, the inner lower zone also contains blocks of coarse-grained troctolite in addition to the anorthositic material.

Upper Zone. The upper zone of the Hettasch Intrusion was not subdivided in this field area into inner and outer units. Plagioclase crystals are large, 5 - 8 cm in length, and well laminated. There is little or no finer-grained plagioclase interstitial to the large laths. The color index is between 15 and 25, with varying relative proportions of olivine and orthopyroxene. The rock varies in composition from leucotroctolite to olivine leuconorite. The mafic silicates, along with oxide minerals, occur interstitially to the plagioclase.

On the northwest shore of the bay just southwest of Mills Harbour several small dioritic bodies were observed within the upper zone. These are variable in extent; one of the larger isolated masses measures 42 m by 30 m. Others are thin (10 - 20 cm across) and dike-like. The dioritic bodies contain xenoliths of upper zone Hettasch material, and locally these bodies are bordered by megacrysts of orthopyroxene, some 7 - 10 cm in length. Very large amounts of oxide materials are associated with these bodies also. Some is disseminated in the diorite as small grains, while much exists as large patches around the margins of the bodies. The color index of these diorites is 40, with patches up to 70. Plagioclase grain sizes are about 4 mm or less;

the mafic minerals are much smaller. The mafic minerals appear in hand specimen to be pyroxene.

Anorthosite Block Zone

The anorthosite block zone occurs in a large area occupying the southern half of the Hettasch Intrusion in the area of interest. It consists of blocks, widely varying in size, of anorthositic material which is identical to that of the neighboring Foliated Anorthosite. These blocks are separated by narrow selvages of more mafic material. The blocks vary in size from less than 0.5 m to hundreds of meters in length. In a very rough sense, the blocks are larger towards the north, and smaller towards the south. In general, the anorthosite of the block zone seems more continuous at lower elevations; at higher elevations it is more fragmented, with selvages of coarsely crystalline material, similar to that of the outer zone of the Hettasch, between the blocks. To the south, the anorthosite block zone grades into the outer lower zone with a decrease in the amount of anorthosite present. The contact with the outer lower zone was drawn where anorthosite blocks constitute more than 25% of the rock. To the north, the contact with the upper zone is sharp because of the larger blocks which characterize that area. Where discrete blocks can be seen in the Hettasch outer lower zone, lamination in the Hettasch Intrusion parallels the edges of the blocks, commonly with concentrations of mafic material extending in a long narrow zone above the block. The contacts of the anorthosite block zone with surrounding rocks, as well as all contacts associated with the Hettasch proper, were lost to the southeast under a cover of glacial debris.

Intrusive bodies younger than the Hettasch Intrusion

Just south of Mills Harbour and within the upper zone of the Hettasch intrusion, there occurs a distinctive body of melatroctolite. The grain size of the plagioclase in this body is 1 - 1.5 cm, with finer grained plagioclase in the groundmass. The color index is 50, most of which is olivine. The rock shows a lamination near the contact, which parallels the contact. The upper contact of this body with the Hettasch Intrusion is marked by a selvage of material consisting almost entirely of olivine (color index 80). What plagioclase there is forms a horizon of "snowflakes" near the Hettasch Intrusion and a spinifiex texture nearer the younger intrusion. The selvage is approximately 1 meter wide at the widest point, tapering to zero in either direction over the top of the body. Internally, there exist layers and stringers of anorthositic material; and there are recognizable fragments of Hettasch upper zone and anorthosite block zone materials within the body also. The lower contact of this body with the Hettasch is also marked by an olivine rich selvage, though it lacks the spinifex and snowflake textures of the upper contact zone. This intrusion is estimated to be approximately 150 meters wide and 80 meters deep. Similar melatroctolites with snowflake and spinifex-textured plagioclase have been described by Berg (1981; FR 1980).

The body described above forms the northern extent of a series of six highly mafic bodies that crop out in a ring. Of these, four are entirely within the upper zone of the Hettasch Intrusion. They are distinguished from the Hettasch lithologies by finer grained plagioclase (1 - 1.5 cm in length), and higher color index (30 - 35). Contact zones of these bodies are typically almost totally composed of olivine, and some exhibit snowflake and spinifex textures. The olivine-rich material locally contains large (2 cm diameter) rounded plagioclase crystals, which increase in abundance outward from the body, eventually grading into unaltered Hettasch upper zone material. The eastern and westernmost of these bodies are similar in texture and composition to the others; however, they occur in the inner lower zone and the anorthosite block zone, respectively. These bodies range in size from 15 to 30 meters in length, and individuals may be locally concordant or discordant to Hettasch lamination.

An additional intrusion, similar in many respects to those just described, occurs in the outer lower zone, near the western contact between the intrusion labelled locality E and the Foliated Anorthosite. Plagioclase grains in this unit are 1 cm or less in length, with interstitial mafic material which is dominantly olivine. The color index is 30. An unusual feature of this body is that it transgresses the contact between the Hettasch and the Foliated Anorthosite, roughly half of it occurring in each. Within the Hettasch outer lower zone, it crops out as a long narrow dike some 15 to 20 meters wide which pinches out to the northwest. This portion of the unit consists of alternating layers of leucocratic and melanocratic material, which are oriented normal to the contact with the Hettasch. There are disruptions in the lamination of the Hettasch outer lower zone along both sides of the body, especially towards the southeast end. The total length of outcrop within the Hettasch Intrusion is approximately 150 meters.

At the southeastern end, the body turns 90^{o} to the southwest and passes out into the Foliated Anorthosite for a distance of 75 meters. At the northwestern contact with the Foliated Anorthosite is a selvage of ultramafic material similar to those described above for other intrusions younger than the Hettasch. There is a spinifex texture, of plagioclase in olivine, developed in portions of this selvage. The selvage is approximately 30 cm wide at its widest point and about 10 meters long over all; tapering out in either direction.

Preliminary Conclusions Drawn from Field Evidence

Based on the occurrence of xenoliths in the Hettasch inner lower zone near locality A, and the observation that the Hettasch outer lower zone truncates the lamination of the troctolitic body of location E, these bodies must be older than the Hettasch Intrusion. A tentative correlation, based upon the persistence of an approximately east-west striking lamination with a southward dip, of the rocks described at localities B and C with those of locality E, would assign these rocks also to an event older than the Hettasch. Based on the attitude of their lamination and their leucotroctolitic nature, these rocks appear to be equivalent to the leucotroctolite just to the east of this area mapped by Wiebe (FR 1980, his unit E). The oldest rocks observed, then, would be those of the Foliated Anorthosite; which are the host rocks for all subsequent intrusions. It seems probable from the field evidence that the southern extremity of the Hettasch was intruded in part into a pre-existing leucotroctolitic complex which was similar to it in character.

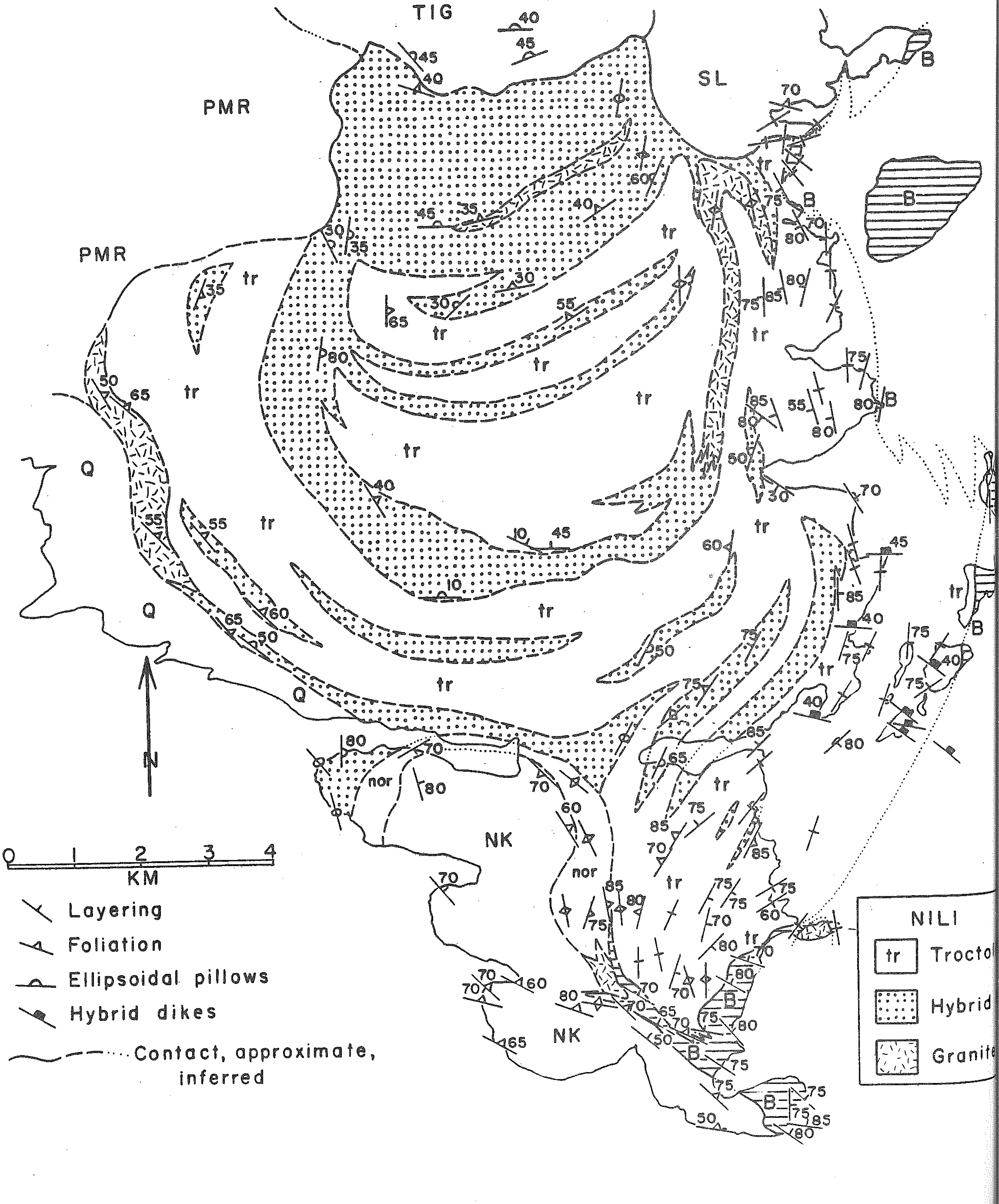
The rock observed at locality D is younger than that at C and also younger than the Foliated Anorthosite. No direct contact was observed between it and the Hettasch Intrusion; and therefore its relationship to the latter is uncertain. It does, however, share the east-west strike and southerly dip observed in the lamination of bodies inferred to be older than the Hettasch; it may therefore be older also.

The youngest rocks observed were the relatively small troctolitic and melatroctolitic bodies within the Hettasch Intrusion, and the dioritic bodies within the upper zone. That these were emplaced before the Hettasch was completely solid seems probable from the disturbances in Hettasch lamination near their contacts. J. H. Berg (pers. comm., 1981) has suggested that the dioritic units may represent the fractionated residuum of the original Hettasch magma. The origin and significance of the troctolitic bodies is a subject for further study. It does seem probable, however, that the intrusions which are seen to form a ring in outcrop in or near the upper zone of the Hettasch, might be portions of a single tabular intrusion exposed by erosion.

Acknowledgements

The services of Mr. Gary Gavie as field assistant during the summer were invaluable. I am indebted to him for his efforts on my behalf.

Fig. 10. Geologic map of the Newark Island Layered Intrusion (NILI). NK = Needles Knoll body; nor = norite; PMR = Port Manvers Run anorthosite; TIG = Tigalak Intrusion; SL = Slambang Bay Leuconorite; B = basement; Q = Quaternary.



THE NEWARK ISLAND LAYERED INTRUSION

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Introduction

The Newark Island layered intrusion (NILI) was originally mapped by Woodward (FR 1971 and 1972), and it was the focus of his Ph.D. dissertation (Woodward, 1976). Although he mapped and sampled the southern third of the intrusion intensively, Woodward made only a few traverses in the northern two-thirds and did not define the northern boundary of the intrusion. The geologic maps in FR 1972 and in the dissertation differ greatly. The extensive changes in the dissertation map appear to have been based solely on petrographic study of the relatively few samples gathered in the northern portion.

I determined to undertake a detailed study of the entire intrusion in order to clarify its structural form and compositional variation and to define the nature of its contact with dioritic and anorthositic rocks which I had previously mapped to the north (FR 1976).

Basement

Rocks belonging to the basement complex occur along the eastern margin of NILI and as a septum separating it from anorthositic rocks to the south. The basement complex is dominated by quartzofeldspathic gneisses and mafic granulites. The granulites vary widely in color index (CI) and appear to consist most commonly of two pyroxenes and plagioclase. Biotite hornblende schists also occur interlayered on a scale of 5 to 20 mm with pink granitic gneisses. Basic granulites commonly show modal and textural layering on a similar scale. Calc-silicate pods are typically present in basic granulite and contain varying combinations and proportions of wollastonite, diopside, sphene, plagioclase, garnet, epidote and calcite. Ultramafic layers up to several meters thick occur rarely. Quartzite occurs widely and is generally associated with small pelitic

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lenses or layers. Purple feldspar-rich granofels and quartzite conglomerates are associated in two localities. Pelitic rocks are mainly garnet-bearing; sillimanite and cordierite are associated in a few outcrops. Many of the quartzitic and pelitic layers are sulfide-rich.

No consistent stratigraphic succession was noted. At least two episodes of tight to isoclinal folding are evident in many outcrops. Granitic veins and larger irregular bodies up to 50 meters in width were apparently emplaced before and after both episodes of folding. Some basic dikes near NILI are tightly folded and cut by zones of remobilized pelitic and quartzofeldspathic gneisses.

Port Manvers Run Anorthosite (PMR)

The northern portion of this unit is briefly described in the report on the Tigalak intrusion (this Field Report). The PMR anorthosite appears to be cut by both the Tigalak body and NILI. Within the area of Fig. 10, the PMR is massive and grades from coarse seriate leuconorite (CI = 15-20) in the north to finer-grained leucotroctolite in the south. The transition occurs within a zone about 100 meters wide which trends roughly east-west. Toward the south the troctolitic rock becomes more mafic (CI = 20-30) and olivine commonly occurs as sub-equant grains about 1 cm in diameter.

Needles Knoll Anorthosite (NK)

The anorthositic rocks which occur south of NILI are here termed the Needles Knoll anorthosite. Exposures are generally poor and more than one pluton may be present. The southern half of the body appears to consist mainly of 1 cm leuconorite (CI = 10-20) with locally abundant blocks of gneissic anorthosite and leuconorite. Gneissic structures are locally strong in the 1 cm leuconorite host. In the northern half of the area mapped as NK, homogeneous seriate leuconorite is dominant with plagioclase up to 12 cm. This rock appears to grade from the interior outward to 1 cm norite (CI = 25 to 35) with subhedral orthopyroxene. The relation of this norite to NILI is uncertain because of poor exposures.

Slambang Leuconorite and Tigalak Intrusion

These units are described in the report on the Tigalak intrusion in this Field Report.

Newark Island Layered Intrusion (NILI)

This intrusion is highly varied in composition and structure. Three main compositional units were mapped (Fig. 10). The dominant unit consists mainly of medium- to fine-grained troctolite. Except along the eastern margin, this unit is massive and homogeneous on the outcrop scale; layering and preferred mineral orientation are extremely scarce or faint. The dominant minerals are olivine and plagioclase. CI ranges between 30 and 40. Oxide minerals, augite, and biotite appear to increase northward.

Layering is a prominent feature of this unit only within approximately 2 km of the eastern contact with basement. There, the unit is highly variable in composition, grain-size, and texture. Troctolitic and noritic layers are dominant and alternate on many scales. Layers rich in oxide and sulfide minerals occur commonly at irregular intervals and are locally dominant. Ultramafic layers are scarce.

A second map unit within NILI consists of a hybrid mixture of granitic and troctolitic rocks. Granite is subordinate, amounting to barely 5% in the southern hybrid areas and to as much as 25% in the northern areas. Granite occurs mainly as a matrix to very fine-grained rounded masses (pillows) of troctolite; see Frontispiece. Some granite also occurs as sharply bounded veins within coarser troctolite. The orientation of these ellipsoidal pillows, the map distribution of the hybrid rocks and the topographic expression of the hybrid zones suggest that the hybrid zones are inward-dipping sheets which alternate with homogeneous troctolite. The northernmost portion of NILI is dominated by hybrid rocks.

Two types of granitic rocks occur widely in the hybrid map unit. One is a fine-grained, white-weathering granite with about 10% disseminated biotite and hornblende. The second type is coarser, buff-weathering and contains variable proportions of 1 cm perthitic alkali feldspar. CI is about 15 to 20, and pyroxene appears to be the dominant mafic mineral. Some finer-grained rocks with intermediate CI contain scattered blocky feldspar of similar size.

The third map unit within NILI consists of homogeneous granite similar to that within the hybrid unit. The largest body of granite (adjacent to the layered sequence) grades to troctolite through a zone of hybrid rocks consisting of troctolitic pillows and granite. The granitic lens along the western margin of NILI cuts the PMR anorthosite sharply and grades through hybrids to NILI troctolite. The northernmost granite body has both sharp and gradational contacts with surrounding hybrid rocks.

Contacts and Age Relations of the Newark Island Layered Intrusion

The eastern contact of NILI is sharp and clearly transgressive to layering and structures within the basement. Inclusions of basement rocks are locally abundant within the eastern layered sequence and essentially absent elsewhere.

The contact between the troctolitic portion of the PMR anorthosite and NILI is complicated by the occurrence of a wide textural variety of fine- to coarse-grained troctolites and granitic rocks. Very fine-grained troctolite dikes and veins (apparently apophyses from a chilled margin of NILI troctolite) locally cut coarse-grained PMR leucotroctolites. Elsewhere the coarser troctolite appears to include blocks of very fine-grained troctolite. These blocks may represent dikes which became segmented because the PMR leucotroctolite was incompletely crystallized. The granite lens which locally separates PMR from NILI includes angular blocks of PMR anorthosite and is cut by one dike of very fine-grained troctolite. On balance, the field relations indicate that the PMR anorthosite is older than NILI.

The nature of the contact between the Needles Knoll anorthosite and NILI is uncertain. In the south a basement septum marks the contact. This septum appears to pinch out to the north (continuous outcrops are lacking), and the two units appear to be texturally gradational from the medium-grained troctolitic and noritic rocks of NILI to the noritic border of the NK anorthosite.

The Slambang leuconorite clearly truncates layering in NILI. A few dikes of fine-grained leuconorite (CI = 10-20) occur within layered troctolite. The dikes range in thickness from about 1 meter to 5 cm and have a uniform granular texture and grain size of about 3 to 5 mm. They resemble the Fox inlet leuconorite dikes (Wiebe, 1979) and may be candidates for the parental magma of the Slambang leuconorite.

The Tigalak intrusion appears to be essentially comformable with layering in the NILI. Inclusions of fine-grained troctolite were noted in one locality within the Tigalak diorite. Because the Tigalak intrusion is younger than the Slambang leuconorite it must also be younger than NILI.

Layering in the Newark Island Layered Intrusion

Steeply dipping vertical layering is a prominent feature of the eastern margin of NILI. In some areas homogeneous troctolitic to noritic layers alternate and range in thickness from 1 to 20 meters. Anorthositic layers (CI<15) are rare and less than 20 cm thick. Plagioclase lamination is developed in some of the more leucocratic troctolite layers. Grain size varies widely, and pegmatitic layers, lenses and patches are locally prominent. Scarce wehrlitic layers (10-30 cm thick) alternate with thicker augite troctolite layers. Layers 5 cm to 1 m thick are commonly defined only by faint modal and textural variation. Between 1 and 2 km from the eastern contact oxide-rich (up to 50%) layers (5 to 10 cm thick) are common. Many are modally graded and consistently indicate tops to the west (interior of the intrusion) even though the attitude of the layering varies from steeply dipping upright to overturned. Modal grading is very scarce in oxide-poor rocks and provides no consistent sense of tops. One layer with more than 50% oxides and minor sulfides is 3 to 4 meters thick and extends for at least one km along strike. The relative proportions of ilmenite to magnetite appear to vary widely in different layers. Well defined channel scours are scarce, but minor truncations of previously deposited layers are common.

Some of the layers appear to have been deformed while they were incompletely solidified. Irregular folds and zones of distorted layers occur locally. Some layers 2 to 3 meters thick appear to be a melange of previously layered material. The scarce wehrlite layers are commonly boudinaged between continuous layers of augite troctolite. Pegmatite patches at the ends of wehrlite blocks contain augite with minor hornblende rims, plagioclase, perthitic alkali feldspar and oxide minerals.

Inclusions of basement are abundant within the layered zone. They range in size from a few cm in diameter to slabs up to 10 by 70 meters oriented parallel to layering. Coarse-grained leuconorite inclusions occur at some stratigraphic levels and generally have rounded shapes. Layering characteristically wraps around inclusions.

Structures in the Hybrid Zones

The hybrid rocks appear to be distributed in inward dipping sheets concordant with layering. The outer (or basal) margins of these sheets are characterized by the best developed and most obviously chilled troctolite pillows. These pillows are generally packed tightly together allowing for a matrix of granite which ranges most commonly between 2 and 10 volume percent (see Frontispiece). Locally the shapes of these tightly packed pillows suggest that the tops of the hybrid units are toward the inner (stratigraphically higher) part of the intrusion.

Upward within a hybrid unit the troctolite characteristically coarsens and the granitic rocks occur increasingly in angular veins which suggest brittle fracture in solid troctolite. Granitic veins typically disappear at higher levels and the hybrid unit effectively grades upward to homogeneous troctolite. The upper boundary of a hybrid zone is therefore gradational and less clearly defined than its lower boundary. In the uppermost part of the intrusion, the area mapped as hybrid rocks contains many individual hybrid zones like that just described, and basal, pillow-rich zones occur at intervals ranging from 50 to 200 or more meters. Homogeneous troctolite which lies beneath a hybrid zone commonly appears to decrease upward in grain size for a distance of roughly 10 to 50 meters toward the pillow-rich basal portion of the hybrid unit.

In some of the hybrid zones with an abundant matrix of porphyritic granitic rock, a gneissic fabric is common. Characteristically the granitic gneiss varies to more mafic and less quartz-rich varieties (i.e. to compositions apparently intermediate between granite and troctolite). Chilled margins are rarely evident in the associated troctolitic rocks, and gradational contacts between troctolite and granite are common. Some areas of troctolite have scattered feldspar phenocrysts which resemble those within the granitic matrix. These hybrid zones appear to record significant mutual contamination of troctolite and granite.

Within one hybrid zone, angular blocks resembling this gneissic intermediate rock occur alongside strongly chilled troctolite pillows in a matrix of leucocratic biotite hornblende granite. In two localities very fine-grained dikes of troctolite clearly cut porphyritic granite. One dike is about 1 m wide and extends irregularly for more than 75 meters to a point where it becomes segmented within the same granite it cuts. Field relations therefore indicate that many episodes of mixing occurred during the consolidation of NILI.

Hybrid Dikes

Many hybrid dikes, consisting of a granitic matrix and chilled pillows of troctolite, occur within the eastern layered sequence (Fig. 10). Both rock types and their mutual relations closely resemble the basal pillow-rich zones of the hybrid unit further within the intrusion. The dikes range in thickness from about 1/2 to 3 meters and have NW to EW trends with moderate dips to the north. These dikes feed smaller hybrid veins with random and irregular orientation. Some of the hybrid dikes appear to lose coherence where they cut thick noritic layers.

Discussion

The Newark Island layered intrusion consists of a steeply dipping layered sequence along its eastern margin and a main sequence of troctolitic and hybrid rocks in the form of a north-plunging trough. Hybrid rocks and the amount of granite within the hybrid map unit are more abundant at higher stratigraphic levels.

The eastern layered sequence extends south of the main intrusion and is intimately interfingered with basement rocks. The presence of hybrid dikes in the layered series indicates that the layered series was established before consolidation of the hybrid interior.

The oxide-rich layers are strongly graded and consistently suggest gravitational accumulation with tops toward the interior - even though the layering is vertical or overturned. It is not clear whether the steep or overturned graded layering could have originated by a flow mechanism or whether it implies rotation of the layered sequence. If the layered sequence originally dipped moderately to the west, its present attitude might be explained by downward rotation during expansion of the adjacent main magma chamber.

Field relations indicate clearly that troctolitic and granitic magmas coexisted at various times and places during the consolidation of the Newark Island intrusion. The small amount (2-10%) of granite present in most hybrid zones appears to be insufficient to explain either the obvious chilled margins of the tightly packed troctolite pillows or the general decrease in the grain size of troctolite in the hybrid unit. Presumably a larger amount of granite was originally in contact with the troctolite than is now present in the hybrid unit.

If granite magma were injected into the troctolitic magma chamber, it seems likely that it would rise rapidly (because of density contrast) and either stabilize beneath the roof of the chamber or continue upward through roof fractures. The upward passage of this cooler granitic magma should be effective in chilling large volumes of troctolitic magma. This chilled (and more dense) troctolitic magma or crystal mush should sink to the chamber floor, perhaps bringing minor amounts of trapped granitic magma with it. When the troctolitic mush became sufficiently brittle, some granitic magma could move upward through developing fractures within the upper portion of the deposit.

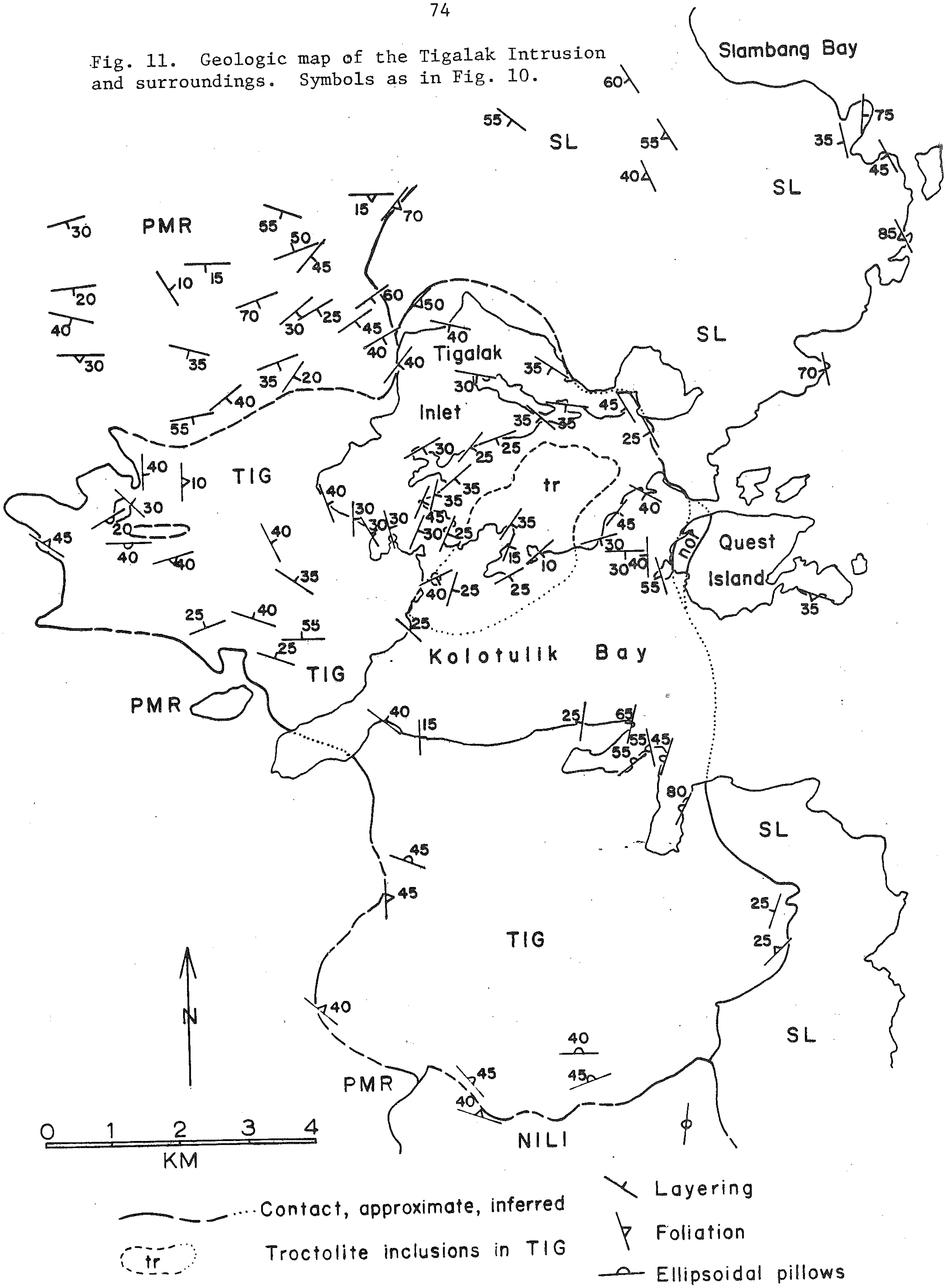
Alternatively, if sills of granitic magma could be established metastably at the floor of the magma chamber, pillows might form within the overlying troctolite magma, sink to the chamber floor, and displace the granite upward.

The homogeneous lenses of granite appear to represent accumulations of granitic magma that developed as the hybrid units were forming. The two largest bodies are parallel with the steep east and west walls and appear to grade downward to hybrid lenses on the gently dipping floor of the chamber. It seems probable therefore that granitic magma accumulated along the walls while troctolitic and hybrid magmas continued to exist inward from the granite. At present it is not clear how these vertical sheets of granitic magma could be gravitationally stable adjacent to the more dense troctolitic magma. Perhaps these sheets originally extended upward to a roof accumulation of granitic magma. If the troctolitic magma of the interior were convecting, granitic magma beneath the chamber roof may have been dragged downward along the walls of the chamber.

The hybrid mixtures of troctolitic magma and superheated (?) granitic magma are the logical source of the hybrid dikes which cut the eastern layered sequence. These dikes indicate that the layered sequence was being stretched and fractured when hybridization was occurring within the chamber. This deformation of the NILI marginal zone may have been related to expansion of the magma chamber in response to new injections of troctolite and/or granite. The attitude of the dikes suggests that major extension occurred approximately normal to the north-dipping floor of the magma chamber (i.e. the chamber was expanding mainly upward and to the north).

The NILI provides an excellent setting for geochemical studies of concurrent multiple injections, contamination, and fractional crystallization within a magma chamber and further provides an opportunity to monitor liquid compositions throughout the stratigraphy of a layered intrusion.

Fig. 11. Geologic map of the Tigalak Intrusion and surroundings. Symbols as in Fig. 10.



THE GEOLOGIC SETTING OF THE TIGALAK LAYERED INTRUSION

Robert A. Wiebe
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Introduction

The Tigalak intrusion was first described in FR 1976. A short visit during the 1980 field season resulted in minor revisions of the northern contact and in the areal extent of troctolite inclusions in norite (FR 1980). These abundant inclusions were reinterpreted as a roof to the Tigalak body, and it was suggested that the leucotroctolite map unit lying north of the Tigalak might also be a roof. The area was revisited in 1981 to extend the mapping of, and to clarify the relations among, the plutonic rocks surrounding the Tigalak body; to examine the troctolite inclusions more thoroughly; and to define the southern boundary of the Tigalak body. On the basis of this recent field work, it is now clear that all of the surrounding plutonic units are older than and lie beneath the Tigalak intrusion and that the troctolite inclusions are isolated bodies lying within a layered sequence and do not represent remnants of an attached roof.

General Field Relations

Figure 11 is a geologic map of the Tigalak intrusion and adjacent plutons. The oldest unit is the Port Manvers Run (PMR) anorthosite which grades from troctolitic in the north to noritic in the southern two-thirds of this map area. The troctolitic Newark Island layered intrusion cuts the PMR anorthosite and is in turn cut by the Slambang leuconorite (SLN) and the Tigalak intrusion (TIG). The contact between SLN and TIG is locally gradational.

Port Manvers Run anorthosite (PMR)

Rocks of this unit were previously mapped as separate plutons of leucotroctolite and leuconorite (FR 1976), but no contact between the two rock types was previously observed. More extensive mapping to the west has shown that the contact is gradational. In the northern part of the map area the

[1] Authors' full addresses are given at the back of this volume.

PMR anorthositic rocks vary from pure anorthosite to leucotroctolite (CI up to 35). Modal layering is common, and layers mostly range between 30 cm and 5 m in thickness. Plagioclase lamination is sporadically present and of varying intensity. On average, layers trend roughly E-W and dip gently to the south. Texture and grain-size are highly variable. Olivine occurs as poikilitic crystals and clots of varying size and shape and less commonly as subequant crystals and clots up to 1 cm.

To the south orthopyroxene gradually replaces olivine as the dominant mafic mineral. Plagioclase becomes dark, commonly iridescent and seriate with crystals up to 15 cm. In the southern two-thirds of the map area PMR is a typical massive seriate leuconorite (CI 10-15). This compositional variation in the highlands above Port Manvers Run appears to be consistent with variation along the run described by Morse in FR 1972. The combined evidence suggests a south-dipping sheet varying from leucotroctolite (An 58) near the base to leuconorite (An 52) near the top.

Newark Island Layered Intrusion (NILI)

The NILI is described in a separate paper in this Field Report. Where it is in contact with the Tigalak body it consists of roughly equal amounts of homogeneous fine-grained biotite-augite troctolite and various granitic and hybrid rocks. Structures within NILI and TIG appear roughly concordant. The younger age of the Tigalak intrusion is suggested by scarce inclusions of troctolite in TIG and by a few areas of dioritic rocks (dikes?) within NILI. The Slambang leuconorite clearly cuts the NILI. Because it is at least slightly older than TIG, the Newark Island intrusion must also be older than TIG.

Slambang Leuconorite (SLN)

The Slambang leuconorite extends along the east side of South Aulatsivik Island from the south side of Slambang Bay to approximately 7 km south of Kolotulik Bay. The dominant rock is a massive seriate leuconorite (CI= 15 to 25). In the area between Slambang Bay and Tigalak Inlet scarce and faint textural and modal layering and lamination occur with a N to NW strike and a westerly dip. Olivine is a minor phase along Slambang Bay. Magnetite and ilmenite are important accessory minerals within a few km of the Tigalak body. Dioritic dikes are common and become more abundant near the Tigalak intrusion. Textural and modal gradations between Slambang leuconorite and Tigalak diorite occur in several locations. In one contact zone there is a relatively abrupt decrease in grain size of SLN where pyroxene increases to about 30 percent and becomes subhedral. Scattered black plagioclase phenocrysts (up to several cm) decrease in abundance and disappear completely beyond 10 meters from the coarse leuconorite. In other areas the gradation is more irregular and involves coarse noritic rocks (CI = 25-40) as on Quest Island.

The SLN appears to truncate layering within the PMR anorthosite. Although some shearing and recrystallization are apparent near the contact within the PMR body, it appears that the contact is a simple intrusive one. The SLN sharply truncates layering in the Newark Island intrusion.

Tigalak Intrusion

The main aspects of the Tigalak intrusion are described in FR 1976 and FR 1980. The general form of the intrusion is that of a highly irregular inverted trough. The floor of the body dips inward, and no roof is exposed. The troctolite inclusions, so prominent in the northern part of intrusion, all occur within a sequence of layered rocks differentiated from fine-grained norite to oxide-rich ferrodiorite.

The western lobe of the intrusion and the area south of Kolotulik Bay consist of ferrodiorite with variable amounts of granite and hybrid mixtures of diorite and granite on scales ranging from a few centimeters to several tens of meters. Contacts between diorite and granite vary from sharp to imperceptibly gradational. The western and southern areas show no evidence of systematic fractionation like that in the northern section.

Discussion

The noritic to dioritic rocks of the Tigalak intrusion may be late differentiates of the Slambang leuconorite. The relatively abrupt transition from coarse-grained leuconorite to fine-grained norite and diorite may correspond to that stage at which the crystallizing magma reached a cotectic between plagioclase and orthopyroxene.

The dioritic magma chamber, whether or nor related to the Slambang leuconorite, was apparently the locus of many injections of granitic magma which disrupted the normal fractionation sequence in the western and southern parts of the chamber. It seems likely that the northern layered sequence was developing at the same time that extensive hybridization was occurring elsewhere. Field relations within the Tigalak intrusion suggest therefore that stirring or circulation (convection) within the magma chamber did not extend significantly between adjacent radial volumes within the magma chamber.

DETAILED MAPPING IN THE TIGALAK INTRUSION

Thomas Wild
University of North Carolina[1]

Introduction

Hybrid rock-types in the Tigalak intrusion have been proposed by Wiebe (FR 1976 and FR 1980) to be the product of magma mixing. Preliminary chemical and petrographic data confirm this possibility. Because of the confusing relationships between the rock types in some parts of the intrusion and the scale at which hybridization seems to occur, mapping and sampling in detail over small areas were undertaken in 1981 to examine the extent and mechanism of the process. The two areas mapped (Fig. 12) are very different in terms of rock types and the extent of hybridization and therefore offer a comparison of environments within the magma chamber.

Rock Types

Three major rock types make up most of the Tigalak intrusion. Medium-grained diorite is dominant in the north and east sections where it occurs as a layered sequence with an iron enrichment trend. In the southern and western parts of the intrusion a medium to coarse grained quartz monzonite to granodiorite is found with the diorite and is locally dominant. In these parts of the intrusion, layering is obscure. Throughout the intrusion, fine grained diorite occurs as blocks, lenses, dikes, and pillow forms with chilled margins. Contact relationships between these three rock types range from sharp to gradational to intermingled on the scale of a few centimeters. For more detail on rock types see Wiebe (FR 1980, FR 1976, and this Report).

Field Area I

Fig. 13 shows a map of the first field area which is an island located in the northeastern section of Tigalak Inlet. This area was chosen because it seems to lie within the stratigraphic sequence of the layered diorites and there is no "granitic" material to obscure the relationships between the cumulate diorite and the fine grained diorite masses. Layering in the medium grained diorite, though not everywhere present, is commonly defined by bands of higher oxide mineral content.

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[1] Authors' full addresses are given at the back of this volume.

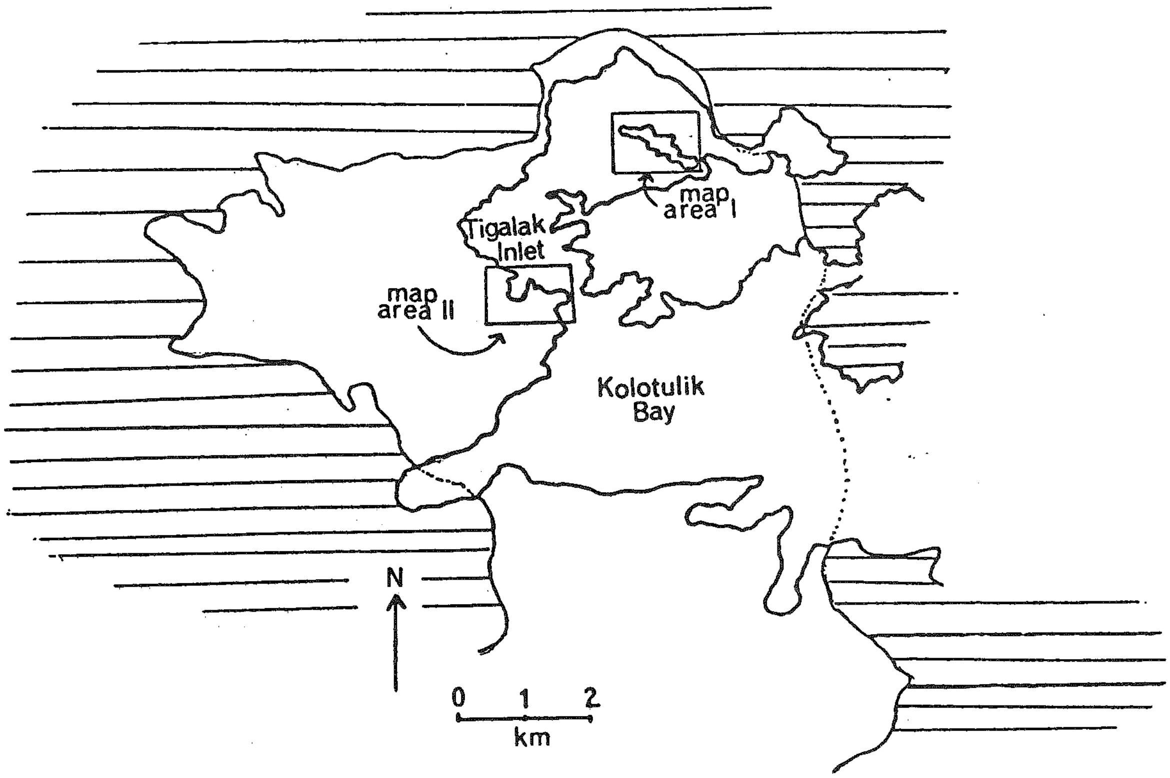
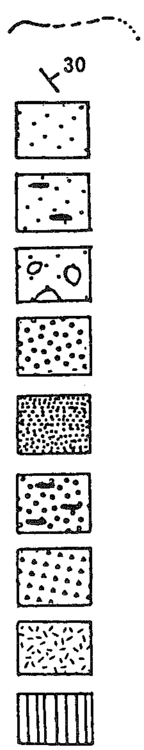


Fig. 12. Index map of the Tigalak Intrusion.

KEY FOR MAPS IN FIGS. 13 & 14



Contact, approximate, inferred

Strike and dip of layering

Medium Grained Diorite

Medium grained diorite with lenses or blocks of finer grained diorite (# of darkened lenses approximately proportional to frequency of fine grained bodies in field)

Medium grained diorite with leuconorite inclusions

Hybrid rock type, ranging from diorite to quartz monzonite

Massive fine grained diorite or areas of greater than 90% fine grained diorite lenses

Hybrid rock with lenses and blocks of fine grained diorite

Quartz monzonite

Troctolite

Cross cutting granite dikes

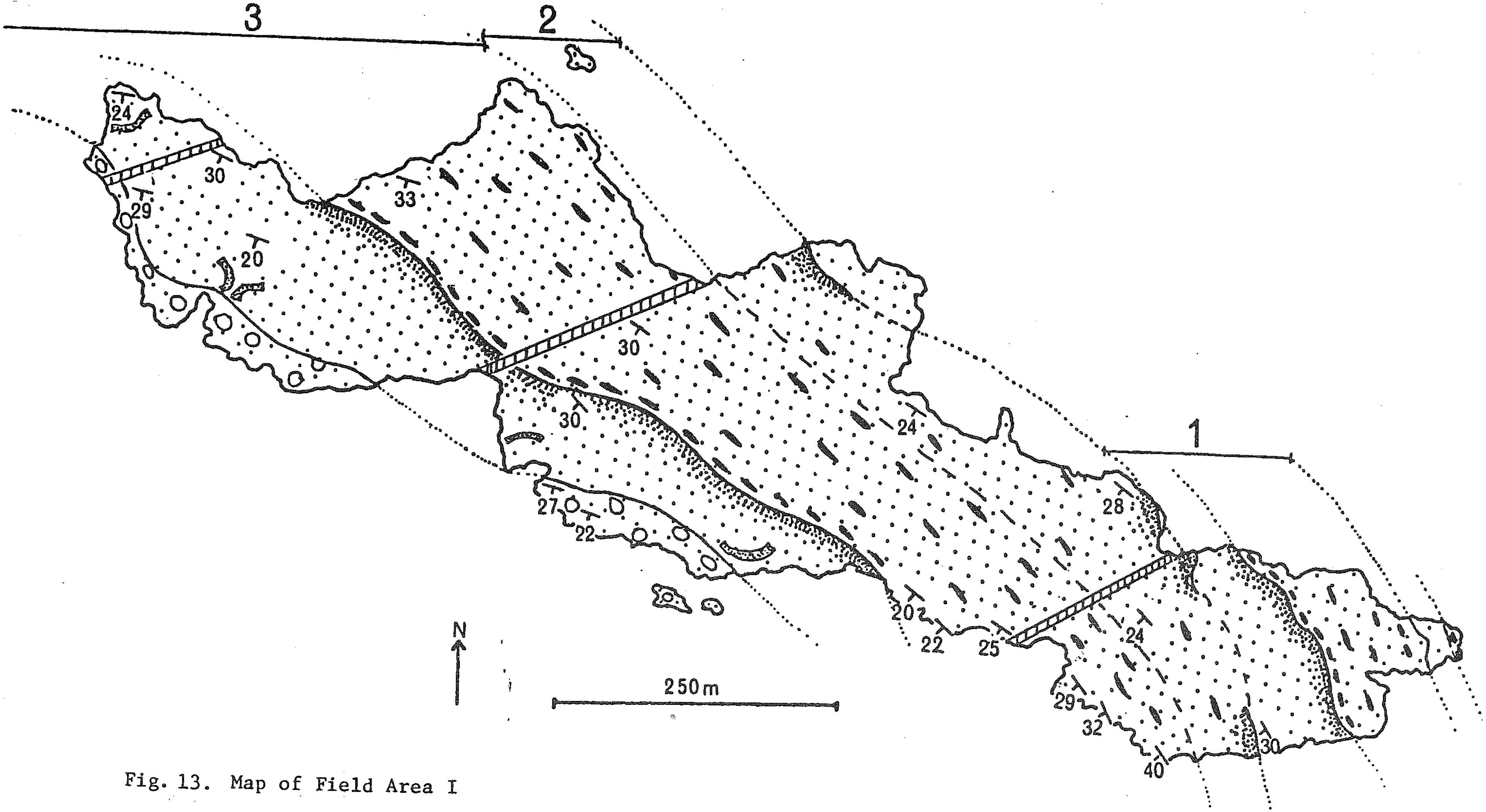


Fig. 13. Map of Field Area I

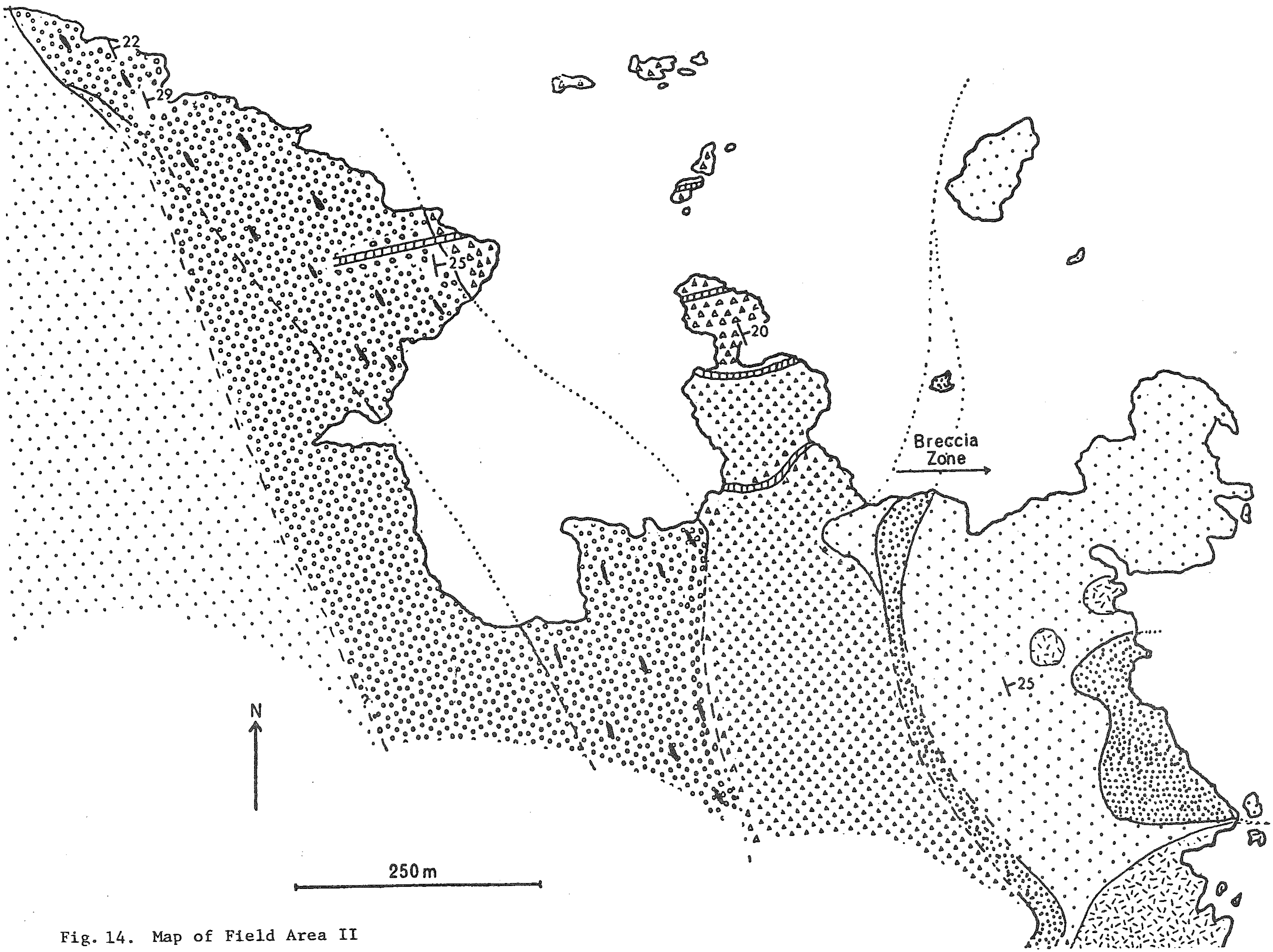


Fig. 14. Map of Field Area II

Stratigraphic units were devised on the basis of relative abundances of fine grained diorite and foreign inclusions. There is a very good correlation between the strike of the layering and the contacts of these units. Strikes of the layered diorites vary systematically from about N30°W in the southeast to N80°W in the northwest. These attitudes fit very well with the general layering trends for this section of the intrusion.

Within the layered diorite sequence in this area are varying amounts and forms of finer grained diorite bodies. The most common forms of fine grained diorite are lenses and blocks with coarser diorite as the matrix. No true "pillows" with chilled margins were found but they have been observed in other parts of the intrusion (Wiebe, FR 1980). The lenses are usually aligned with their long axes parallel to layering, and they occur in lengths ranging from 5-6 cm to a few meters, 1/2 meter being common.

In some areas these fine grained lenses may make up 90 percent of the outcrop. Other areas show massive fine grained layers with no medium grained diorite at all. In cases such as these the fine grained zones commonly show sharp contacts with the medium grained diorites down section, and gradational contacts to the medium grain diorite up section. In cases where the fine grained zone is made up of individual lenses, the lenses show sharp contacts with the medium grained matrix near the base of the zone. The lenses tend to coarsen up section and the boundaries between lenses and matrix fade. This transition occurs over a distance of a few meters until the outlines of the lenses can no longer be distinguished.

The stratigraphic units in the first field area can be interpreted as a series of repeating cycles. The cycle begins with the increase of fine grained dioritic bodies up section followed by a transition from fine to coarser grained diorite with relatively few fine grained lenses. Cycles 1 and 3 labeled in Fig. 13 are based on this definition. Cycle 2 does not strictly adhere to this definition because it does not begin with a pronounced increase in fine grained lenses but it does show the transition from fine to medium grained diorite. Defining the beginning of cycle 3 is somewhat arbitrary but there is an increase in the relative abundance of fine grained lenses where this boundary is drawn.

At the base of the uppermost stratigraphic unit on the island fined grained diorite occurs as small dikes 10 to 20 cm thick. These dikes have no consistent trend and cut across the strike of the layering. The contacts between the dikes and the surrounding medium grained diorites are everywhere sharp but do not show chilled margins. In one case the fine grained material of the dike was fractured and the fractures filled with the surrounding cumulate diorite. No fracturing is evident in the surrounding rock, suggesting some sort of plastic movement in the cumulates after the injection and solidification of the dike material.

The uppermost unit in this area is defined by a zone of cumulate diorite with leuconorite inclusions, which range in size from 1 to 8 meters. Chemistry and petrography indicate that these inclusions are probably xenoliths from the leuconorite body to the north and east which is cut by the Tigalak intrusion (R.A. Wiebe, personal communication 1981).

Also in this area are granite dikes which cut across all earlier features. These are medium to coarse grained, composed of K-feldspar, quartz, plagioclase and biotite, and they commonly range between 1 and 3 meters in thickness. All granite dikes in this area and in the second field area trend N65^{O}E to N85^{O}E.

Field Area II

Fig. 14 shows an area on the west side of the mouth of Tigalak Inlet which has zones of intense hybridization. Here again contacts between map units are closely related to the strike of the layering. The lowest unit in this section, lying to the west, is a medium grained oxide-rich diorite. Fine grained diorite bodies can be found in this unit but are not common.

Up section the diorite grades to a zone of hybrid rock types which range in composition from quartz monzonite to ferro-diorite. The diorite is commonly equant and medium grained and the quartz monzonites have coarser feldspar. In this hybrid zone gradations between these two textures are common. In some localities rock types which have dioritic textures and abundant oxides appear to contain quartz. This hybrid unit is subdivided, the western half containing very few fine grained diorite masses and the eastern half containing more abundant masses. Fine grained bodies in this eastern section occur as lenses and stringers which are swirled and interfingered with the coarser material. Also within this unit occurs small areas of leucocratic granite interlayered with the quartz monzonite.

Up section from this hybrid zone the rocks grade to a relatively homogeneous quartz monzonite. A tabular feldspar habit is well developed and quartz occurs as equant 4-8 mm grains. Biotite and fayalite are common interstitial phases. In this unit the numbers and sizes of the fine grained diorite bodies decrease and lenses are the most common forms.

Above the quartz monzonite unit is a breccia zone which covers the rest of the map area. The majority of the breccia blocks are medium grained diorite and the matrix between the blocks appears to be the underlying quartz monzonite. The quartz monzonite unit can be traced into the breccia zone at several points. The breccia blocks range in size from 10 cm to 30 meters and there is very little evidence for movement during brecciation. The matrix commonly accounts for less than 20 percent of the rock on the outcrop scale.

Two units of fine grained diorite are found in the breccia zone. One is a band of fine grained blocks which parallels the contact of the breccia zone. The second area is located on the west shore of the mouth of Tigalak Inlet. Here the breccia fragments are not always well defined. Some blocks have rounded or gradational contacts with the matrix.

The final unit in this breccia zone is an area of troctolite which is not related to the Tigalak intrusion. This zone of troctolite is continuous across Kolotulik Bay just outside Tigalak Inlet (Wiebe, FR 1976 and FR 1980). Stratigraphically, this is the highest exposed section in this area. These troctolite blocks or slabs may represent stoped material from the roof and may even be related to the brecciation event.

Discussion

The fine grained diorite bodies which are more or less pervasive throughout these two map areas probably represent chilled liquids, as demonstrated by their occurrence as small dikes and as pillows. In the first map area the abundance of fine grained bodies as lenses and massive layers up through the stratigraphic sequence of cumulate diorite suggests that the formation of these masses was continuous or frequently occurring.

If the Tigalak intrusion is a composite intrusion with granitic magma injecting a dioritic magma chamber as suggested by Wiebe (FR 1976), the repeating masses of fine grained diorite may represent some periodic process within the intrusion. Multiple injections of cooler granitic liquid rising through the chamber might produce alternating cooling rates. The initial pulse of cool material chills the diorite rapidly, producing the sharp boundary between fine and medium grained diorite. Up section the transition from fine to medium grained diorite represents a gradual return to a normal cooling rate. The same result could be explained by multiple injections of dioritic magma into a cooler hybrid magma chamber. In this case the massive fine grained layers seen in the first field area could represent the initial pulse of new dioritic magma. As the pulse continues it heats the magma already in the chamber, resulting in the transition zone of fine to coarser grained diorite up section.

The hybrid zone of the second map area is interesting because it represents a gradation by obvious intermingling and hybridization from stratigraphically lower diorite to an overlying quartz monzonite. Whole rock chemistry and $^{87}Sr/^{86}Sr$ initial ratio studies may help to define the mixing processes.

The transition from the quartz monzonite unit into the overlying breccia zone of diorite and troctolite shows that the granitic material was not solid during the brecciation event. The troctolite and diorite breccia may represent part of the roof which collapsed into quartz monzonite that had risen to the top of the chamber. This sequence seems plausible if the quartz monzonite unit is a stratigraphic layer as suggested by mapping in this area. Similar quartz monzonites on the east shore at the mouth of Tigalak Inlet, however, seem to cut across stratigraphy, suggesting that the orientation of this unit in the second field area is fortuitous.

Acknowledgements

This field work was partly funded by a Martin fellowship granted through the UNC Department of Geology.

I thank Ted Daeschler for his outstanding assistance and enthusiasm in the field.

THE KIGLAPAIT INTRUSION

XENOLITHS IN THE KIGLAPAIT INTRUSION

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S. A. Ball, University of Massachusetts

Introduction

When the Kiglapait Memoir (Morse, 1969) was published, only one discrete xenolith of country rock other than anorthosite was known from the layered group, and this was a meter-sized inclusion of pyroxene granulite near Partridge Point. Other evidence for contamination was known from the pyroxenite lenses near 35 PCS in the Kiglapait Mountains (Memoir, p. 52-55). The inferred rarity of xenoliths from the basement complex, combined with suggestive evidence for an anorthosite roof over much of the intrusion and the critically-undersaturated differentiation trend, led to the conlusion that assimilation could have played only a very minor role in the magmatic evolution of the Kiglapait body. The major element variation, and particularly the strong iron enrichment shown by the FMA trend (Morse, 1981) supports such a conclusion. However, the upward enrichment of radiogenic strontium (Simmons and Lambert, FR 1980) and depletion of radiogenic neodymium (DePaolo, 1981) in the intrusion can be taken as evidence for crustal assimilation, which nevertheless appears subject to stringent limits imposed by the low Rb content of the intrusion (Morse, 1981).

We now report discovery of numerous xenoliths in the Kiglapait layered rocks, at three different localities in the southern part of the intrusion. It is expected that the abundance, diversity, and good preservation of these xenoliths will make them of great value in constraining the kind and degree of contamination introduced to the crystallizing magma. The xenolith localities are shown in Fig. 15.

Xenoliths near Slambang Bay, 8 PCS

This locality stratigraphically underlies the site of sample KI 3109 in

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[1]Authors' full addresses are given at the back of this volume.

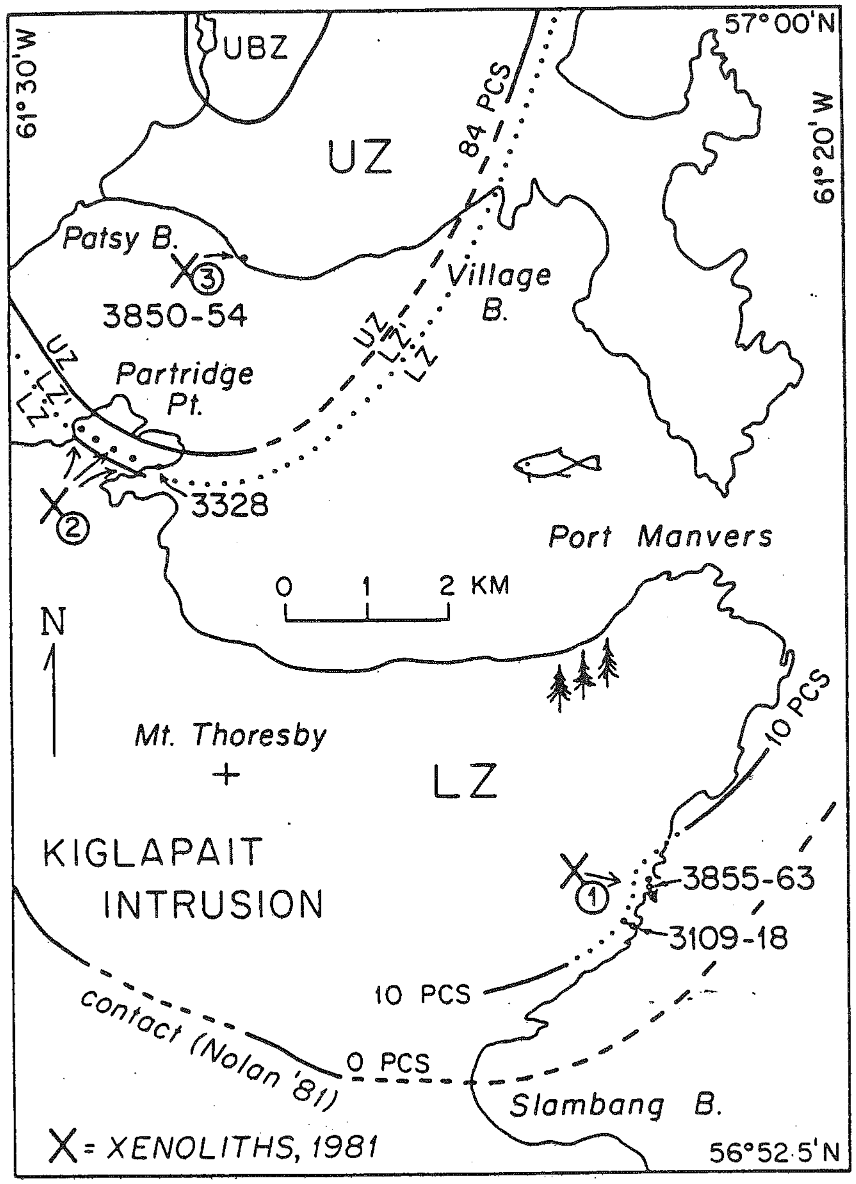

Fig. 15. Sketch map of southern part of Kiglapait intrusion showing localities where xenoliths were found in 1981.

which reverse rims on plagioclase were reported last year (Morse and Nolan, FR 1980). The locality occurs some 700 meters northerly along the shore from the KI 3109 site, and about 100 meters below the stratigraphic level of KI 3109. Percent solidified (PCS) levels are difficult to assign here because the strike swings inland locally and the contact occurs offshore; tentative correlation is made by taking the olivine-rich strata just above KI 3109 to represent the 10 PCS level, as discussed in the Memoir (Morse, 1969, p. 45).

Xenoliths occur in a mappable zone along strike in Lower Zone troctolite, and occupy a stratigraphic interval possibly 50 meters thick (Young, this Report). Typically, they are light colored rocks, with or without banding or foliation, in sizes smaller than 30x50 cm and as large as 0.5 x 13 m. Most xenoliths are surrounded by a rind, typically 1-2 cm thick regardless of the size of the inclusion, composed of what appears in the field to be black pyroxenite, but which may contain hornblende as well. The zone of xenoliths also contains disoriented autoliths of layered troctolite.

The number of xenoliths in this zone of inclusions probably reaches at least several dozen, and perhaps as high as one hundred. Lithologic types include leucocratic banded gneisses, greenish calc-silicate rocks, fine-grained metabasalt, a fine-grained, soft, pale-gray rock which appears to be rich in apatite, and anorthosite with coarse granophyre segregations. The sampled xenoliths are catalogued in Table 3 . Samples KI 3857 and 3862 represent a troctolite autolith and host-rock troctolite, respectively, taken to see what local geochemical effects, if any, can be ascribed to assimilation of country rock material.

Partridge Point, 83 PCS

Numerous fine-grained inclusions, typically ellipsoidal and of 1-2 meters length, occur in a horizon above the first appearance of 2-cm pyroxene clots and below the first appearance of cumulus augite (Ball, this Report). The inclusions are augite-rich labradorite gabbros having mineral compositions unlike those of the Kiglapait intrusion. Three inclusions have been sampled, as discussed by Ball in this Report.

Shore East of Patsy Brook, 97 PCS

This locality, sketched in Fig. 16, warrants special attention because it appears to provide a link between xenoliths and the enigmatic gabbro pegmatite patches that appear throughout most of the Kiglapait layered intrusion, and in many other anorthositic and troctolitic rocks. Such a gabbro pegmatite zone occurs here, and as shown in the figure it is clearly discordant to the attitude of regional layering. The presence of 20-cm long pyroxene crystals growing inward from the contact with UZ olivine ferrodiorite suggests that the gabbro pegmatite is locally intrusive into the UZ. Within the outline of the gabbro pegmatite, in the tidal zone near shore, occurs a coarse granophyre containing white K-feldspar, quartz, and hornblende. Three xenoliths of leucocratic banded gneiss occur at localities marked 1-3 in Fig. 16. Details are cataloged in Table 4.

Discussion

The presence of granophyre in gabbro pegmatite on the shore east of Patsy Bay, and also at Slambang Bay, is considered genetically significant. The normal Kiglapait differentiation trend, as recorded in the layered rocks, fails to produce quartz. The presence of granophyre bespeaks local contamination by a low-melting fraction of country rock. The presence of hornblende shows that some water was present in the granophyric melt which, however, was not H_2O-saturated because hydrous alteration has not spread to the surrounding gabbro pegmatite or ferrodiorite. The gabbro pegmatite is most likely a product of contamination by slightly hydrous melt, which promoted the locally rapid, hence coarse crystallization of plagioclase, augite, and perhaps other minerals, followed by local segregation of the hydrous melt itself as a residuum, now granophyre. Because the gabbro pegmatite is discordant to the regional layering, it may represent either a foundered block of roof-nucleated crystals or a floor-grown reef, or possibly both. The coarse material must have remained molten longer than the surrounding cumulate ferrodiorite, and must have become remobilized, in part at least, to cause the wall-grown, elongate pyroxenes to crystallize. Such a sequence would explain the common observation that gabbro pegmatite zones are commonly roughly strata-bound but locally cross-cutting. Contamination would also explain why cross-cutting gabbro pegmatite zones occur in the Lower Zone troctolite (Morse, 1969), where

Table 3. Description of xenoliths core-sampled near Slambang Bay.

Xenolith No.	Sample No.	Field Description	Core Location	Remarks
South end of small peninsula				
1.	KI 3855	30x50 cm metasedimentary rock with 1-2 cm rind.	Central, no rind	
2.	KI 3856	Meter-long foliated leucocratic xenolith with rind.	Penetrates rind and underlying troctolite	
100 meters northwest along strike				
3.	KI 3857	Autolith of troctolite from cognate layered block 2x3 m with 10-20 cm layering.	In locally average rock	Presumed block from near wall or roof margin. Presumed uncontaminated because exotic.
4.	KI 3858	Fine-grained, foliated metabasalt xenolith here 0.5x4 m but nearly continuous for 13 m in plane of local layering.	Central	
5.	KI 3859	Banded leucocratic gneiss stratigraphically 0.5 m below No. 4 and 2 m SE of KI 3858. One-cm rind.	Central	
1-meter ledge with numerous inclusions				
6.	KI 3860	Small (20-30 cm diam?), weathered ultramafic rock, probably not just thick rind of pyroxenite on vanished xenolith.	Central	
20 meters north				
7.	KI 3861	Subangular 0.5x0.75 m xenolith with 1 cm rind. Uniform, pale gray, fine-grained rock of hardness around 5, but seemingly very fresh. Suspect apatite.	Central	
6 meters above 1-m ledge inclusion zone				
—	KI 3862	Olivine-rich troctolite, in place, near base of 0.5-m layer.	Base of layer	Host rock
100 meters west in small cove				
8.	KI 3863	Anorthosite pod about 5 m in diameter, with prominent patches of coarse (1 cm) granophyre.	In granophyre	

Table 4. Description of xenoliths and core samples on the shore east of Patsy Bay

Xenolith No.	Sample No.	Field Description	Core Location	Remarks
1.	KI 3850	30 cm x 1m, oval with cm-scale variation in color index and 1-cm mafic rind.	Central. Penerates through xenolith into underlying olivine ferrodiorite.	Apatite, andesine seen
1.	KI 3851	same	15 cm from SW end.	
2.	KI 3852	50 cm x 2m, oval. 1-2 cm mafic rind. Same lithology as (1).	Central	
3.	None	Small, irregular, but rounded at corners. Like (1) and (2).		
--	KI 3853	Coarse granophyre in gabbro pegmatite zone.	In granophyre.	
--	KI 3854	Normal ferrodiorite host rock away from obvious hydrous veins and xenoliths.		Host rock

augite normally does not crystallize.

Large-scale examples of foundered roof material may occur in the mappable units UZ(y) and the Whalear Lake Transgressive Zone (Morse, 1969), the former perhaps representing foundered UBZ material and the latter, anorthositic country rock.

The mafic rinds commonly observed on xenoliths at all levels of the intrusion help to explain why the inclusions were not completely digested. The inclusions acted as local heat sinks and the rapid crystallization of pyroxene rinds (even in the augite-unsaturated LZ) generated an effective barrier to material transfer.

The occurrence of xenoliths strikingly proves the incorporation of exotic material, probably by stoping near the roof, during at least 97 percent of the intrusion's crystallization history. On the other hand, the survival of small xenoliths enclosed by mafic rinds proves that even small fragments were not totally incorporated into the melt. The mafic rinds themselves represent *extraction* of material from the melt. Furthermore, the retention of granophyric material in gabbro pegmatite shows that even the low-melting fraction of foreign material tended to be locked up locally rather than mixed into the main magma. The paradoxical conclusion is that xenoliths (and gabbro pegmatite zones) by themselves document the *local preservation* of foreign material (perhaps with subtle local contamination which will be detected by chemical and isotopic analysis) rather than its *incorporation* into the fractionating magma. Nevertheless, the xenoliths should serve as useful indicators of what was potentially available for assimilation, particularly in terms of isotopic ratios.

The low Rb content of the intrusion suggests that the contaminant to the magma was already depleted in Rb prior to assimilation. On the other hand, the presence of abundant apatite in at least one xenolith (No. 1 on the shore east of Patsy Bay) may indicate a most desirable component of the contaminant, having abundant Sr and REE (presumably with crustal Sr and Nd isotopic signatures) and low Rb.

The effect of contamination on apparent partition coefficients (Morse, 1981a, 1981d, 1982) is, ignoring material extracted into rinds on xenoliths, to contribute to a liquid concentration $\underline{C}_i^L$ some increment in the future not present when the contemporary crystals formed. Such an increment now reports in the overlying rocks and therefore is calculated as contemporary liquid. The value of $\underline{C}_i^L$ is therefore inflated, and the calculated value of the partition coefficient $\underline{D}_i = \underline{C}_i^S/\underline{C}_i^L$ is therefore deflated, so calculated values of apparent $\underline{D}$ are minimum values with regard to contamination. If a component $\underline{i}$ is, however, decreased in the magma by dilution or extraction into rinds, the calculated $\underline{D}$ is a maximum. In the cases of K and Rb in feldspar versus melt, whose values of $\underline{D}$ are already "too large" by conventional phenocryst-matrix standards, the process of contamination would almost surely introduce K and Rb to the magma and therefore the calculated D's are minima; that is, they are underestimated.

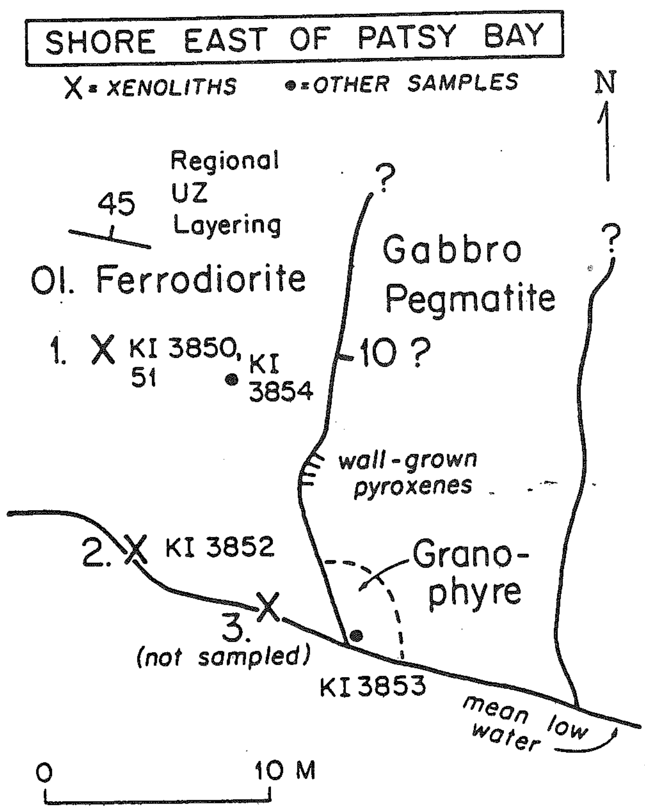

Fig. 16. Sketch map showing xenoliths near the gabbro pegmatite zone, and sample locations on the shore east of Patsy Bay. For general locations see Fig. 15. Dots: xenoliths; X's: other sample locations.

GEOLOGY OF THE PARTRIDGE POINT AREA OF THE KIGLAPAIT LAYERED INTRUSION

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Introduction

The Partridge Point area of the Kiglapait Intrusion was first sampled by S. A. Morse in 1964. Additional samples were collected this summer from the Upper and Lower Zones. This study is intended to complement data on the LZ/UZ transition from the Caplin-Patsy, David-Billy , and Sally Lake traverses, (Morse, 1979). During this study, a xenolith horizon was discovered just below the LZ/UZ boundary.

Samples

Samples were collected primarily from the west shore of Partridge Point (Fig. 17). These are to supplement those collected by Morse from the east shore. Mapping of the west shore resulted in relocating the LZ/UZ boundary 145 meters north of the boundary determined by Morse (1969). The boundary is placed at the first occurrence of cumulus augite.

Xenoliths

Within the Lower Zone is a series of pyroxene-plagioclase granulite xenoliths, of which fifteen were seen. In cross section the xenoliths are oval, 20-40 cm long by 15-20 cm thick. The long axes are sub-parallel to the strike of nearby layering. One xenolith, observed in three dimensions, has the shape of an oblate spheroid. The xenoliths occur in a zone about 8 to 10 meters thick, just above but not within a series of 2 cm pyroxene clots. This stratigraphy is repeated on the east and west shores of Partridge Point. Although, due to extensive weathering, this stratigraphy cannot be observed inland, three xenoliths were observed along strike between the two shores.

Typically the xenoliths are fine grained, 1 to 2 mm, and sugary textured.

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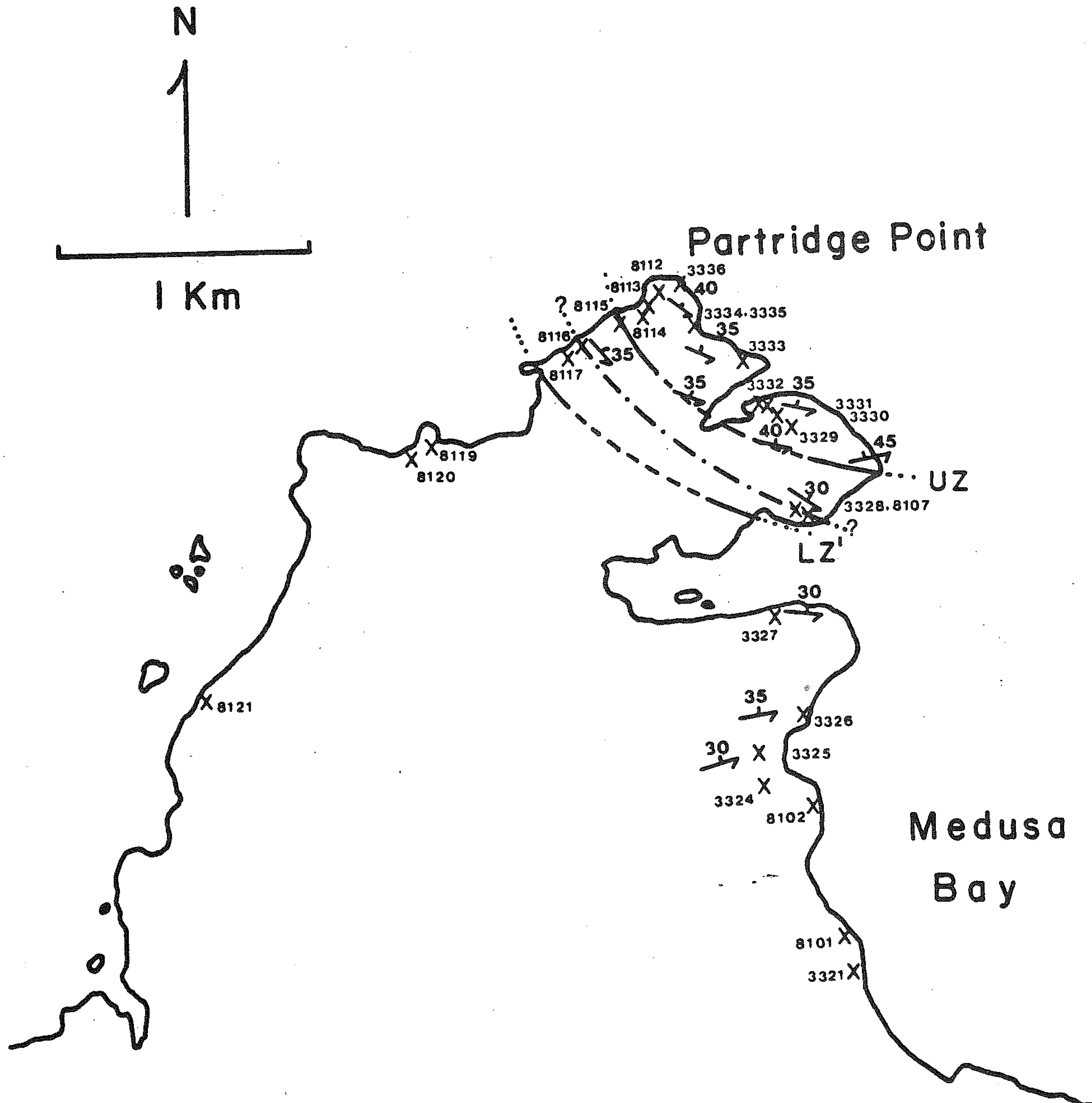
[1] Authors' full addresses are given at the back of this volume.

Fig. 17. Geologic map of the Partridge Point area of the Kiglapait Intrusion. Compiled from Morse (1969) and the present study.



Contact; indefinite; inferred

Strike and dip of layering

Xenolith horizon

X Sample localities
3300 series by Morse
8100 series by Ball

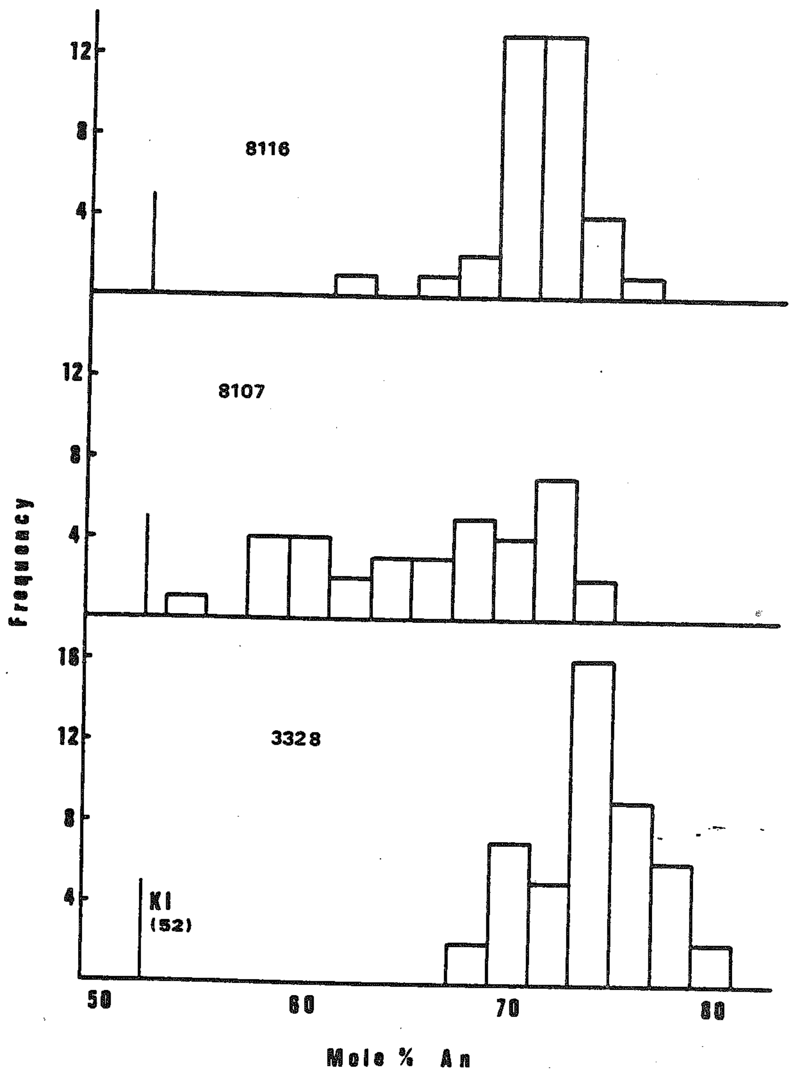
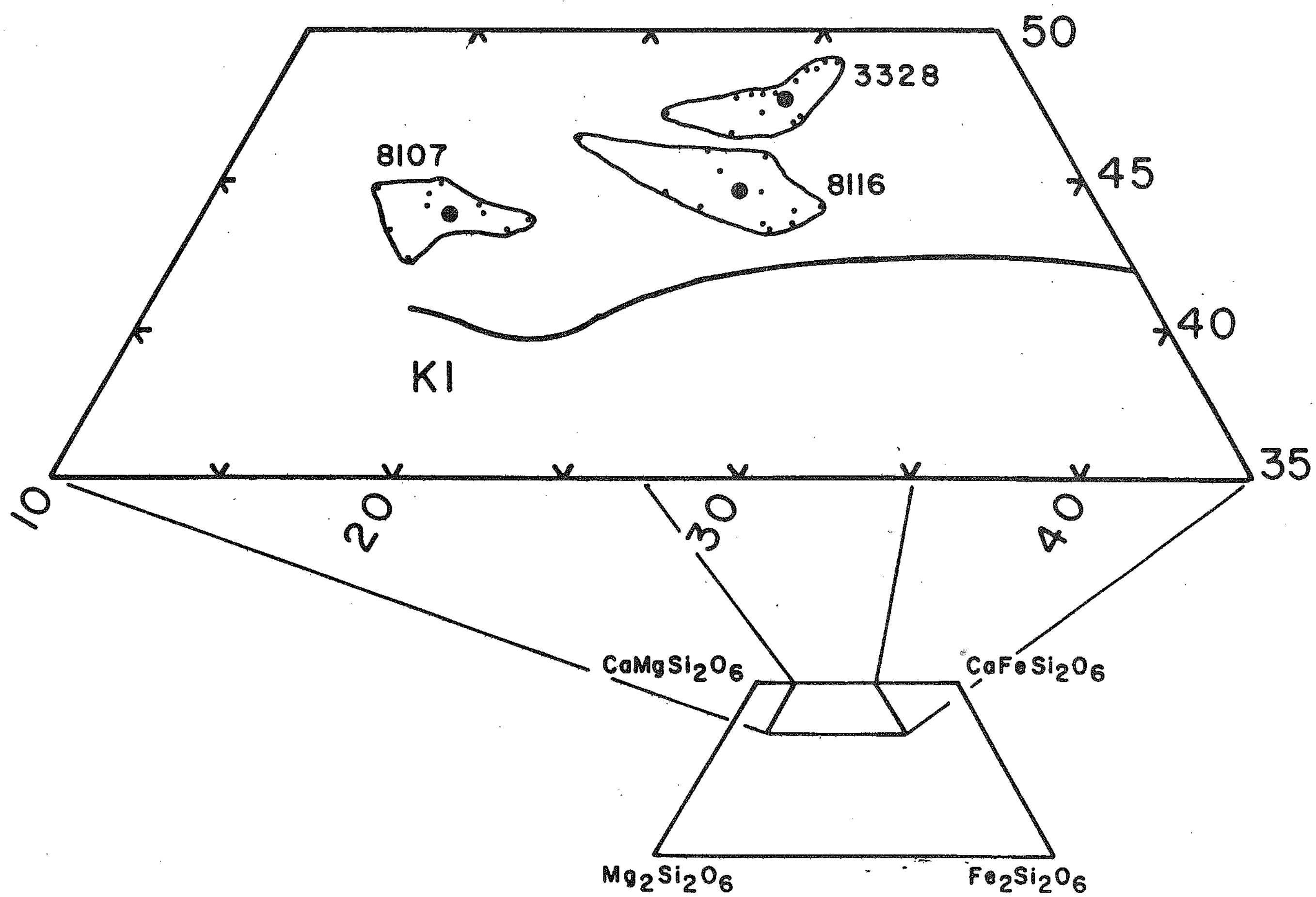


Fig. 18. Histograms of plagioclase compositions in the xenoliths at Partridge Point. Composition of plagioclase in the adjacent part of the Kiglapait Lower Zone is shown by the bar at An 52.



Mole percent

Fig. 19. Pyroxene compositions in the sampled xenoliths. The compositional trend of Kiglapait cumulus augite (KI; Morse, 1980) is shown for comparison.

One xenolith was observed to have an internal lamination of 5 mm pyroxene and plagioclase. Three xenoliths had noticeable reaction rims with the surrounding troctolite. Of the fifteen xenoliths observed two, one from each shore, were sampled for later analysis. One xenolith (KI 3328) from the east shore, sampled by Morse in 1964, was included in the analyses.

The xenoliths are composed of approximately equal amounts of plagioclase and green clinopyroxene plus trace amounts of apatite (Table 5). Electron microprobe analyses of plagioclase from the sampled xenoliths are shown in Fig. 18. It is apparent that the xenolith plagioclases, An 60 to An 80, are distinct from the troctolite plagioclase (An 52) at that level of the intrusion.

Microprobe analyses indicate that the clinopyroxene in the xenoliths is also distinct from the Layered Group augite as well as from sample to sample, as shown in Fig. 19. The small dots in the figure represent individual analyses and the larger dots are sample averages. The compositional trend of cumulus augite is represented by the curve labeled KI, taken from Morse (1980). The xenolith augite is more calcic than cumulus augite and two samples are much more iron rich than basal UZ clinopyroxene.

Discussion

On the basis of modes and mineral composition, the xenoliths are truly foreign to the Kiglapait magma. Shoreline and inland observations reveal that the xenolith horizon is discordant to both the LZ/LZ' and the LZ'/UZ boundaries which are, however, parallel to each other. If the xenoliths represent an instantaneous or nearly instantaneous collapse of a portion of the roof then three interpretations are proposed:

The LZ/UZ boundary and the xenoliths both represent time horizons. If this is the case the discordance may represent cross bedding on a very large scale. There is no reason to assume that this is not the case, but for lack of additional evidence this will not be considered further.

Alternatively, either the LZ/UZ boundary or the xenolith horizon is a time horizon and the other is not. This is perhaps most likely. The xenoliths are more mafic and An rich and therefore denser than the surrounding rocks. They should have sunk quite rapidly compared to the rate of crystal accumulation. Since the sizes of the xenoliths are comparable along strike, implying that they settled at about the same rate, they would presumably mark a true time horizon. Thus in the Partridge Point area at least the chemical evolution of the magma proceeded at different rates along different radii and the LZ/UZ boundary is a modal and chemical but not a time horizon. Since heat loss surely was not uniform over the entire intrusion, chemical evolution of the magma may not have been uniform.

Thirdly, it is possible that neither the LZ/UZ boundary nor the xenoliths is a time horizon. This idea is rejected based on the orientations and sizes of the xenoliths. Every observed xenolith is oriented with the long axis subparallel to nearby layering. This is the expected orientation of objects that settle through a liquid. Moreover, the sizes of the xenoliths are comparable along strike, hence, they must represent a time horizon.

Summary

New mapping and sampling in the Partridge Point area will provide a detailed picture of the Lower Zone-Upper Zone transition for comparison with other LZ/UZ crossings. Field observations of a xenolith horizon suggest that the LZ/UZ boundary is time-transgressive.

Table 5. Xenolith Modal Analyses

	Sample No.		
	3328	8107	8116
Plagioclase	46.3	53.6	62.7
Augite	53.7	46.0	37.3
Apatite	tr	tr	tr
Magnetite	--	0.4	--
An, plag.	74.0	65.5	71.0
En, cpx.	52.6	69.3	54.5

TWO NEW BRECCIAS IN THE KIGLAPAIT LAYERED INTRUSION

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Introduction

In the course of work undertaken on layering styles in the Kiglapait intrusion (Young, this Report), two breccia zones were discovered. One situated on the north shore of Slambang Bay has predominantly xenolithic clasts in a troctolite matrix while the other is of autolithic material in a predominantly dunitic matrix (see Fig. 20). Previous to this only one other brecciated zone was known in the intrusion, situated to the west of Caplin Bay at the 15 PCS level and investigated by Morse (1969). Xenoliths were also virtually unknown in the intrusion; see Morse *et al* (this Report).

Slambang Bay Breccia

A lens of xenolithic and some presumably autolithic fragments set in a troctolite matrix was mapped on the north shore of Slambang Bay (see Fig. 20) at around 8 PCS. The lens is conformable with the regional layering. At its maximum it reaches 50 m in thickness. To the northeast the lens thins slightly until outcrop disappears underwater and does not occur along strike on the other side of the small bay. Neither the base nor the top of the lens is sharply defined but rather the fragments become less abundant and eventually become absent.

Fragments range in size from a few centimeters in diameter to one which is 13 m x 0.5 m. Elongate fragments tend to lie in the plane of the regional layering, though there are notable exceptions. The matrix is of unlayered, though occasionally laminated, troctolite. There is a tendency for this lamination to be parallel or sub-parallel to the regional layering.

Lithologies represented include metasediments (gneisses and calc-silicates), pyroxene granulite, anorthosite (one fragment of which is found associated with granophyric material) and layered and unlayered troctolite and possibly gabbro. The metasedimentary fragments are surrounded by a 1-2 cm rind of pyroxene (and

[1]Authors' full addresses are given at the back of this volume.

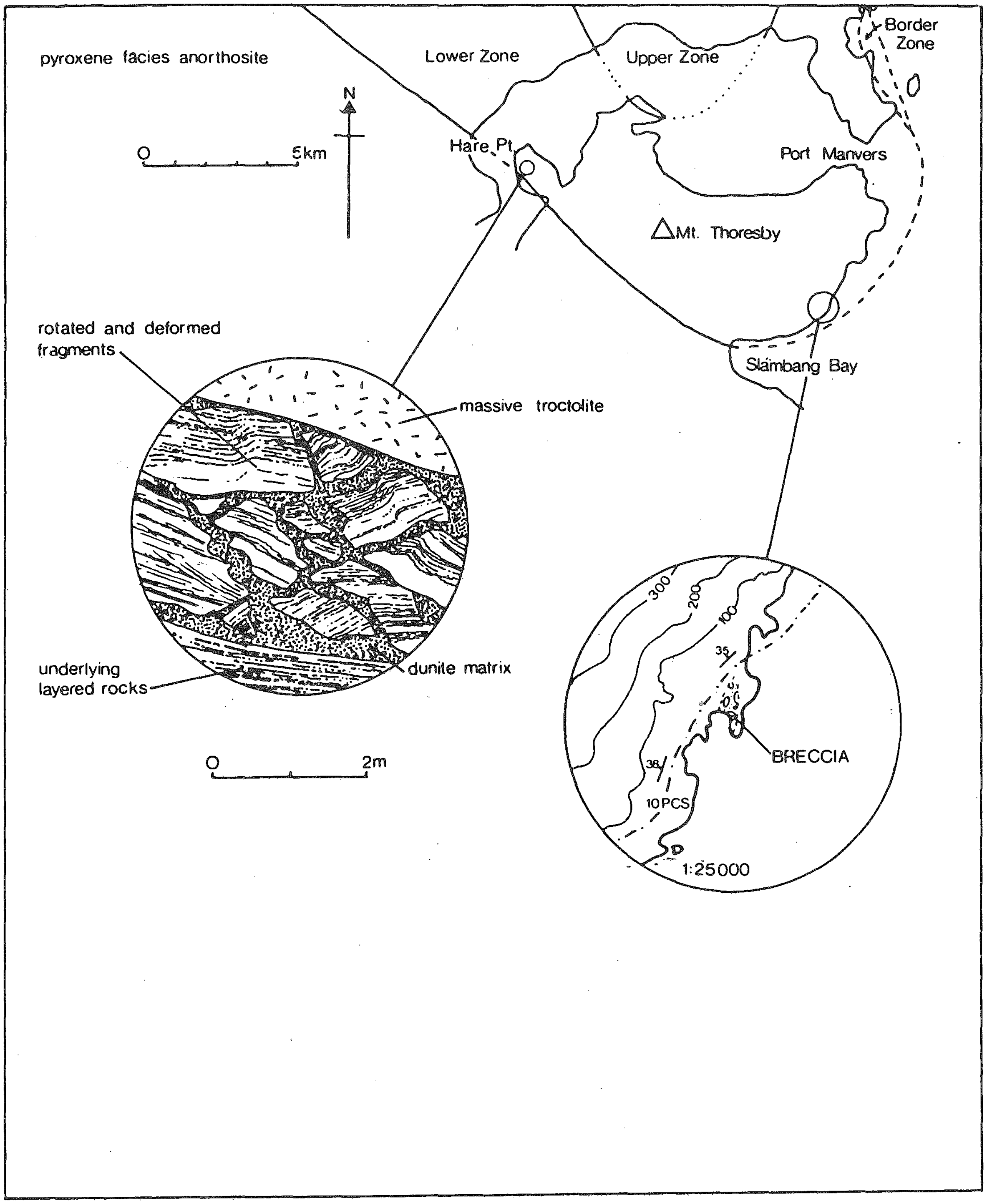

Fig. 20. Map of the southern portion of the Kiglapait intrusion showing the position of the Slambang Bay and Hare Point breccias. Details show a sketch from a photograph of the Hare Point breccia and a large-scale map of the area around the breccia zone in Slambang Bay.

perhaps a little amphibole or oxide). Fragments appear generally angular except for the smaller of the metasedimentary xenoliths which are more rounded.

Hare Point Breccia

This breccia lies at the stratigraphic top of the finely layered rocks of the dunitic horizon at Hare Point (approximately 15 PCS). It occupies a zone approximately 4 m long by 3 m thick set between the finely layered rocks of the dunitic horizon and unconformably overlying massive troctolite. The fragments are of broken and deformed troctolite, similar to that immediately underlying the breccia. Several of the fragments appear to fit together in a jigsaw-like fashion. The margins of the fragments are generally sharp. There is one small (20 cm x 8 cm) xenolith- of pyroxene anorthosite. The matrix is of dunite with a few small feldspathic segregations. The underlying layered rocks have been plastically deformed in places. Minor dislocations are also common. Deformed zones are, however, separated from one another above and below by undeformed layered rocks.

Discussion

The Hare Point breccia crops out on the opposite side of Port Manvers Run from, and along strike from a breccia lying to the west of Caplin Bay, described and illustrated by Morse (1969, plate 22). The similarity of style both of brecciation and deformation in the underlying cumulates in the two breccias suggests that they may be correlative across Port Manvers Run. Suggestions about the mode for formation of this style of breccia have been made by Morse (1969). Whether they represent the remnants of a once much larger breccia zone or not, their presence indicates significant change in the conditions under which crystals accumulated. This deformation may have been related to movement along the large fault to their immediate southwest.

The conformable nature and preferred orientation of the fragments in the Slambang Bay breccia suggest that it is neither an intrusive breccia nor a fault scarp deposit, unlike some of the breccias of the Rhum intrusion (Wadsworth, 1961; Donaldson, 1975). It cannot be an autobreccia since most of the material is foreign to the intrusion. The restriction of xeno- and autolithic fragments to such a small area makes it unlikely that they accumulated randomly from the overlying, circulating magma. In the Skaergaard intrusion it is common to find large numbers of foundered blocks in restricted horizons in the layered series (McBirney and Noyes, 1979). These authors suggest that breccias of this type in the Skaergaard intrusion were deposited from vertical density currents. A similar process operating in the Kiglapait intrusion can account for all of the field observations.

The similarities of the lithologies within the Slambang Bay breccia to those in the Snyder Group (Berg, FR 1975; Docka, FR 1980) is noteworthy and may indicate that this group bounded a greater part of the intrusion than is indicated by the present exposure level.

The presence of xenolith-bearing breccia indicates possibly significant departures from the closed system conditions proposed elsewhere (Morse, 1969; 1979). The question of possible assimilation of foreign material and contamination of the Kiglapait magma has been addressed elsewhere (DePaolo, 1981; Morse et al, this Report).

OBSERVATIONS ON LAYERING STYLES IN THE KIGLAPAIT INTRUSION

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Introduction

The Kiglapait intrusion records the strong fractionation of a high-alumina, high-FeO, low-K basaltic magma under essentially closed system conditions. Lithologies range from early troctolite to late Mg-free ferrosynenite (Morse, 1979). The intrusion is layered on a variety of scales and in a number of styles described by Morse (1969). Until recently, most layering in igneous rocks was generally regarded as being due to the mechanical separation of solid phases from magma and their accumulation on the floor of the chamber, sorting processes of several types producing the observed spectrum of layering types. It was recognized, however, that in the dense iron-rich magmas of the Kiglapait and Skaergaard intrusions plagioclase was less dense than the fluid it was supposed to have settled from (Morse, FR 1972; Bottinga and Weill, 1970). This fact formed the basis of Campbell's (1978) attack on cumulus theory and has led recent authors, e.g. McBirney and Noyes (1979), to attempt reinterpretations of layered rocks in terms of in situ crystallization. Morse (1979), writing about the Kiglapait intrusion, opted for a compromise solution by proposing that mafic minerals may have settled and that feldspars crystallized in place and were then retained on the floor of the intrusion by the rheologic changes in the fluid accompanying plagioclase precipitation. Irvine has recently (1980) suggested a means whereby plagioclase may be transported and laid down by density currents even in conditions where it has a negative density contrast with the liquid.

As Morse (1979) has pointed out, however, most hypotheses of layer formations are too unspecific to allow any clear-cut testing. In particular, little is known of the variation within individual layers along strike and down dip, i.e., in the second and third dimensions. For example, if graded layers are the result of current deposition then this should presumably be mirrored in

[1]Authors' full addresses are given at the back of this volume.

structural changes as any layer is traced both laterally and distally. Similarly, structural changes in other styles of layering may place constraints on their origin.

Such an approach has been used by Parsons and Butterfield (1981) to compare and contrast the modes of formation of layers in two chemically similar syenite intrusions, the Klokken and Nunarssuit Intrusions in south Greenland. In this report a number of different layering styles and their associated structures in the Kiglapait Intrusion are described and some preliminary conclusions drawn. Observations were made chiefly in the Lower Zone, north of Slambang Bay and at Hare Pt. (Fig. 20), but also in higher-level parts of the Lower Zone and lower Upper Zone south of the Kiglapait Mountains.

Macrorhythmic Layers

A distinctive style of ratio layering was recognized which closely resembles the macrorhythmic layering described by Irvine (1980) from the Skaergaard intrusion. The layering is defined by alternations of leucocratic and melanocratic rocks between 0.5 m and 5 m thick. The cumulus mineralogy of each layer appears identical, variation only occurring in the plagioclase/mafic ratio. The contacts between layers are generally gradational over distances between 10 cm and 20 cm, although they can be sharp. Layers of this type are invariably conformable with one another. Other styles of layering may be developed within a macrorhythmically layered sequence but these generally seem to have little effect on the overall sequence (see Fig. 21a). Macrorhythmic layers are laterally extensive and in some places can be traced by eye for several hundred meters. Outcrop was nowhere good enough to indicate whether these layers are as laterally extensive as the Skaergaard examples, which extend over areas of up to 4 km^2 (Irvine, 1980b). The best examples of layers of this type seen in the portions of the intrusion examined are to be found on the upper slopes of Mt. Thoresby overlooking Slambang Bay (at around 35 PCS) and in the Kiglapait Mountains, east of Sally Brook, in the upper part of the Lower Zone and the lower part of the Upper Zone (at around 70-90 PCS).

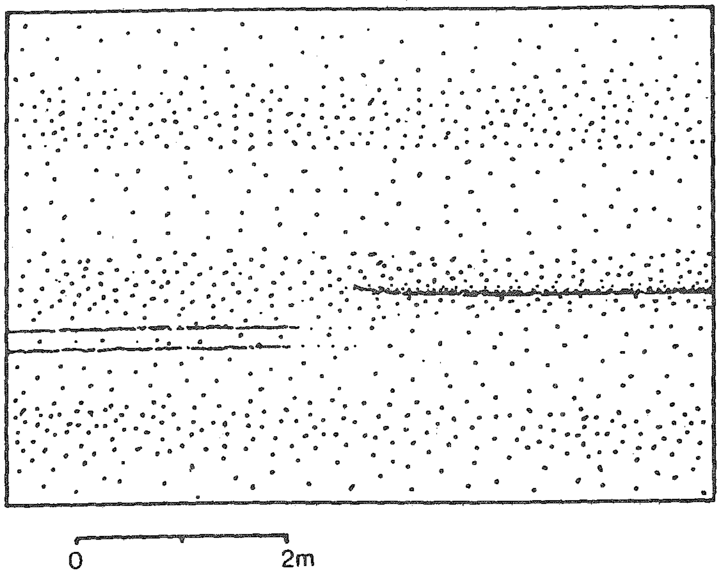
Normally Graded Layers

These are layers which grade from a mafic base to a feldspathic top, both of which have sharp contacts. Such layers are the "gravity stratified layers" of Wager and Brown (1968) or "graded layers" of Morse (1979). They tend to occur in groups in the intrusion (Morse, 1979). Layers of this type range from 5 cm to 1 m thick. The mafic portion can represent anywhere from 20% to 80% of this amount. No individual layer could be traced for more than 70 m along strike. However, groups of layers may be traced for much longer distances (hundreds of meters). Many graded layers cannot be followed due to smearing and shearing of individual layers together. Several graded layers were seen to contain autolithic fragments. In such cases the top of the layer may be draped across the top of the autolith, or more rarely the fragment may protrude into the overlying layers. In all cases there is slight asymmetry of the structure when viewed in dip section (see Fig. 21b). Graded layers may be seen to rest unconformably on one another especially when viewed in dip section. In several places graded layers were traced passing down dip into a pair of sharply defined mafic and leucocratic layers (see Fig. 21b).

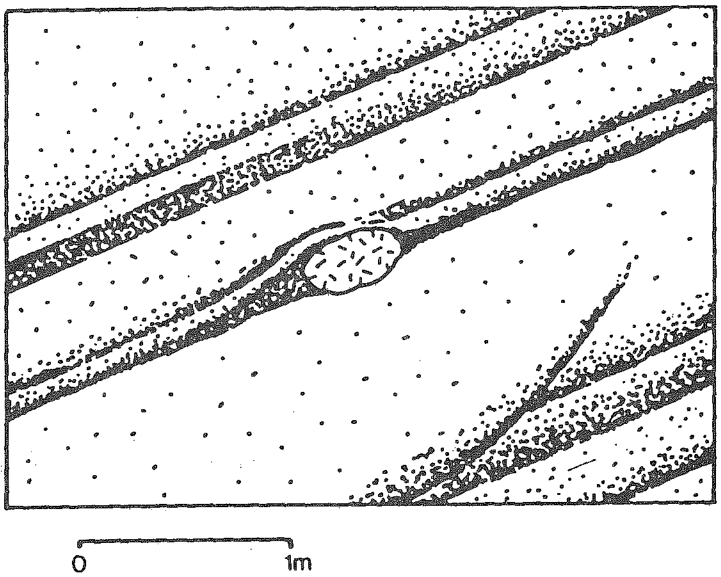
Lenticular Layers

This term is something of a misnomer since all layers appear to be lenses (apart from the major phase layers like the Main Ore Band). However, some ultramafic layers show a much more extreme development of a lenticular geometry. Layers of this type are best exposed on the north shore of Slambang Bay, although well developed examples can be found elsewhere in the intrusion (e.g. in the Lower Zone at 65 PCS south of the Kiglapait Mountains). A diagram showing strike and dip sections of the salient features is shown as Fig. 21c. The following points are of particular importance. Layers of this geometry were invariably seen as ultramafic lenses set in a more leucocratic matrix. Lenses have generally convex lower boundaries and have concave or straight upper ones. They vary from a few centimeters to approximately one meter in thickness and range in length from a few meters to approximately 30 m. Their bases are generally sharp but tops may be sharp or gradational. In strike sections lenses appear generally symmetrical. In dip sections lenses appear to attenuate more sharply up dip. In dip sections lens attenuations are numerous enough to suggest that lenses are not extremely elongate down dip. Cross-cutting

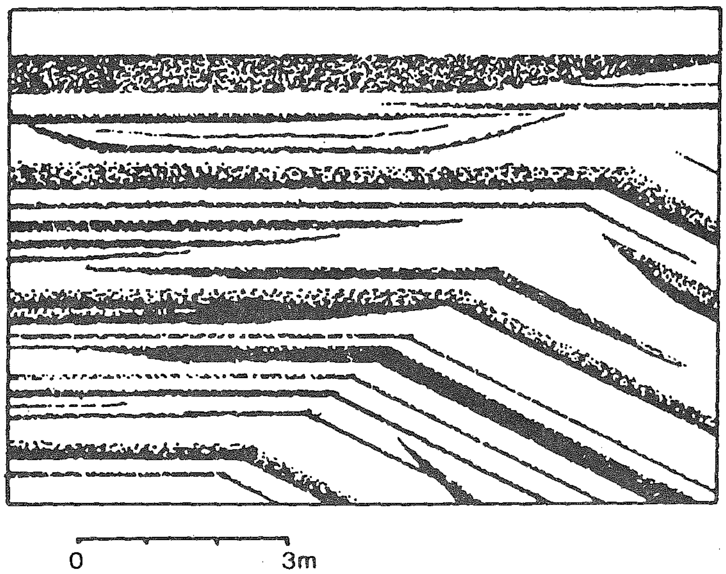
Fig. 21. Stylized sketches from photographs showing features of layering styles and their associated structures in the Kiglapait intrusion.



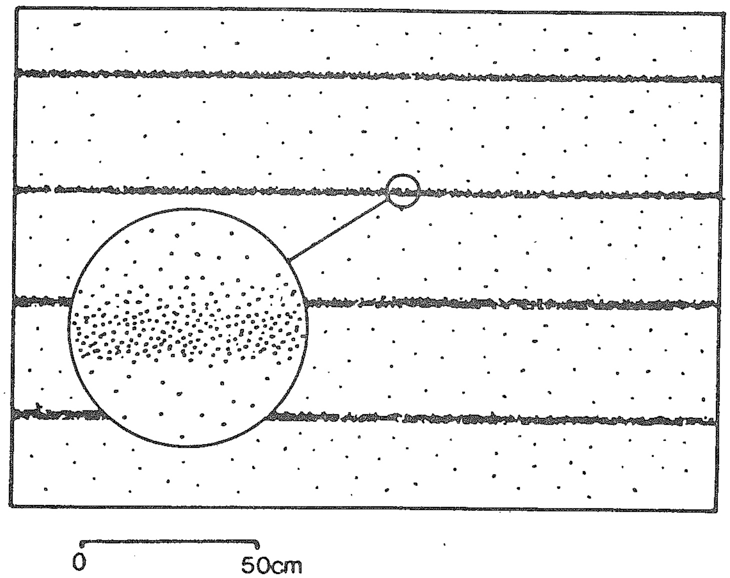
a) Macrorhythmic layering, strike or dip section; note superposition of other layer types.



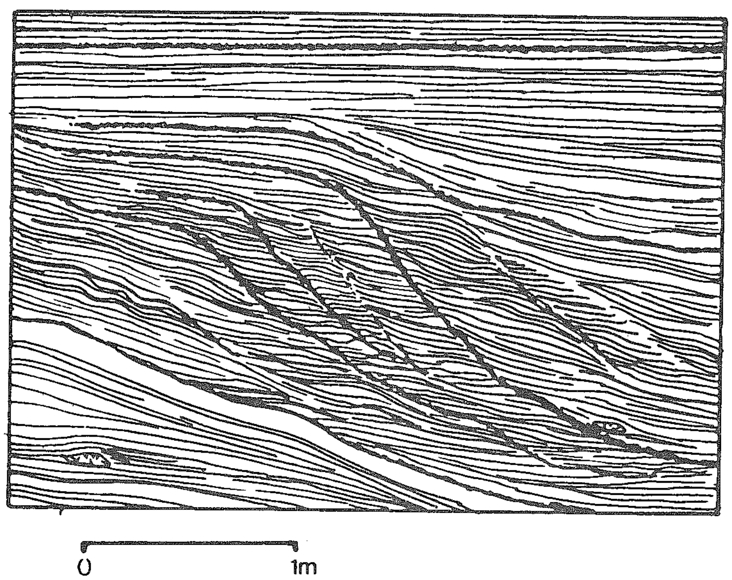
b) Normally graded layering, dip section; note cross-cutting relationships and relationship of layering to autolithic fragment.



c) Lenticular layering, strike and dip sections; note differences in dip and strike sections, lens attenuations and local cross-cutting relationships.



d) Fine scale layering (i), strike or dip section.



e) Fine scale layering (ii), strike section; note thick ultramafic layers changing along strike from conformable to crosscutting relationship, deformation of layers and relationship of layering to autolithic fragments.

relationships between layers of this type are rare, but more common in dip sections. The thickness of any particular ultramafic or leucocratic layer is not directly related to the thickness of the leucocratic or ultramafic layer immediately below.

Fine Scale Layering

The vertical dimension of this layering type is measured in millimeters or centimeters rather than decimeters or meters. Two distinctive types were recognized:

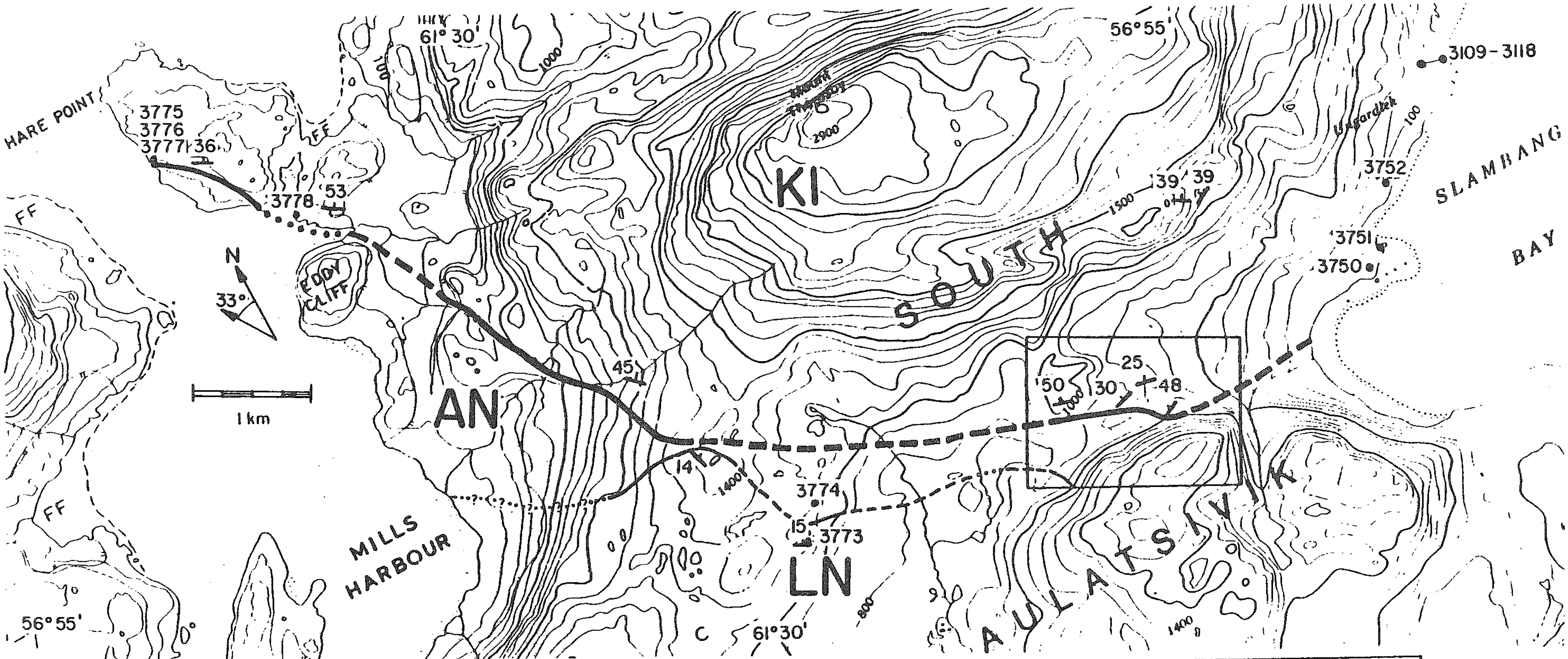
(1) One is characterized by 1-2 cm of mafic material in otherwise "normal" troctolite. In the Lower Zone such layers are olivine concentrations whereas in the Upper Zone they may be pyroxene or pyroxene and oxide concentrations. Commonly they have a slightly sharper base than top (see Fig. 21d). These layers commonly occur in groups, although isolated examples exist, and they are remarkably persistent along strike (one such layer in the Lower Zone was traced for over 200 m before being lost due to lack of exposure). Where these layers occur in groups they are parallel. No layer of this type was seen to cut any other layer. When traced along strike groups of layers tend to become less clearly defined as a group (although they retain a constant thickness and separation) until they become indistinguishable from the surrounding normal rock.

(2) The other type of fine scale layer recognised was much more variable in character. Such layers range in thickness from 2 mm (one crystal) to 8 cm. They generally have sharp upper and lower boundaries, although grading may occur. There is no obvious relationship between the thickness or character of successive layers. Individual layers may be extremely short, 20 cm, or remain remarkably constant for distances of up to 50 m along strike. Zones of layering of this type may however be very persistent along strike (up to 1 km; Morse, 1969). Bifurcations and truncations of one layer by another are common. Deformation is common and has apparently led to the formation of "new" layers in some cases (see Fig. 21e). Where autolithic fragments are present layers may exhibit asymmetry of structure around them (Fig. 21e).

Discussion

Layering in the Kiglapait intrusion has recently been discussed generally by Morse (1979), who suggests that co-operative settling of mafic phases and plagioclase feldspar together with oscillatory nucleation about a cotectic boundary can account for all the field and laboratory observations. It seems reasonable to suggest, however, that under specific conditions a specific style of layering is produced. Thus Irvine has argued (1980) that graded layering may be produced in any mafic or ultramafic intrusion by deposition from a crystal-laden density current. Other authors, for example McBirney and Noyes (1979), have suggested quite different layering mechanisms in investigations on, for example, the Skaergaard intrusion. The most fundamental distinction to be made is between layers produced by deposition and those produced by in situ crystallisation. Most authors agree that erosion may take place by current scour and lead to truncation of one layer by another. Unusual and asymmetric accumulations of material around obstacles may be other indications of current activity. Three of the layer types described above show truncation and/or accumulations around obstacles, namely normally graded, lenticular and one type of fine scale layer. The other layers, macrorhythmic and 2 cm mafic bands, show neither of these structures and their most remarkable feature is their parallelism. Note also that these layer types are identical when viewed in strike or dip section, unlike the other styles described (see Fig. 21). If both processes occur, then it seems that the most likely candidates for an in situ origin are the 2 cm mafic bands and the macrorhythmic layers. A similar conclusion was reached by Irvine, 1980b, in his discussion of macrorhythmic layering in the Skaergaard intrusion. Layer types showing unconformable relationships with one another are the most likely candidates for mass transport processes.

Another intriguing possibility, suggested by the deformed layers at Hare Point, is that some layering may be produced by reworking and segregation of cumulus grains within the crystal mush. The recognition of large scale oscillations of mafic content in the field (macrorhythmic layers) may explain the rarity of samples of apparently average rock with the cotectic ratio (see Morse, 1969, 1979).



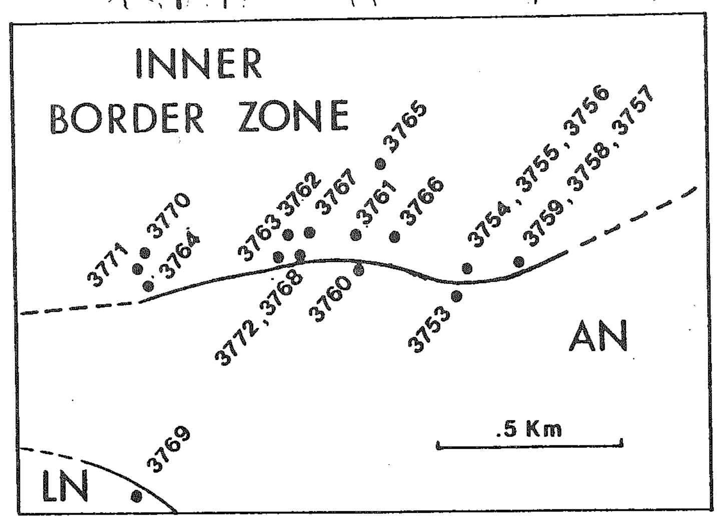


Fig. 22. Geologic map showing contact relations between the Kiglapait intrusion, anorthosite, and leuconorite found on South Aulatsivik Island.

SOUTHERN MARGIN OF THE KIGLAPAIT INTRUSION

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Introduction

The Kiglapait Layered Intrusion, located in the Nain Province of coastal Labrador, is exposed over an area of 560 km^2 and has a depth of approximately 8 km (Morse, 1969). The estimated bulk composition for the parent magma, obtained by summation over all the rocks of the intrusion, is an anhydrous high alumina olivine tholeiite (Morse, 1981b). The intrusion was emplaced 1.41 Gyr ago (DePaolo, 1981) at a pressure of about 2.5 kbar (Berg, 1977, 1979). Evolution of the Kiglapait magma is assumed to have occurred within a closed system after one major emplacement event (Morse, 1979a).

Bulk compositions of layered intrusions have been estimated with varying degrees of success by analyzing chilled margin samples. Within the Tranquil Division of the Skaergaard Intrusion, Wager found a chilled margin which he described as a fine grained olivine gabbro with poikilitic pyroxene (Wager, 1960). This sample was later shown to lie within a broad spectrum of chilled margin compositions (McBirney, 1975). Berg (FR 1972) described a chill zone for the Hettasch Intrusion which consists of a fine grained (0.2-3 mm) olivine gabbro. The average composition of five samples from this chill zone (Berg, 1980) was found by Morse (1981b) to correspond very closely to the calculated bulk composition of the Kiglapait Intrusion.

Except for a fine grained olivine gabbro found in the Falls Brook section overlying the Snyder Group of metasedimentary rocks (Berg, FR 1974) a chilled margin sample has not been previously described for the Kiglapait Intrusion. Previously described contacts have either been 1) shown to contain large portions of supracrustal rocks as seen in the Falls Brook Group in the north 2) obscured by shear zones in the anorthosite to the west or in the migmatites and paragneisses at Loaf Head Island in the east or 3) complicated by abundant

[1]Authors' full addresses are given at the back of this volume.

Fig. 23. Stratigraphic column showing the variation in texture, grain size, and composition from 0 to 9 PCS in the Kiglapait intrusion.

Stratigraphic thickness (meters)	LOWER ZONE	Sample numbers	Description	Average grain size: Feldspar	Olivine	Augite	AN	FO
	9% solidified	KI 3109 - 3118	Laminated and layered troctolite			trace	57.0	67.0
225	INNER BORDER ZONE	KI 3765	Laminated olivine gabbro	4mm	1.5mm	poikilitic	55.2	66.5
		KI 3767	Coarse grained olivine gabbro pods	2cm	2.5cm	poikilitic	56.2	
			Laminated olivine gabbro					
30								
		KI 3762	Granular olivine mela-gabbro	subophitic	1.5mm	1mm	59.0	61.1
25								
		KI 3770	Plagioclase-bearing wehrlite sill	subophitic	2mm	poikilitic		65.0
		KI 3761	Laminated olivine gabbro with pyroxene oikocrysts (5cm)	3mm	1.5mm	poikilitic	56.0	62.9
		KI 3766	Gabbro pegmatite dike			poikilitic	55.0	
			Poorly defined modal Layering (olivine rich, plagioclase rich) Average thickness of 4cm					
10								
			Disturbed or slump horizon					
			Cognate inclusions					
6		KI 3768	Chilled margin: subophitic olivine gabbro	2mm	0.5mm	1mm	53.7	61.7
5								
		KI 3772	Laminated olivine gabbro	7mm	subophitic	subophitic	57.0	62.0
0	0% solidified							
	CONTACT ANORTHOSITE	KI 3774	Medium grained anorthosite	3mm		Interstitial	54.9	

pyroxenite pods, schlieren, and granitic dikes as seen at Topaz Point in the eastern part of the intrusion (Morse, 1969).

The southern margin of the Kiglapait Intrusion against the bordering anhydrous and refractory anorthosite was chosen for detailed mapping and sampling (Fig. 22). Field investigations along 10 km of contact of South Aulatsivik Island revealed an Inner Border Zone similar to the previously described Inner Border Zone in the northwest (Morse 1969; Berg, 1971). The southern Inner Border Zone contains a fine-grained rock interpreted as an uncontaminated chilled margin.

One detailed stratigraphic section of the Inner Border Zone on South Aulatsivik Island is shown in Fig. 23. It is characterized by troctolites and olivine gabbros which solidified as orthocumulates and lack pronounced modal layering. This texture distinguishes the unit from the overlying Lower Zone, comprised of rhythmically layered troctolites which solidified as adcumulates. The modes for the rocks, along with the estimated bulk composition for the intrusion and the cotectic trace for 1 atm. and 4 kb are shown in Fig. 24. A description of the country rocks and Inner Border Zone follows along with a general discussion.

Country Rock

The anorthosite bordering the intrusion has an average grain size of 3 mm. The dark, iridescent feldspars ($An_{54.9}$) occur as anhedral interlocking grains with white rims consisting of sericite and prehnite. Fine opaque, oriented rods and randomly oriented clear inclusions are abundant within the feldspar grains, which show concentric normal zoning and local reverse zoning. Locally the anorthosite has a bimodal texture, with large subhedral feldspar grains (2.5 - 15 cm in length), surrounded by medium grained feldspar, subophitic clinopyroxene, orthopyroxene and magnetite.

A contact between the anorthosite and a laminated leuconorite was found this summer. The plane defined by the feldspar lamination has a shallow dip to the northeast. Coarse grained gabbroic sills mark the contact in the east while in the west a possible shear zone separates the two bodies. An age relationship between the two rock types was not determined in the field.

The medium grained, laminated leuconorite (C.I. = 5) consists of tabular feldspar crystals ($An_{52.8}$) which vary in length from 1 to 8 mm. The longer feldspars are subhedral while the smaller ones are anhedral. Opaque, oriented inclusions may account for the pinkish beige tint of the feldspars. Broad normal zoning and narrow reverse zoning on rims were observed. Intercumulus minerals include inverted pigeonite, ilmenite and magnetite. The inverted pigeonite has an orthopyroxene host with coarse irregular blebs of augite oriented in the (001) plane of the original pigeonite.

Contact

Fig. 22 shows the trend of the contact on South Aulatsivik Island. A rubble zone with a minimum width of 15 meters separates the Kiglapait Intrusion from the bordering anorthosite. Contact relations suggests that this rubble zone is due to weathering rather than faulting.

Beneath the contact, anorthosite blocks (1.5 x 2m) are enclosed by a gabbroic matrix. One block has a porphyritic texture comprised of subhedral feldspars (10 x 15 cm) which are surrounded by white rimmed, medium grained feldspars and subophitic pyroxene. Another block consists of medium grained feldspars with a minor amount of interstitial pyroxene, olivine and oxide.

The irregular boundaries of the blocks have V-shaped fractures facing towards the Kiglapait intrusion. Coarse ophitic clinopyroxene, olivine, oxide minerals, and euhedral feldspars aligned normal to the surface, fill the fractures.

Consolidated blocks of the bordering anorthosite appear to have been caught up in the intruding Kiglapait magma. There is no variation in grain size from the cores to the margins of the blocks, which implies they were refractory enough to be unaffected by the Kiglapait magma. Therefore, contamination caused by the assimilation of country rock was minimal.

Inner Border Zone

The margin of the Kiglapait Intrusion consists of gabbros and troctolites which vary both in mode and texture roughly as a function of distance from the contact (Fig. 23). After approximately 55 meters, variation lessens and the typical rock type can be described as a medium grained, laminated olivine gabbro with poikilitic pyroxene.

In some areas a fine grained olivine gabbro with wispy layers of cumulus pyroxene crystals (2 mm in diameter) is closest to the contact. The trend of the layers is discordant both with the trend of the contact and with the lamination of the overlying olivine gabbro.

If the layering and lamination were created by flow then the first currents did not flow parallel to the present contact as did the later currents.

Chilled Margin. The chilled margin is approximately 5 meters above the laminated olivine gabbro closest to the contact. It defines a thin (less than 1 meter) irregular horizon which extends over 0.4 km.

Of the samples collected, KI 3768 looks the most promising for a chilled margin sample. It is a medium to fine grained olivine gabbro with a subophitic texture. It contains less then 1 percent phenocrysts of feldspar (10 x 4 mm) and pyroxene. Intercumulus phases include a total of less than 2% magnetite with ilmenite lamellae, red biotite, pargasite, and orthopyroxene.

As can be seen in Fig. 24, the modal composition of the chilled margin plots on the Kiglapait modal liquid path and remarkably close to the estimated bulk modal composition for the intrusion. In fact, the modes for the Inner Border Zone olivine gabbros and troctolites, as distinguished from the gabbroic pods, sills, and Lower Zone troctolites cluster in the region between the cotectic trace at 1 atm and 4 km. Crystallization of orthocumulates with average rock modal compositions versus crystallization of rhythmically layered adcumulates is seen as evidence for chilling at the margin. This impression is further supported by the low An content of the feldspars (An_{54} versus An_{57}) and the small size of the numerous olivine grains (0.5 mm versus 1.5 mm). Nucleation induced by supersaturation can be promoted not only by supercooling but also by shearing or mechanical perturbation of the liquid (Wager and Brown, 1968). Perhaps in this example, where the effects of chilling are found some distance inward from the contact, nucleation was promoted by mechanical processes.

Disturbed or slump horizon. Above the chilled margin, a felsic olivine gabbro layer is sandwiched between mafic olivine gabbro layers. The felsic layer thickens and thins, forming asymmetrical folds with a counterclockwise rotation sense to the west. This is opposite to the rotation sense found in the Lower Zone of Hare Point (Morse, 1969). The attenuated overturned limb of the fold is fractured, suggesting that deformation occurred when the layers were partly solidified.

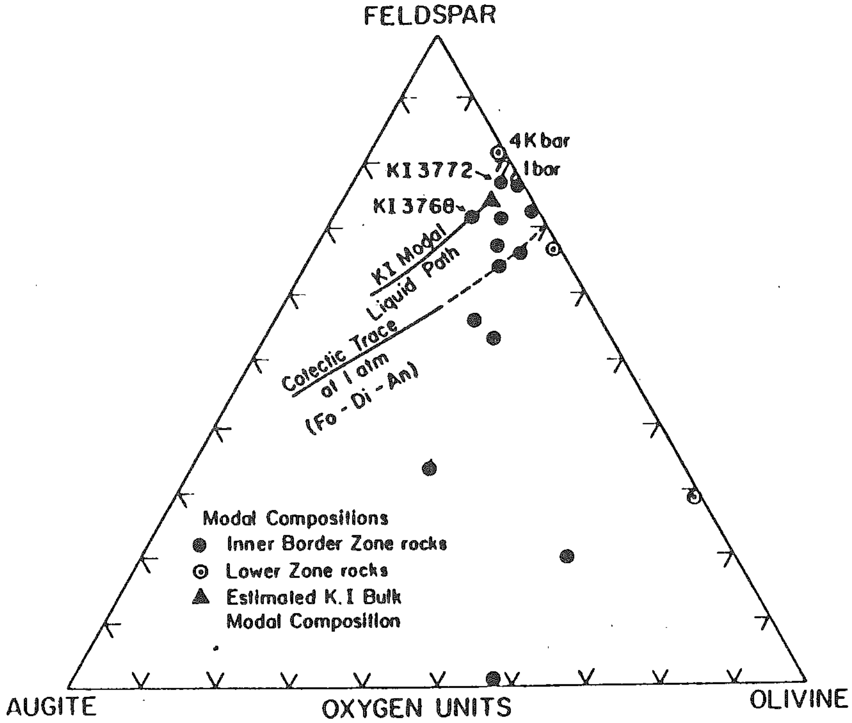

Fig. 24. Modal compositions of rocks from the Inner Border Zone and Lower Zone of the Kiglapait Intrusion plotted in the system Fo-Di-An along with the estimated bulk composition, the liquid path for the Lower Zone (Morse, 1979) and the cotectic traces for 1 atm (Osborn and Tait, 1952) and 4 kbar (estimated from Emslie, 1971).

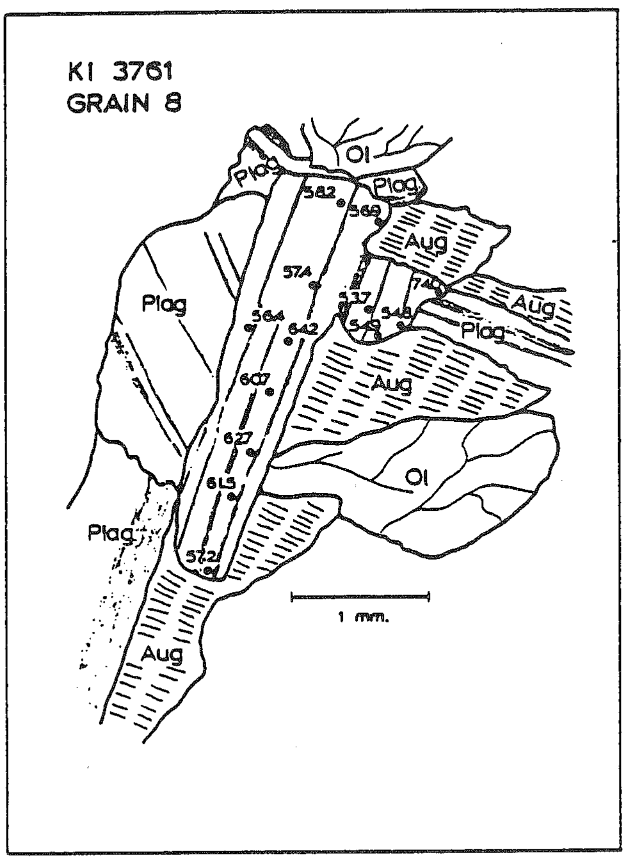

Fig. 25. Cumulus plagioclase grain (Plag) with postcumulus overgrowth, Kiglapait IBZ. An content, determined by electron microprobe, shows broad normal zoning with narrow reversed zoning at rim. Note poikilitic augite (Aug) with exsolved magnetite plates, and olivine (Ol).

Cognate inclusions varying in length from 3 to 30 cm are enclosed within the mafic layers. The ellipsoidal inclusions consist of coarse grained olivine gabbro with 1.5 cm euhedral pyroxenes. Their upper margins are surrounded by a concentration of olivine crystals.

Transition zone. Overlying the slump horizon is a laminated olivine gabbro with poorly defined modal layering. A gabbro pegmatite dike crosscuts both sets of layering. It consists of very coarse subophitic clinopyroxene and feldspar.

Coarse olivine gabbro pods, contained within a laminated olivine gabbro, consist of subhedral to subophitic olivines with diameters up to 2.5 cm, poikilitic pyroxene regions continuous up to 13 cm, subhedral to anhedral feldspar and a minor amount of oxide minerals. The laminated olivine gabbro contains 5 cm oikocrysts of pyroxene enclosing radiating feldspar plates and olivine. The oikocrysts are orb-shaped and evenly spaced. A plagioclase-bearing wehrlite sill (20 cm thick) occurs 0.5 km to the west. Along with subhedral olivine grains, poikilitic pyroxene and subophitic feldspar, it contains a composite cluster of pyrrhotite, pentlandite and chalcopyrite.

Approximately 250 meters away from the contact, there is distinct modal layering within the olivine gabbro. Alternating olivine-rich and feldspar-rich layers have a thickness of approximately 15 cm. This unit is considered still to be part of the Inner Border Zone as it contains 2% intercumulus pyroxene.

Mineral Compositions. Figure 23 shows in a stratigraphic context the compositions of the feldspars and olivines. The average An_{56} and Fo_{63} values plot with the northwestern Inner Border Zone compositions on the trend described for the intrusion (Morse, 1979B). The Inner Border Zone compositions are lower than the maximum compositional values of An_{67} and Fo_{70} found at approximately 20 percent solidified. As it is assumed the magma was emplaced in one major event, the low compositional values might be attributed to supercooling of the melt. The low Fo values might be due to re-equilibration of the olivines with the trapped liquid.

As can be seen in Figure 25 the feldspars show broad normal zoning and reverse zoning on thin rims. The broad normal zoning (range of 10% An) indicates a residual porosity of 15 percent (see Morse, 1979c). Therefore 15 percent of the rock consists of former pore liquid which was isolated from the overlying magma. Intercumulus phases include the excluded components of augite, magnetite and a trace of sulfide. However, no apatite has been seen.

The pyroxene compositions plotted in the pyroxene quadrilateral along with the trend for the compositions of the Upper Zone are shown in Fig. 26. Both the Inner Border Zone and Lower Zone pyroxene compositions are more magnesian and more calcic than the Upper Zone compositions. Crystallization of pyroxene from a magma with the Kiglapait bulk composition could have occurred by local fractionation of the magma until the eutectic in the system Fo-Di-An was reached or through supercooling of the melt until the metastable extension of the augite field was reached. The high magnesian and calcic compositions suggest that the pyroxenes crystallized from a magma which was less evolved than the magma of the Upper Zone. Therefore it is assumed that augite crystallized due to supercooling.

Accessory minerals include magnetite with ilmenite lamellae, orthopyroxene, pargasite and red biotite. The orthopyroxene forms discontinuous rims on the olivines and also occurs with magnetite in oxysymplectites. Pargasite partially rims olivine, augite, and magnetite. The red biotite occurs as partial rims on oxysymplectites, magnetite and as small plates aligned on the surface of the augite. Such a minor amount of hydrous minerals indicates that there was little water at the contact with anorthosite.

Summary

The first 55 meters of the margin consists of laminated, subophitic, and granular olivine gabbros. This wide variation in texture reflects how variable were the deposition and crystallization of the average rocks during the initial stages of solidification. The average modal composition of the orthocumulates is seen as evidence of chilling at the margin.

Pyroxene compositions enriched in Ca and Mg indicate that the magma was less evolved than the Upper Zone magma and therefore it is suggested these rocks crystallized from a melt of composition equivalent to the bulk composition of the intrusion. However, the absence of apatite implies that these rocks were only partially chilled and that later solidification proceeded slowly, allowing some excluded components to escape. Therefore, the whole rock compositions are not truly representative of the parent magma composition.

The contact was dry and contamination was minimal. The folding, cognate inclusions and dikes are evidence of a disturbance at the margin after it was partly solidified. The granular olivine melagabbro might have slumped into the partially solidified crystal mush, causing the fold in the underlying layers. As the gabbro pegmatite dike does not cross-cut olivine melagabbro, perhaps the dike predates or is contemporaneous with the slumping. It is uncertain whether the dikes and sills originated from the Kiglapait magma or from another intrusion. Preliminary work on their mineral compositions shows that they are similar in composition to the laminated olivine gabbro. Therefore they are interpreted as related to the Kiglapait magma.

The southern margin provided a fairly unobscured view of the boundary of the intrusion. With the previously described relations in mind, it is hoped to study other sampled margins of the intrusion, which might tell us more about the initial processes of solidification.

Acknowledgment

I would like to thank Suzanne Nicholson for her generous assistance in the field.

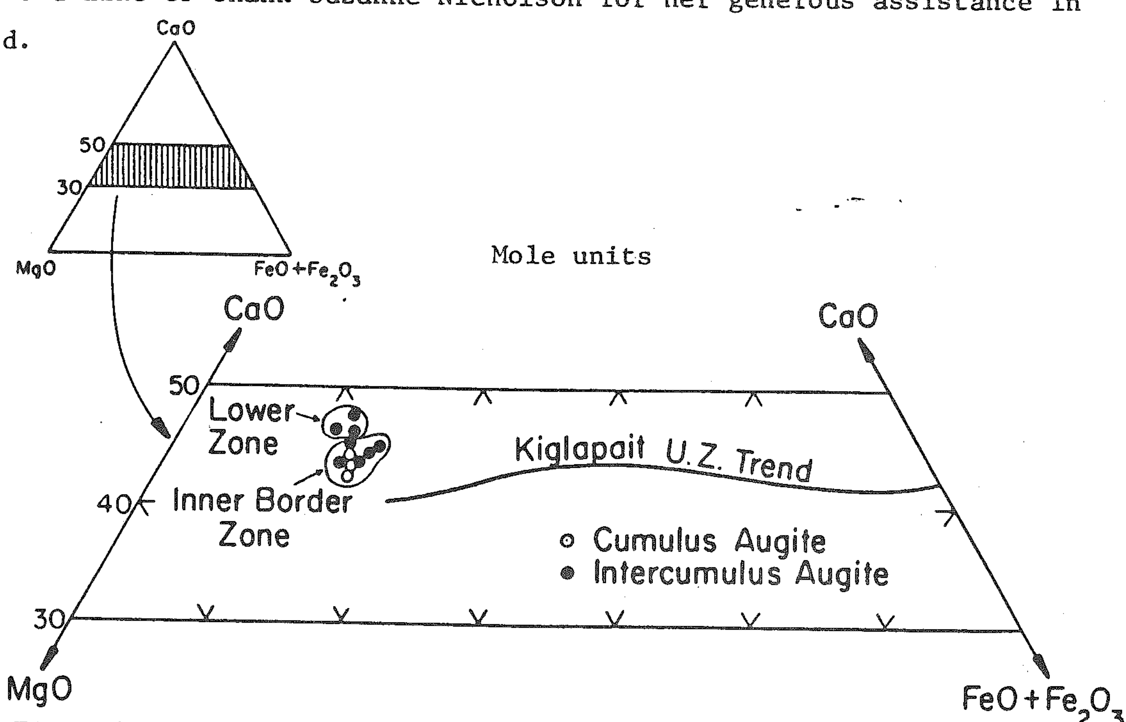

Fig. 26. Pyroxene quadrilateral, projected from SiO_2, showing both cumulus and intercumulus augite compositions from the Inner Border Zone and Lower Zone along with trend from the Upper Zone (U.Z.) taken from Morse (1980).

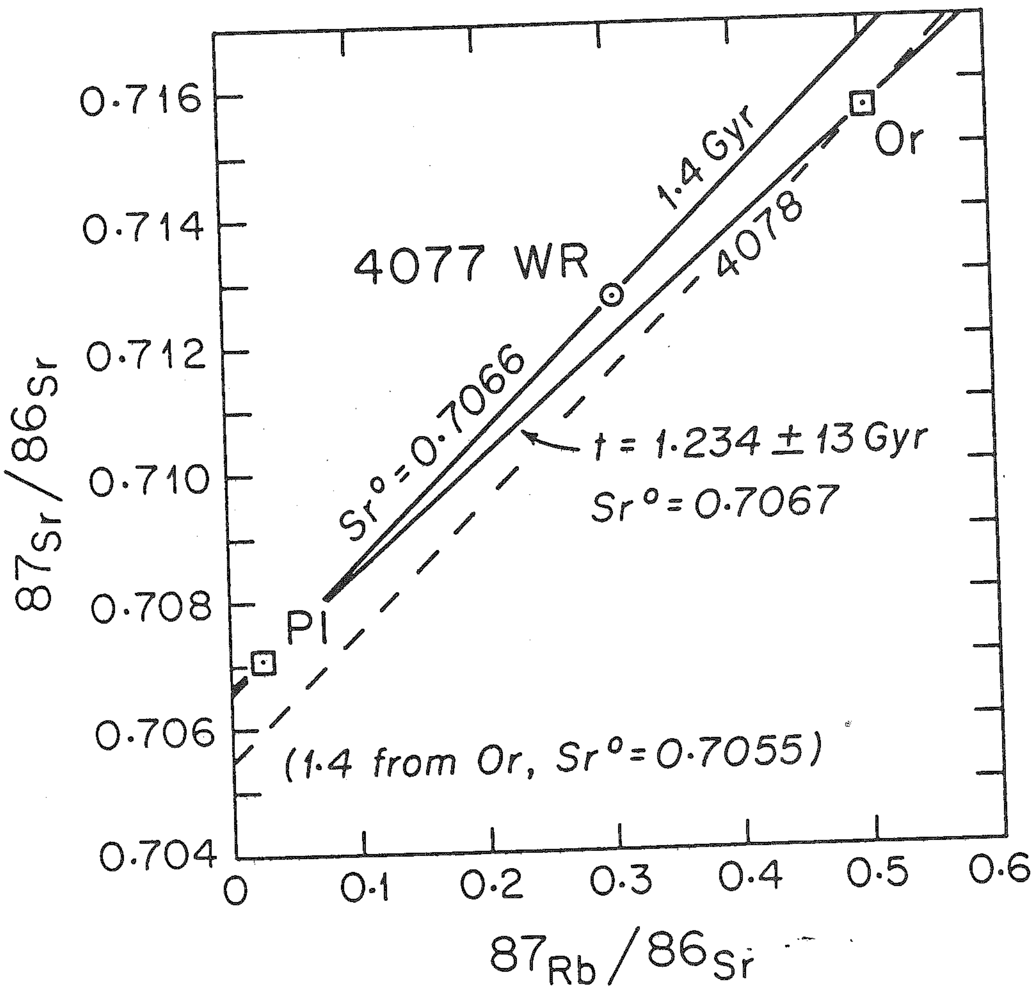

Fig. 27. Rb-Sr relations of separated feldspars from sample KI 4078. A line connecting the two feldspars gives an apparent age of 1.234 Gyr and falls below wholerock sample KI 4077, taken at the same locality and studied by Simmons and Lambert (FR 1980). Steeper lines show that model isochrons for 1.4 Gyr require the orthoclase separate to be less radiogenic than plagioclase, contrary to the "sanidine parcel" hypothesis of Morse (1981c).

Rb-Sr ISOTOPIC RELATIONS OF SEPARATED FELDSPARS FROM THE UPPERMOST KIGLAPAIT LAYERED GROUP

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Introduction

Data reported by Simmons and Lambert (FR 1980) showed that the initial strontium isotope ratio at 1.4 Gyr (hereinafter Sr^o) rises abruptly at 90 percent solidified (PCS) from 0.7040 in the Lower Zone to a value as high as 0.7066 at 99.985 PCS. Simmons and Lambert ascribed this variation to magma mixing. Morse (1981b) showed that mixing and contamination models were so restricted by the low Rb content and other chemical features of the intrusion as to appear unlikely, and he proposed instead that radiogenic ^{87}Sr was retained in sanidine-like parcels of the magma, which were concentrated upward during fractional crystallization. If such a process occurred, the question arises whether strontium isotopic disequilibrium would still be present today between ^{87}Sr-rich orthoclase and coexisting plagioclase. The present study was undertaken to test for the presence of such disequilibrium.

Sampling

The sample chosen was KI 4078. Its major element chemistry (Morse, 1981) is essentially identical to that of sample KI 4077, whose wholerock Sr^o value was found by Simmons and Lambert to be 0.70662. The samples were taken 5 m apart at the 99.985 PCS level of the intrusion, and are presumed to represent the "last liquid" sampled because of their extreme major element fractionation (Morse, 1981). The two samples differ petrographically in that KI 4078 is somewhat coarser grained, with two-feldspar intergrowths suggesting barely subsolvus crystallization, and coarse enough to allow separation. The previously purified feldspar fraction, ground to approximately -100 mesh (150 μm), was

[1] Authors' full addresses are given at the back of this volume.

separated in bromoform progressively diluted with "Neothene" solvent until an orthoclase-rich fraction floated and plagioclase sank. The resultant plagioclase fraction was about 99% pure, and the orthoclase-rich fraction contained about 5% plagioclase as estimated in oil immersion mounts. Wet chemistry and Rb and Sr isotopic analyses were done by SRH using diffusion-purified reagents and the normal ion-exchange column and automated mass spectrometry procedures used at the Center for Geoalchemy at M.I.T.

Results

1. The separated feldspars (Table 6) define an apparent two-point isochron age of 1.234 ± .013 Gyr (Fig. 27, $\lambda^{87}Rb = 1.42 \times 10^{-2}$ Gyr^{-1}), with Sr^o = 0.7055.

2. The wholerock sample KI 4077 lies above this isochron as shown in the figure.

3. If a model age of 1.4 Gyr is assumed, the orthoclase has a lower value of Sr^o (ca. 0.7056) than the plagioclase (ca. 0.7066), contrary to the "sanidine parcel" hypothesis. However, the suggestion of a younger resetting (see below) prevents any firm inferences being drawn about the isotopic relations at 1.4 Gyr. The implied Sr^o of plagioclase is consistent with the wholerock Sr^o = 0.70662 for the nearby sample KI 4077 (Simmons and Lambert, FR 1980).

Discussion

The feldspar isochron age found here is identical, within experimental error, to the age of the Manvers Granite (Morse, 1969; Barton, 1977), which sharply cross-cuts the Kiglapait intrusion. The similarity in ages suggests that this mineral isochron may have been reset by Manvers Granite. If so, the Manvers-age reheating must have been a local effect only, because sample KI 4076 at 99.98 PCS, less than 50 meters away, gives a total feldspar-wholerock-pyroxene Rb-Sr isochron age of 1.413 ± 0.054 Gyr, in excellent agreement with a plagioclase-wholerock-augite Sm-Nd isochron age of 1.416 ± 0.050 Gyr at 98.6 PCS (DePaolo, 1981). As a result of the unexpectedly young two-feldspar age, no clear-cut test of the "sanidine parcel" hypothesis emerges from the new data.

An alternative but unlikely explanation of the young apparent age is that the plagioclase successfully separated is xenocrystic and residual from assimilation of country rocks of higher Sr^o than the Kiglapait magma, or that the plagioclase is endogenous and plagioclase structural units in the magma were carriers of high Sr^o. In either case, the age is fictitious and the plagioclase is in isotopic disequilibrium with the orthoclase-rich fraction.

A third possibility is that the most fractionated Kiglapait rocks at 99.985 PCS represent a later intrusion of magma emplaced at 1.25 Gyr. No field evidence is known to support such a conjecture, and the emplacement of Manvers Granite in brittle fractures at 1.25 Gr, the singular chemical composition of the most fractionated rocks, and the difficulty of emplacing a sheet of such rocks without disturbing the 1.4 Gyr Rb-Sr systematics at 99.98 PCS, less than 50 meters away, render a separate emplacement event very unlikely.

The Nd-isotopic data of DePaolo (1981) support the hypothesis of progressive contamination of the Kiglapait magma with crustal material during crystallization, and newly discovered xenoliths provide tangible evidence that contamination did indeed occur (see Morse, Young, Ball; this Report). However, the influence of the Manvers Granite event needs further evaluation, and more detailed studies of mineral and wholerock isotopic relations will clearly be needed before the progressive upward enrichments in ^{87}Sr and ^{144}Nd are adequately understood.

Acknowledgement

The feldspar separation was ably performed by K. M. Nolan.

Table 6 . Rb-Sr data for separated feldspars of sample KI 4078.

Fraction	Rb (ppm)	Sr (ppm)	$^{87}Sr/^{86}Sr$*
4078 plagioclase	2.805	341.0	0.70712 ±4
4078 orthoclase	49.95	287.4	0.71559 ±4

* Corrected to 0.70800 for E. & A. standard.

RECENT ABSTRACTS AND NAIN BIBLIOGRAPHY

We reprint in the following pages some recent abstracts and the complete bibliography of the Nain Anorthosite Project, bringing it up to date through 1982. Included are papers which make extensive use of samples or data gathered in the course of the Project. The bibliography is organized in two sections: I) Papers, theses, reports, and II) Abstracts. The count at the close of 1982 is 16 theses, 54 papers, 8 reports, and 38 abstracts.

RECENT ABSTRACTS

1. Geology of the Avakutakh Iron Formation, Labrador, by Mary Louise Schuh

The Avakutakh iron formation, the basal unit of the Aphebian-aged Falls Brook Group, is exposed in the Snyder Bay-Avakutakh River area of Labrador. Together with the metasedimentary Snyder Group, it forms part of the contact aureole of the Kiglapait intrusion. Thin section study, oxygen isotope analysis, and microprobe analysis were used to determine the petrography, mineral chemistry, and metamorphic history of the Avakutakh iron formation.

The Avakutakh iron formation is comprised of three metamorphic zones: grunerite-zone, hypersthene zone, and pigeonite zone. During the metamorphic event, temperatures ranged from 625 - 860°C over a distance of 565 m and pressure was essentially constant at 2.2 kbar. Anomalously low temperatures were obtained from oxygen isotope analysis and appear to be the result of diffusion of ^{18}O between quartz and magnetite with cooling.

Chemical diffusion between the Avakutakh iron formation and adjacent mafic orthogranulites is limited to a band several centimeters wide. Thus, it can be assumed that the Avakutakh iron formation behaved as a closed system with respect to major non-volatile components.

--MS Thesis, Northern Illinois University, Dec. 1981

2. Oxygen Isotope Geochemistry of the Kiglapait Layered Intrusion, by Ruth I. Kalamarides

The Kiglapait layered intrusion is the first major intrusion found to have all whole rock and calculated liquid $\delta^{18}O$ values close to the "normal gabbroic" value of 6.0. The data support the view that the intrusion experienced no exchange with its surrounding rocks and that cooling of the magma was conductive. The $\delta^{18}O$ values of average whole rocks vary smoothly from 6.0 at the end of crystallization. The calculated liquid values of $\delta^{18}O$ lie practically superimposed on the whole rock trend. The data show that little change occurs in the $\delta^{18}O$ of a high-alumina basic magma which undergoes extreme fractional crystallization. The whole-rock data and the modelled $\delta^{18}O$ of the magma and cumulates rigorously demonstrate that the effect of incoming cumulus phases on the $\delta^{18}O$ of the liquid and rocks during fractional crystallization is negligible. This circumstance is explained by the cancelling effects of complementary modal variations among the mafic mineral phases and feldspar, which keep the $\delta^{18}O$ of the whole rocks constant to within ± 0.1°/oo. The minor change in $\delta^{18}O$ that does occur with fractionation is consistent with the enrichment of residual liquids in feldspar component and the increasing fractionation factor ΔLiquid-Fsp with falling temperature. Liquids at or near a cotectic will not experience a large change in $\delta^{18}O$ by themselves during strong fractionation. Only where an excess of mafic or felsic minerals crystallizes, in cases such as picrites or anorthosites, would one expect to see a noticeable shift in the $\delta^{18}O$ of the residua.

The fractionation of $\delta^{18}O$ between liquid and temperature-corrected mineral phases has been determined and for the basaltic portion: ΔL-Fsp=-0.4; ΔL-Cpx=+0.2; ΔL-Ol=+0.8; ΔL-Opq=+1.5. These values are similar to other reported values except for that of ΔL-Fsp, which is less than most reported values due to the plagioclase-rich nature of the liquid.

RECENT ABSTRACTS
(continued)

Modelling with oxygen isotopes has shown possible contamination of the intrusion indicated by published radiogenic Sr and Nd isotopic data to be minor. The $\delta^{18}O$ of the country rocks bracket the estimated $\delta^{18}O$ of the Kiglapait magma. The most probable contaminant had $\delta^{18}O \simeq 7.7$ and the contamination most likely occurred at >99% solidified.

--PhD Thesis, U.Mass, Dec. 1982.

PROCEEDINGS OF THE THIRTEENTH LUNAR AND PLANETARY SCIENCE CONFERENCE, PART 1
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Adcumulus Growth of Anorthosite at the Base of the Lunar Crust

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Unzoned plagioclase crystals imply isothermal adcumulus solidification and cannot result from reactive equilibrium crystallization in dry magma. Extraction of latent heat upward through lunar crust results only in chilled or cotectic mesocumulate rocks, not anorthosite or adcumulates. Adcumulus growth of anorthosite requires exchange of refractory for incompatible components between the site of crystal growth and nearby fresh magma, and the extraction of calories from growing crystals to the flowing, supercooled magma. Supercooling can be acquired at remote sites like upwellings and then be carried by convective flow beneath crust which is accreting plagioclase by flotation or in situ nucleation and growth. If transport distances are larger than the scale of rockbergs, cotectic norites and troctolites may result. Impact-induced upwellings tend to promote growth of buoyant rather than mafic crust, hence impacts are not solely destructive.

AGE, SOURCE, AND CRYSTALLIZATION-ASSIMILATION HISTORY OF THE KIGLAPAIT INTRUSION AS INDICATED BY Nd AND Sr ISOTOPES

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Sm-Nd and Rb-Sr isotopes were measured in the Kiglapait layered mafic intrusion (LMI), Nain Province, Labrador (Morse, GSA Mem. 112) as part of a continuing effort to characterize the mantle sources for continental tholeiitic basalt through time and to understand the interaction of large mafic magma bodies with their surroundings. A Sm-Nd mineral isochron age of 1416±50 my was obtained on plag-augite-whole rock from upper zone (UZ) ferromonzonite. Plag+augite account for only 20% of the whole rock Nd. A Rb-Sr mineral isochron on ferrosyenite gives 1413±54 my ($\lambda = 1.42 \times 10^{-5}\,my^{-1}$), in excellent agreement with Sm-Nd. Initial $^{143}Nd/^{144}Nd$ exhibits a range from $\epsilon_{Nd} = -1.1$ in the lower zone to -4.9 in the latest differentiates. Initial $^{87}Sr/^{86}Sr$ varies in like manner from 0.70400 to 0.70623 ($\epsilon_{Sr} = +17$ to +48). ϵ_{Nd} of the LZ indicates that the magmas may have been derived from primitive mantle ($\epsilon_{Nd} \approx 0$). ϵ_{Sr} is high for primitive mantle, but similar to some continental flood basalts and other LMI's. LMI's through time (Stillwater, 2701 my, $\epsilon_{Nd} = -1.6$; Gt. Dyke 2510 my, $\epsilon_{Nd} = -0.7$; Duluth gabbro 1100 my, $\epsilon_{Nd} = -1.4$, Kiglapait) provide suggestive evidence for a chondritic-REE magma source that has existed throughout earth history. All of these LMI's intruded older continental crust and may be contaminated to some degree prior to emplacement. Variation of $\epsilon_{Nd}, \epsilon_{Sr}$ within the Kiglapait is confined to the UZ, representing the last 10% crystallization (Morse, J. Pet. 20, 555), and requires that country rock assimilation accompanied the last ≥10% of crystallization. Mathematical models (DePaolo, EPSL 53, 189) suggest that the assimilation rate was 0.1 x the crystallization rate, so that the magma assimilated a total amount of country rock equal to 1% of its own mass. For country rocks at 300°C, assimilation of 1g of country rock could be thermally balanced by crystallization of 2.5 g of magma. The data indicate that the conductive heat loss was >3 times the heat lost by assimilation over the last 10% of crystallization ($Q_c/Q_a > 3$). For the intrusion overall, $Q_c/Q_a \approx 50$, demonstrating that in general assimilation at shallow crustal levels (<10 km) may be expected to be relatively minor.

V21B-2

Origin of Strongly Reversed Rims on Plagioclase in Cumulates

S. A. MORSE (Geol/Geog, UMass, Amherst MA 01003)

Narrow reversed rims (RR) on plagioclase are ubiquitous in troctolites and olivine gabbros of the Kiglapait intrusion (KI) and may be a common feature of all such cumulates (1-4). RR occur a plag/plag, plag/ol, and less at plag/aug grain boundaries; they are optically obvious at $\Delta An<10$ mole % and can reach $\Delta An=32$ mole %: eg An58 core An90 rim (plag/plag) and $\Delta(K/Na)$ up to 6: eg 607 E-4 core, 93 E-4 rim (both examples sample KI310 grain 17). Although ubiquitous from sample to sample, RR are only locally present at grain boundaries even for the same pair of crystals in contact; they are prominent in linear networks suggesting the last trace of intercumulus liquid

Subsolidus origin of RR is ruled out by 1) absence of reactants at plag/plag and plag/ol, 2) intermittent rather than pervasive development. An origin by growth from intercumulus liquid is required and explained by the increase of $D^{pl/L}$ for X_{An} with augite content of melt (5,6). From (5), $D^{eff} = F_{pl}D^{pl/L} + F_{oth}D^{oth/L} = 1.8F'\underline{di}+1.0$ For $D^{oth/L} = 1.0$, $D^{pl/L} = 1 + (D^{eff}-1)/F_{pl}$. Then for troctolitic liquid and cumulus An58 with $\underline{fsp}=67$ and $F'\underline{di} = 0.07$, $D^{eff} = 1.17$, $D^{pl/L} = 1.25$, and $An^L = 46$. Assume for intercumulus aug-rich liquid $\underline{di} = 15$, $\underline{fsp} = 55$, $F'\underline{di} = 0.21$, then D^{eff} 1.42, $D^{pl/L} = 1.76$; if there is no change in An^L rims can be 1.76 x 46 = An81. $F'\underline{di}$ reaches 0.3 in KI so An^L can be <46 and rims still >81. Rims may grow at constant or falling T as D increases. Part of the rim An may reside in the augite component of the liquid.

RR are important tracers of late-stage solidification history in plag-rich cumulates and the K/Na gradients prove that simple cation exchange may not occur (predicted equilibration distance >3m, observed <30μm), suggesting that low K is site-bound to tetrahedral Al/Si.

Refs: 1 Speer & Ribbe '73 AJS 273A,468; 2 Emsli '80 GSC Bull 293,46; 3 Morse & Nolan '81 Nain F 80 (UMass),47; 4 Dymek '81 GSA Abs 444; 5 Morse '79 J Geol 87,202; 6 Drake '72 thesis, Oregon.

AGU '82

OXYGEN AND STRONTIUM INVESTIGATION OF FRACTIONATED ROCKS FROM THE SOUTHERN NAIN COMPLEX, LABRADOR

№ 04250

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The Goodnews plutonic complex shows the relationships of fractional crystallization, liquid immiscibility, and magma mixing. Field relations distinctly show that anhydrous dioritic magma, derived by filter pressing of leuconorite, was invaded by and locally mixed with hydrous granitic magma of probable crustal origin. Dioritic liquids, now in the form of chilled pillows, were quenched by the invading hydrous granite at various stages of immiscibility. The pillows form two distinct compositional trends away from the common dioritic parent: one toward granite (anhydrous) and the other toward ferrodiorite. Major and minor element data suggest the diorites to be related to the leuconorites by fractional crystallization, and the ferrodiorites and granites (anhydrous) to the diorites by liquid immiscibility (Wiebe, 1979, J. Petrol., v. 20, 239). Oxygen and strontium isotope data illustrate that the ferrodiorites themselves form two distinct trends: low-Fe ferrodiorites (<15% FeO^T) trend from initial $^{87}Sr/^{86}Sr$ (Sr^0) = 0.7060, $\delta^{18}O$ = 7.1 to Sr^0 = 0.7067, $\delta^{18}O$ = 7.4; and high-Fe ferrodiorites (>15% FeO^T) trend from Sr^0 = 0.7067, $\delta^{18}O$ = 6.5 to Sr^0 = 0.7084, $\delta^{18}O$ = 7.4. The positive correlation of strontium and oxygen suggest that contamination by crustal derived material is involved. Assuming that the ferrodiorites are derived from a common parent, these separate trends within the ferrodiorites appear to require either two distinct ratios of contamination to crystallization, or two different sources of contamination. The latter case seems unlikely since the hydrous granite is the only likely source of contamination. The ferrodiorite trends constrain the original parent to have Sr^0 = 0.7040 - 0.7050 and $\delta^{18}O \approx$ 6.5.

ABSTRACTS WITH PROGRAMS, 1982 GSA

FIELD RELATIONS AND MINERALOGY OF A SEQUENCE OF METAMORPHIC BASEMENT ROCKS INTRUDED BY THE NAIN ANORTHOSITE COMPLEX, LABRADOR

№ 01269

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Archean metamorphic basement rocks intruded by anorthosite and monzonite of the Elsonian Nain complex 40 km west of the Kiglapait intrusion and just south of Okhakh Bay are granulite grade gneisses and granulites of tonalitic to peridotitic composition. Nearly continuous outcrop along Garnet Brook south of Okhakh Bay reveals five major metamorphic units, of which four are repeated. Mutual age relations are unknown, but the apparent sequence is: (1) highly sheared cordierite-hypersthene-plagioclase ± garnet gneiss; (2) fine-grained, iron-stained quartz-plagioclase-sulfide granulite; (3) fine-grained quartz-hypersthene-plagioclase granulite with minor sulfides; (4) weakly foliated, medium-grained orthopyroxene-cordierite-biotite-plagioclase gneiss; and (5) medium-grained orthopyroxene-plagioclase ± cordierite gneiss. The thickness of these units varies from 3 m to 70 m, and they are commonly intruded by younger granitic dikes similar in mineralogy to the nearby monzonitic rocks of the Nain complex. Rocks of tonalitic composition (average S.G. = 2.79) are the most abundant throughout the area. However, occurring in the southern part of the field area are fine- to medium-grained ultramafic rocks composed of olivine and pyroxene ± plagioclase ± iron oxides (average S.G. = 3.20). These rocks occur as layers or layered sequences within tonalitic or more mafic pyroxene granulites in the vicinity of Laura Lake.

Nearly anhydrous granulite mineral assemblages, the uniformity of grain size and orientation of layering, and isoclinal folding indicate a polymetamorphic and deformational history for these rocks. Although a terrigenous parent for these rocks cannot be ruled out, it is more likely that they represent a metamorphosed series of lava flows which range in composition from tonalitic to peridotitic.

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HYDROGRAPHIC REPORT

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INTRODUCTION

Most of the new territory encountered during the 1980 and 1981 field seasons was in Kolotulik Bay (approaches to Tigalak Inlet) and the Jonathon Island area (David Island Sheet 14 C/14). Compared to previous years, relatively little surveying was done because most of the working territory is by now well-laced with sounding tracks. The accumulated total for the two recent seasons was 37 miles of new sounding track, bringing the total for eight years to 800 miles sounded by R/V Pitsiulak. Edited field sheets and fathometer records are being submitted concurrently with this report to the Dominion Hydrographer.

Occasional readers of these reports may be interested to know that new editions of the Sailing Directions, Labrador and Hudson Bay are now computer-based and continuously up-dated, with new editions planned at intervals of every four years. The 1979 edition at hand contains many contributions from the earlier work of R/V Pitsiulak. The introductory parts of this volume, particularly Parts B and C, dealing with geography and natural conditions, are masterpieces that any traveller should enjoy reading.

DANGERS TO NAVIGATION

1. New data on shoal lying off the southern shore of Tunungayualok Island; see "Note 1", Fig. 28, and note on Sheet 14 C/3 (Akpiktok Islands), submitted separately. In Fig. 22 of our 1976 Report, least depths of 3 and 1 fm were shown on what was presumed to be a bar reaching offshore from Tunungayualok I. at Lat. 56°01.2' N, Long. 61°09' W. Air observations made from 1500 ft. altitude on 30 July 1981 showed that the 1-fathom spot appeared as just that, a spot, not a bar reaching out to the small twin rocks. It is possible that good water lies between the 1-fm spot and the twin rocks, but this possibility needs further investigation. However, good water of depth 6 and 5 fm was found on 11 August 1981 inshore of the 1-fm spot, located a

[1]Authors' full addresses are given at the back of this volume.

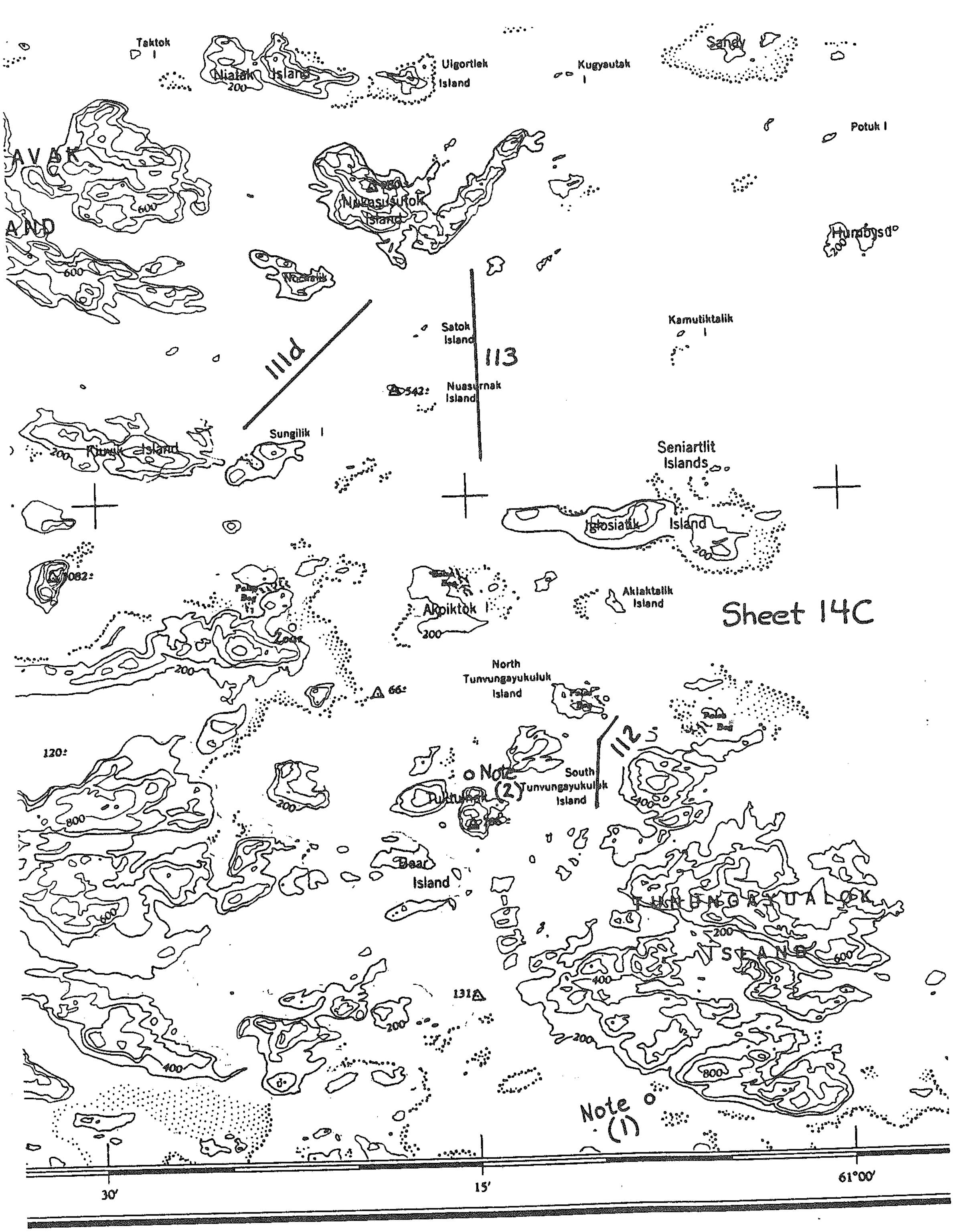

Fig. 28. Locations of new sounding tracks and notes on sheet 14 C, south.

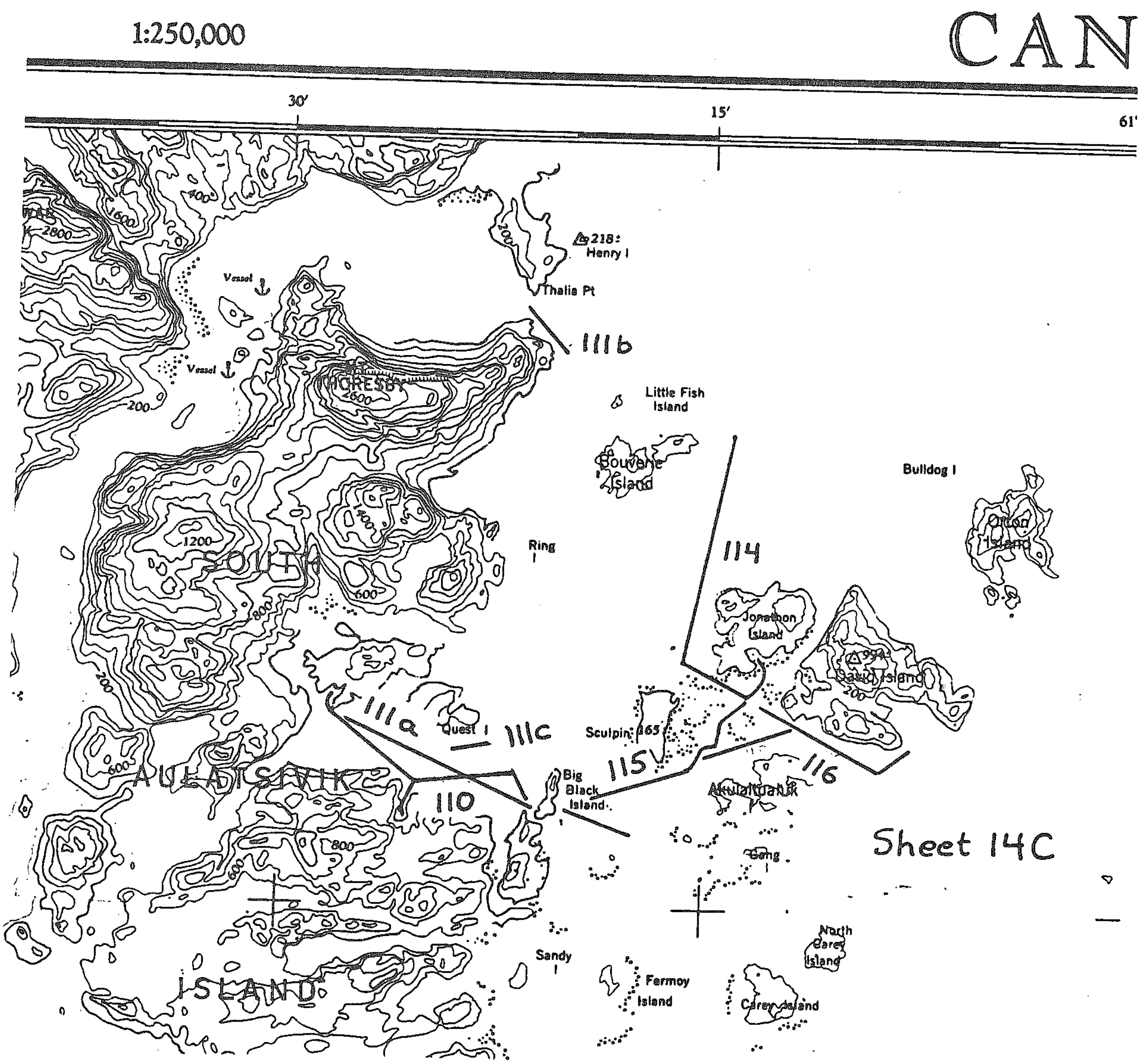

Fig. 29. Locations of new sounding tracks on sheet 14 C, north

little more than one-half (55%) the distance from the island shore to the twin rocks, as estimated by radar ranges. Again, more investigation is needed, but from our newest observations it appears that ones goal should be to stand about 3 to 4 cables off-shore while crossing this bar, rather than 2.5-3 cables as indicated earlier.

Accordingly, it is recommended that paragraph 382(p.220) of Sailing Directions (1979) be amended as follows:

Line 17. Delete "0.25 or" so that the line reads "be maintained to within 0.3 mile of the".

Lines 26-28. Replace first part of sentence after "Island shore." with "Shoals of 5.5 m (18 ft) and 2 m (6 ft) occur 0.3 and 0.5 mile, respectively, off the mouth of the brook in the first such indentation,"

1. Perrett Tickle; see "Note 2," Fig. 28, and Sheet 14 C/3. Air observation from 1500 ft altitude on 30 July 1981 showed the existence of a shoal SW of the 9 fm sounding, about 0.25 mile off the small islet in mid-channel. No changes are required in Sailing Directions (paragraph 384, p.220), which already call attention to the deeper water on the north side of the islet.

NOTES ON THE TRACKS

Track

110. Track runs from Black Island to Bakeapple Bay, thence out past Redberry Point to the harbor in the entrance to Tigalak Inlet (off Kolotulik Bay).

111a. Inner Kolotulik Bay via Black Harbour to a point NNE of Turnagain Island.

111b. Entering Port Manvers from the south; this track is laid a constant distance of 0.2 mile offshore of the common tangent to Medusa Bluff and Fletcher Point. A least depth of 4 fm was encountered off Fletcher Pt.

111c. Short track SSE of Quest Island.

111d. Track from Sungilik Island toward Wyatt Harbour, ending at right tangent Nochalik I: least depth 24 fm.

112. Two-fathom Cove to North Tunungayukuluk I: depths 30 to 70 fm.

113. Track runs from western end of Iglosuaktalialuk Island to passage SE of Nukasusutok Island; least depth 8 fm.

114. Track from Bouverie Island to the small harbor on the SE side of Jonathon Island has a least depth of 4 fm and appears clear of dangers.

115. Track runs from south of Jonathon Island, east of Sculpin Island to Black Island; least depth 4 fm.

116. Starts at western end of Collyers Bight and runs out to southern entrance of Eastern Harbour, then resumed running WSW from Collyers Bight to a junction with track 115.

DESCRIPTIONS AND DIRECTIONS

Bakeapple Bay (Track 110). A least depth of 3 fm was encountered near the mouth of the Bay, which is elsewhere deep (5-12 fm) and apparently clear of dangers.

Tigalak Inlet (Tracks 110,111a). A small harbor ($56^{\circ}49'$N, $61^{\circ}28'$W) protected from NE winds lies just outside (east of) the entrance proper to Tigalak Inlet. Anchorage in 4 fm is obtained near the NW side of this harbor, which deepens inward to 7 fm near the head and shoals to 3 fm near the entrance. This harbor can be entered along the indicated track by keeping the central entrance islet close aboard to port, and thereafter swinging northward to keep the starboard point of land 0.1 mile distant. Continue toward the NW shore of the harbor to clear a drying shoal which lies less than 0.1 mi NNW of the south entrance point. A least depth of 2.5 fm (8 m) is encountered along the track a little more than 0.1 mile inside the entrance islet. However, a 1-fm (2 m) shoal lies 0.15 mile due west of the southern entrance point, west of the track.

Strong currents set in and out of Tigalak Inlet and require close attention when entering and leaving the harbor except on slack water.

Tigalak Inlet itself may be entered by small motorboats only through the entrance rattle, preferably at high slack water.

Port Manvers (not indexed in Sailing Directions (1979), but described on pp. 231, 233 therein). Entrance from the south: From a position east of Medusa Bluff, a course lying 0.2 mile offshore of a line connecting Medusa Bluff and Fletcher Point will lead to the range Willis Rock on Trio Islands described in paragraph 531 of Sailing Directions (1979), with a least depth of 4 fm (13 m) off Fletcher Point. However, it should be noted that the 4-fm depth lies very near (but probably slightly NE of) the inner fairway rock plotted on BA 265. The outer fairway rock is plotted (P.A.) on that chart north of Medusa Bluff approximately at our 26 fm sounding, hence that rock also may lie inshore of our track. Entrance from the north. The water north and west of Willis Rocks is encumbered by numerous sharp pinnacles, many of which break in heavy seas. However, local boats and R/V *Pitsiulak* generally make use of a track running 240° to leave the higher Willis Rock 0.1 mile to port until the range from Willis to Trio is reached, thereafter following the usual course 283° to clear the rock off Fletcher Point. Pinnacle depths of 5 to 7 fm are encountered north and west of Willis Rocks on this track.

Table 7. 1980 and 1981 Sounding Tracks, Listed in Chronological Order

Track Description	Date	Sheet	DR Roll	Mileage
	—1980—			
110. Black Island to Tigalak via Bakeapple Bay	10 Jul	14 C/14	1-80	5.9
111a. Kolotulik B. to Vernon Is. group	12 Jul	-do-	1-80	5.5
111b. Port Manvers	13 Jul	-do-	1-80	1.1
111c. Quest I., Kolotulik B.	14 Jul	-do-	1-80	0.6
111d. Sungilik I. to Wyatt Hr.	20 Jul	14 C/6	missing	3.0
112. Two-fathom Cove to North Tunungayukuluk I.	27 Jul	14 C/3	2-80 (missing)	2.0
113. Iglosuaktalialuk I. to Nukasusutuk I.	27 Jul	14 C/6	2-80	4.2
	—1981—			
114. Bouverie Is. to Jonathon I.	2 Jul	14 C/14	1-81	7.3
115. Jonathon I. to Black I.	2 Jul	-do-	1-81	4.6
116. Collyers Bight	12 Jul	-do-	1-81	3.2
		TOTAL, 1980-81		37.4

Note: *Pitsiulak* tracks 105-109 were made by C.W. Williamson in Northern Labrador, 1977-78.

TOTAL, 1971-76,1980-81 799.8

OPERATIONS

S. A. Morse

NARRATIVE REPORT

As in the past, the work of this Project was facilitated by the uncommon Petrographic Research Vessel Pitsiulak, used as the principal logistic support vehicle and shelter in time of need. From her current home base at Port Saunders, Newfoundland, she can reach the field area in 60 hours elapsed time, barring ice or storms enroute. No pack ice appeared during the 1981 season, but high winds and seas delayed her passage north by an additional 43 hours spent in shelter, and her return by 26 hours likewise spent. Not surprisingly, weather that delays Pitsiulak is also likely to inhibit flying, so those travelling by air fared no better than those by sea in terms of time lost. And although air support is still required for servicing field crews remote from salt water, the vessel, in the capacity of a floating base camp, facilitates excursions that would otherwise be difficult, dangerous, or very costly to undertake, as she did in 1981 to the Mugford area. In the course of her work in this season, the vessel travelled some 3000 miles, hauled a ton of scientific samples, attended the needs of 16 geologists, fed about 1000 superb meals aboard and provided supplies for another 2000 ashore, furnished as usual a stylish custom drilling service to investigators having worthy outcrops, and all this at a cost per worker-day that is the envy of the exploration industry. As a safe logistic base, the vessel would appear to have earned her keep handily, allowing shoestring science to survive in this day of the megabuck.

It has become customary to provide this working vessel with a very high caliber of seamanship, made possible by the unusual challenge and attraction of the work and its location. Our Project has been the fortunate heir of goodwill, interest, and uncommonly gifted personnel from the burgeoning sailing education movement, and it is by now our routine expectation to acquire the services of staff with extensive experience in deepwater sailing, seamanship, navigation, pilotage, training, and command afloat. Indeed, the operation of our Project requires close integration of all these skills, for even though sail-handling is not a normal possibility with a motor vessel, she has but one engine, and the ability to make some way or lie-to under canvas cannot be discounted as an eventual need. The ability to train assistants and to manage thoughtfully and effectively the daily operations of eight scattered field parties, as well as the vessel and its household, are crucial in such an operation. By all accounts, the Project hit its peak stride in 1981 with its new master, J. C. Wigglesworth, in company with the accomplished veteran steward P. M. Brooks and a new mate, D. S. Peat. Fortunate indeed is the vessel with a cook who can find fish and also be a fount of common sense, and rare is the knockabout research vessel in the hands of one whose regular command is square-rigged. It is a pleasure to pay tribute to the many talents of this new generation of doers with grace.

Our operations began on 21 June, when Pitsiulak left Port Saunders for Nain and the first field crews began to leave for Labrador by air. Vessel and crews both arrived on 25 June in Nain, and the first crews were put ashore, with camps, the very next day. They were allowed little time to work before a northeaster struck. By 30 June, all field crews were in place, including Ranson's remote party, airlifted to Laura Lake. There ensued an intensive three weeks of field work, both ashore and from the vessel, accompanied by resupply operations requiring intricate scheduling. In the third week of July, the vessel took Berg's party north to inspect the Mugford Group of volcanic and metasedimentary rocks, and to survive a nasty gale (see "Weather", below). Most of the remaining crews were clustered around the area of Port Manvers and Black Island Run, where their needs were more conveniently attended to than in past seasons when a day's run separated the crews farthest apart. Possibly feeling crowded, Young and Marshall trekked two-thirds of the way across the Kiglapait intrusion only to be rained out in a gale; they returned to shelter, dried out, and walked all the way back again to resume work. Morse and Marshall were later airlifted to the area west of Bird Lake, and spent a week traversing by canoe the upland lakes back toward salt water, studying several anorthosite massifs and taking much delight in the presence of some thousands of migrating caribou, part of the world's largest caribou herd (the Hebron herd, numbering more than a quarter-million animals by 1982). The portage out to sea from this upland plateau was generously assisted by Berg and Briegel, while Pitsiulak stood by in Tikkoatokhakh Bay and all hands marvelled at the caribou. The season came to a close the following day with departure of the last scientific crews from Nain to Goose Bay, and one last spurt of drilling as the vessel proceeded south. By chance, she encountered near the Strait of Belle Isle an old friend in the form of the three-masted barkentine Regina Maris of Boston, returning from a whale count off Greenland. Greetings were exchanged and pictures taken. Pitsiulak later sought shelter from pounding head seas at Cape Charles, then the next day proceeded through the Strait as far as St. Barbe before needing once again to find shelter for the night. She reached Port Saunders on 15 August and was instantly given, by friendly fisherman, a 30-lb bag of fresh shrimp. Her stalwart crew did their best by these, laid the vessel away, and went home.

TOPICAL SUMMARIES

Ice

Once again, for the third time in the history of this project, no pack ice was encountered. Its absence facilitated travel, but deprived newcomers of the opportunity, so often exploited in previous seasons, to learn the art of ice pilotage.

Weather

According to the weather table for Hopedale, the nearest station to Nain compiled in Sailing Directions, Labrador and Hudson Bay (1979), one may expect rain on half the days in July and August. The period of record was 1943-1970, and one wonders if the statistics since the inception of this project in 1971 haven't improved a bit, and one wonders indeed about the meaning of a threshold as low as 0.25 mm for recording rain! Certainly our normal experience of losing one working day in five would suggest some improvement, even granting that Hopedale is possibly more inclement than Nain. By any standard, then, the 1981 season was a record-breaker: in 54 days of record, only six were bad enough to prevent work, and only two of these fell next to each other. Rain or drizzle occurred during parts of three more days, and tent repairs occupied most of another. If we count a total of eight days directly or indirectly lost to weather, we have a ratio of one bad day in seven, a remarkable ratio for the Nain area. There were 17 straight days of good weather beginning on 28 July, and we gather that good weather continued in August after our working season ended.

Among the curiosities of the season was a dry westerly gale on 3-4 July, during which the barometer dropped precipitously from 30.1 inches of mercury in the morning of the 3rd to 29.55 inches at midnight, and then bounced back up to 30.3 inches on the morning of 5 July. On 3 July, a temperature of 83°F (28°C) in the shade was recorded, and the temperature is said to have exceeded 90°F in Nain during midday. The wind picked up in the evening, reaching gale force, still with clear skies, by 0100 on 4 July and remaining violent through most of the day. The gale played havoc with the field crews, damaging three tents. Pitsiulak had no problems hanging on in Khaukh Harbour.

A far more serious gale for the vessel was encountered during work in the Mugfords. Once again, as in 1972, a northeast storm caught her on 22-23 July in Horr Harbour (otherwise named, perhaps by some cynic, "Calm Cove"). This is a difficult harbor to hold on in, partly because of a funneling effect of the wind buffeting around the 1,200-meter Khaumayät Mountains, and partly because of grassy seaweed that clogs the anchor flukes and can cause great tribulations when resetting the anchors. However, the able skipper and crew of Pitsiulak proved that it can be done in extreme conditions, although at great cost in human effort and at some risk. Gusts at water level regularly reached 60 knots and at peak intensity were timed by Jon Berg at 90 knots (a velocity later affirmed at Saeglekh). Waterfalls ashore were dispersed and blown horizontally. In one gust, the wind caught the vessel abeam, laid her over on her ear, and carried away the forward hatch cover, which came off its fitted seat and flew off over the lifelines. This was replaced by a canvas tarp stoutly lashed. The wheelhouse was later found to be stripped of paint, in places to the bare wood, by the blasts of salt spray and sleet. Excursions on deck could only be made crawling and tied to lifelines; standing was impossible. This nightmare continued for 36 hours, during which the vessel rode to two and sometimes three anchors, at times motoring to reduce yawing. On the following day (24 July), Berg found a foot of snow in high elevations of the Khaumayät Mountains. Your correspondant was away at the time and, in retrospect, glad of it.

And what were the dates of the previous set-to in Horr(ible) Harbour? They were 22-25 July, 1972, nine years to the day earlier.

Vessel Maintenance

After major advances in the previous season, R/V Pitsiulak proved to be in excellent condition in the spring of 1981, requiring only one day's work before launching and one more to ready her for sea, including putting all stores aboard. A vigorous program of maintenance and repair improved her condition throughout the summer, and the only sour note was the renewed failure of a salt-water exhaust fitting which will always be troublesome until replaced with stainless steel.

Communication and Health

Radio conditions were again good throughout most of the summer, and no health problems arose.

SUMMARY OF OPERATIONS

The 1981 working season lasted 46 days, from 26 June to 11 August. Field conferences were held from time to time, usually in conjunction with sampling operations using portable core drills. With 16 scientific personnel in the field, this was the busiest and most productive season in the history of the project. More than 40 drums of samples, weighing about 1000 kg, were processed by the staff and shipped by air freight to destinations in the U.S. and U.K. The calendar below summarizes the main events.

CALENDAR

June 16	Early crew to Pitsiulak at Port Saunders, Nfld.
18	Vessel launched; engine test good.
19-20	Vessel overhaul; stores brought aboard.
21	Underway 0730 to Nain
23	First field crews to Goose Bay, holding for weather.
25	Pitsiulak and field crews arrive Nain.
26	First field crews ashore for work (Tigalak).
27	Northeaster

June	28	Field crews to Port Manvers Run sites.
	30	Second field crews to Nain. Ranson to Laura Lake.
July	1	Field crews to Slambang Bay.
	2	Transferred Berg crew to Jonathon I.
	4	Gale
	5-7	Work at Khikkertavak I.
	8-12	Work in area of Port Manvers Run and Jonathon I.
	13	Ranson to Okhakh B. by Petrocan helicopter.
	13-16	Nain
	17-18	Resupply camps, drill ashore for samples. Berg aboard for Mugford.
	19	Resupply Ranson at Okhakh B., continue to Okhakh Hr.
	20	Work at Kraaken Inlet, Tent Hill I., Rifle Bay.
	21	Sunday Run, work.
	22-24	Northeaster at Horr Hr.
	24	Work at Lost Channel and Mugford Tickle; return south to Okhakh Hr.
	25	Return to Manvers Run area
	26-28	Resupply and move camps.
	29-30	Nain, resupply vessel.
	31	Return to Manvers Run area
August	1	Resupply camps and drill ashore.
	3	Morse and Marshall by plane to Bird Lake area. Vessel to Tigalak.
	4	Moving camps; drilling
	5	Berg to Snyder Bay
	6	First field crews out to Goose Bay.
	7	Fetch Wiebe camp to Khaukh Hr.
	8	Second crew out. North to pick up other crew.
	9	To Tikkoatokhakh Bay to await Morse crew.
	10	Morse crew out to salt water; return to Nain.
	11	Last crews out to Goose Bay. Vessel enroute south with drill stop at Kiuvik.
	12-13	Vessel to Strait of Belle Isle area.
	13	Spoke _Regina Maris_ of Boston; to St. Charles Hr. for shelter.
	14	To St. Barbe Hr. for shelter from stiff head wind.
	15	To Port Saunders in heavy weather.
	16	_Pitsiulak_ hauled out and laid up for season. Crews home.

PERSONNEL

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Henry Webb, Nain	Agent and Expediter

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