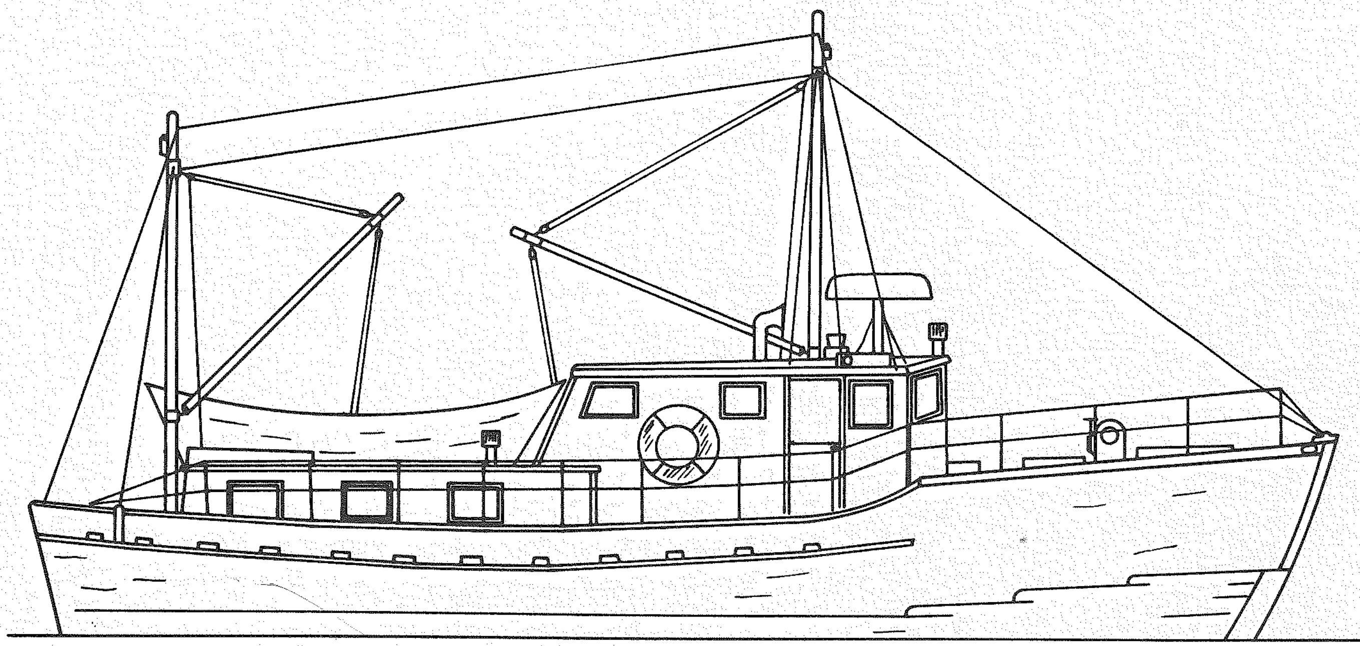
THE NAIN ANORTHOSITE PROJECT, LABRADOR: FIELD REPORT 1973

S. A. MORSE, EDITOR



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THE NAIN ANORTHOSITE PROJECT, LABRADOR:

FIELD REPORT 1973

S. A. Morse, Editor

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"Evolution of anorthosite and related crustal rocks in coastal Labrador."

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PROLOGUE

On a Boat in Labrador

Sometimes gray sea, gray sky, gray rain,
And when it's rough you're ill;
Or else the sea and the sky are blue,
And the sun shines with a will.

-- Elise E. Morse

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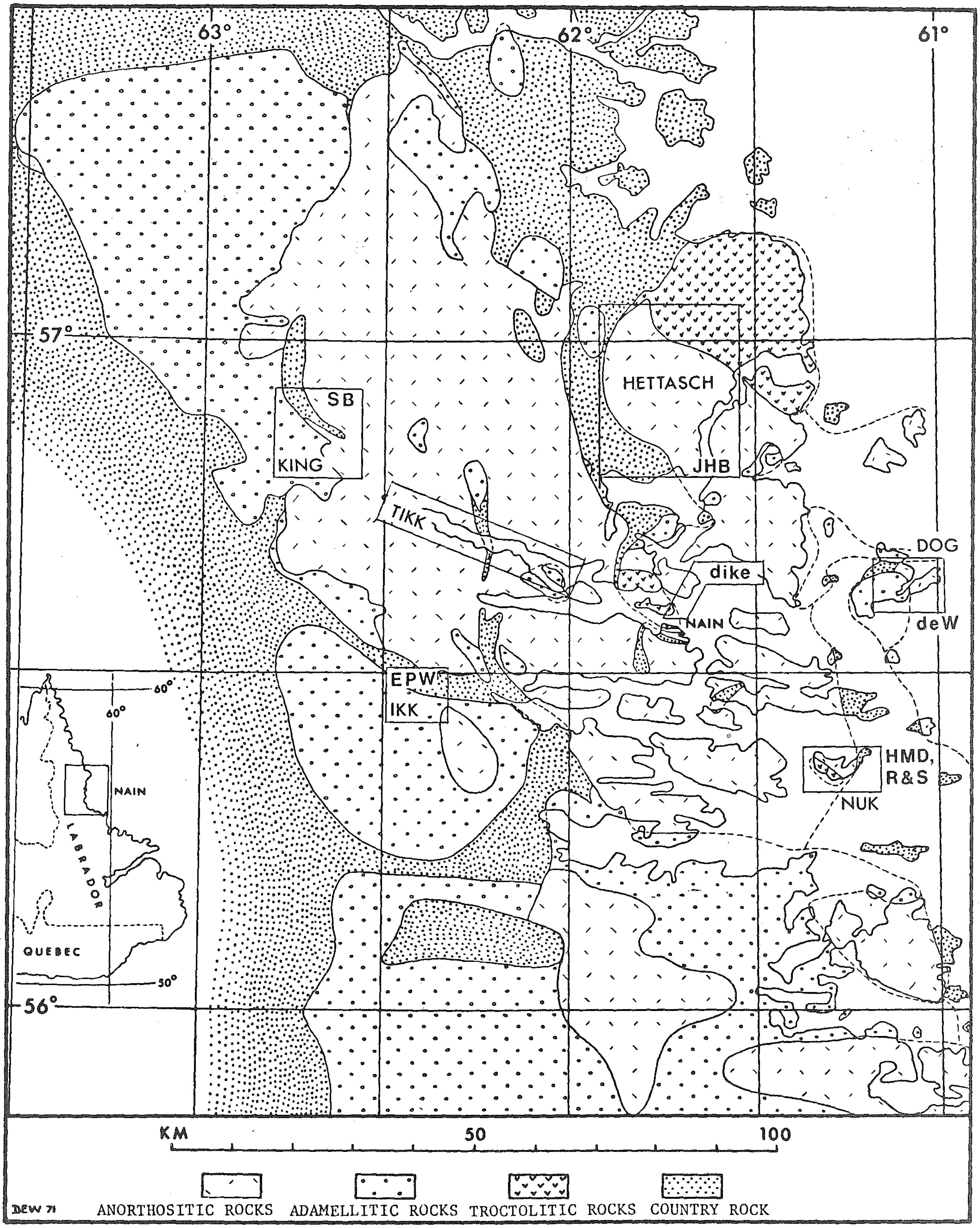

Fig. 1. Regional geology of the Nain area, after Wheeler (1968), showing locations of 1973 field areas. Identifications, north to south: JHB, Berg (Hettasch intrusion); SB, Brand (Lower Khingughutik River); TIKK, Tikkoatokhakh Bay; "dike", de Waard and Hancock; de W, de Waard (Dog I.); EPW, Wheeler (Ikkinikulluit area); HMD, Davies; R&S, Runkle and Saunders (both Nukasorsuktokh I.). Other Labrador localities may be found on Figs. 5 , 9, and 40.

THE NAIN ANORTHOSITE PROJECT, LABRADOR: FIELD REPORT 1973

INTRODUCTION AND REVIEW

This report is the third of a series describing a major cooperative effort to set forth, understand, and illuminate the problems of anorthosite around Nain, Labrador, and elsewhere. In this report we are able to announce the discovery by Hurst of Archaean anorthosite in Labrador, a payoff on our early intent of examining systematically the regional setting of the Paleohelikian anorthosites on the Labrador coast. The new discovery, along with Hurst's identification of 3.5 Gyr old rocks in Labrador, materially strengthens correlations to West Greenland and the rest of the North Atlantic Archaean craton (Bridgwater et. al., 1973).

The anorthosite problem is easy to solve, in principle: all we need to know is what the parent magma was, why plagioclase was concentrated, how the magmatic products were emplaced, where the magma came from, and whether or why the anorthosite massifs were emplaced only at special times and places in the earth's crust. It is practically child's play to put forward a plausible hypothesis for any of these questions alone, but no general theory has met with much success as yet. One reason for this may be that we often do not know when part of a theory is good and when it is bad. The keen edge of demanding hypothesis strikes into the amorphous ball of fluff which passes for our factual knowledge, and the result is usually indecisive. The Nain Project is intended to put firm objects of fact, worthy of the intellectual sword, into the ball of fluff.

An example of fluff is the following dilemma. It has been proposed (e.g. by Anderson and Morin, 1968) that massif anorthosite might be the partial fusion product of an older, more calcic, more widely distributed anorthositic material. If we wish to play this game, the Archaean anorthosites of the oldest shield regions (now including Labrador) provide one possible source example. Is such a parent-daughter relation chemically reasonable? Fragmentary data suggest not: the calcic plagioclase of a Nain anorthosite xenolith has notably low Rb, like other Nain plagioclases, a high K/Rb (Gill and Murthy, 1970), whereas the Archaean hornblende anorthosite at Okhakh Harbour has high Rb and a low K/Rb (J.M. Barton, personal communication, 1973). Our present understanding of Rb partitioning suggests that a partial melt of such a hornblende anorthosite would yield a daughter melt and granddaughter plagioclase at least as Rb-rich as the whole-rock parent. But a paucity of natural and experimental data leaves one not wholly convinced (the facts here perhaps reach the soft curd stage between fluff and cheese), and the need for a general backlog of geochemical data is obvious.

At Nain, we have assumed that lack of metamorphism would enable us to assemble the pertinent genetic facts, unembellished by the irrelevant ambiguities imposed by metamorphism south of the Grenville Front. Our many observations of primary igneous features including layering, growth of stellate plagioclase clusters, subophitic textures both undeformed and stretched, abundant xenolith zones, and olivine in the basal parts of anorthositic intrusions, suggest that this optimism was well founded. We have assumed, applying Ockham's razor, that our observations would be relevant to massif anorthosite everywhere. Martignole and Schrijver (1973) have taken another view, difficult to evaluate, that the absence of garnet from anorthosite at Nain simply reflects a lower pressure of crystallization ("emplacement", in their view), and that garnet elsewhere may be autometamorphic, thus an integral part of the anorthosite genetic scheme. To disprove this, one would need to prove that garnet did not grow during the first subsolidus cooling in the Grenville bodies, or that it could have grown at the pressures of Nain, given the requisite prograde metamorphism. Most Nain workers will probably find it more fruitful to pursue the primary igneous features and their implications than to worry about the metamorphic features elsewhere, but the divergent views are so profoundly different in their implications regarding the timing and genetic interrelationship of deformation, metamorphic crystal growth, and P-T history that we should perhaps make special efforts to state our assumptions and the abundant evidence against a regional metamorphism of the Nain anorthosite upon which they are based.

The lack of younger Precambrian penetrative deformation is conspicuous in this part of Labrador. At Okhakh Harbour, the massive granite having an Rb-Sr isochron age of 2,386 ± 30 Myr (Barton, this report) is unfoliated and undeformed; the famous Mesozoic Conway granite of New Hampshire is hardly more strikingly post-tectonic in aspect than the granite at Okhakh Harbour. It is probable that the last regional metamorphic recrystallization in north central Labrador predates this granite. Countless exposures of the Nain Complex show perfect preservation of primary textures and structures, down to the scale of 1 mm layers. While kink-banded hypersthene, bent plagioclase, and such varieties of local deformation as stretching and foliation occur, these can be shown to be late magmatic or local intrusive features, because examples of undeformed basic rocks can always be found close by. The essentially static environment of post-crystallization history recorded by the vast majority of Nain complex rocks stands in striking contrast to the profound regional, penetrative deformation exhibited by the Grenville anorthosites and their envelope rocks.

The depth of anorthosite emplacement has always been a central part of the anorthosite problem, and as mentioned in FR 1972,[1] the Abukuma-type metamorphism of the Snyder Group studied by Speer suggests that the magmatic emplacement of at least the Kiglapait intrusion must have occurred at relatively shallow levels of the crust. Contact metamorphic reactions involving cordierite are commonly encountered at the margins of the anorthositic rocks, and Berg has now found contact metamorphic assemblages against the Hettasch intrusion which, judging from current experimental evidence, limit the inferred pressure to between 3 and 4 kbar. Detailed analysis of such critical assemblages, both in the field and laboratory, will be essential for confident estimates of emplacement depth, but it appears very probable that the great crustal depths once assumed will not prove essential to anorthosite genesis.

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[1]FR designates past field reports of this series.

A series of studies by Wheeler, de Waard, Brand, and Davies in 1973 illustrates the complexities found among anorthosites, country rocks, and younger acidic intrusions. A problem common to at least three of these areas is the occurrence of a finer grained intermediate rock having some mineralogical characteristics of both the anorthositic and adamellitic suites. These characteristics commonly include plagioclase insets reminiscent of anorthosite on the one hand, and quartz-K feldspar associations predictive of adamellitic rocks on the other hand. At Dog Island, de Waard finds this intermediate rock everywhere between anorthosite and granodiorite of the adamellite group. In keeping with his earlier hypothesis of a single parent magma type for the Nain complex, de Waard proposes an inventive scheme of differentiation and emplacement, making all three rock types cognate. Whether such a literally monolithic origin for the Nain complex will survive all closer scrutiny remains to be seen, but the fact remains that bewilderingly intimate relationships among the three rock types have turned up in widely separated field areas, offering one of the most challenging problems for interpretation in any plutonic rock association.

Among the acidic rocks encountered by Wheeler are excellent examples of ovoidal rapakivi, which lead him to re-emphasize, in an illuminating discussion, the similarities between the Labrador and Finland occurrences, also noted some years ago by Kranck (1968). The petrographic similarities between ovoidal rapakivi and the finer grained intermediate rock are particularly striking in his 1973 area, and a good circumstantial case can be made for a parent-daughter relationship. Wheeler's account affords a glimpse of the exceedingly intricate relationships among country rock, two types of anorthosite, the finer grained intermediate rock, and the suite of acidic rocks culminating in ovoidal rapakivi.

In the Lower Khingughutik Brook area, Brand has encountered a comparable set of lithologies, and in addition, a second type of buff weathering anorthosite. At Nukasorsuktokh I., Davies finds an even greater number of rock units, including a suite of dioritic and monzonitic rocks containing hypersolvus subcalcic ferroaugite of the type reported by Smith (1974) from the Nain complex. Such pyroxenes indicate high temperatures, and by inference low water pressures. These dioritic rocks include an aptly, if paradoxically named "black leucodiorite", first noted with alarm in FR 1971.

Also at Nukasorsuktokh I., Runkle and Saunders have given a detailed description of the block structure, where calcic plagioclase was reported in FR 1972 (p. 106). The xenoliths, of which more than two hundred were mapped and classified, range in size from a fraction of a meter to many tens of meters. Their distribution is indicated on a reduced version of a map originally prepared at a scale of 1:240.

Among the more mysterious features of the Nain complex is a very extensive dike, apparently part of a cone sheet, described first by Wheeler (1968 and ms maps) and now in more detail by de Waard and Hancock. The dike appears to vary from gabbro to granodiorite in composition, and at one locality (Barth I.), includes xenoliths representative of most or all of the lithologies--basement, supracrustal, and intrusive--present in the Nain area.

Berg has continued his investigation of the Hettasch intrusion, and found an eastern closure against older anorthosite injected on a large scale by troctolitic magma from the Hettasch body. This area continues to furnish spectacular examples of magmatic currents and crystal growth under supersaturation conditions. The snowflake troctolite described in FR 1972 was found to contain slender "perpendicular feldspars", normal to the layering but bent towards parallelism at the upper end, presumably by currents. A troctolite channel or sluiceway in older anorthosite was also discovered in 1973, and contains stacked trough bands and other erosional features produced by strong currents as well as further examples of "snowflakes," i.e. plagioclase grown or accumulated in radial clusters. Berg concludes from structural evidence that part of the Hettasch intrusion has been removed by a younger leucogabbronorite, and from chemical evidence that upper fractions of the intrusion are missing if the chilled margin is at all representative of the parent magma. The Hettasch intrusion continues to afford one of the best opportunities for demonstrating the origin of anorthosite within a closed layered intrusion, despite the missing pieces.

A brief reconnaissance of Tikkoatokhakh Bay by Morse and Wheeler has led to the identification of three sizeable massifs of layered anorthosite. Two of these are upright, and they are separated by the third, which is a steeply dipping, foliated monoclinal slab some 10 km thick. Both granular and lamellar intergrowths of plagioclase and hypersthene occur in this slab, along with cumulus ilmenite, which is at least of potential genetic interest in terms of the impressive ore bodies of ilmenite found in some Grenville anorthosites.

Geochemical studies have been continued by Barton, Hurst, and Upton; these include geochronologic studies in which Barton finds an Rb-Sr isochron age of 1.418 Gyr for granophyre and basic minerals in anorthosite pegmatite at Higher Bight (FR 1971, p. 20). The initial strontium isotope ratio of this assemblage is high enough to suggest that wall-rock contamination was involved in the origin of the granophyre. Barton also reports Rb-Sr data suggesting an age in excess of 2 Gyr for the supracrustal Mugford Group. Barton's report includes chemical comments on the Mugford group, Okhakh granite, Higher Bight granophyre, and the Snyder group, which yields an Rb-Sr age of about 1.7 Gyr. Upton's analyses of diabase dikes collected in 1971 demonstrate the existence of an unusually K-rich alkali suite, and a tholeiitic suite, both distinguished by low MgO.

This report is organized by subject rather than by region as in the past. Localities not identified on Fig. 1 will be found in the appropriate field maps, and regional names can be found on maps in Barton's report and in the Hydrographic Report. A brief account of operations follows the geologic report, and a complete list of 1973 field personnel will be found before the references at the end of the volume.

-- S. A. Morse

GEOLOGICAL REPORT

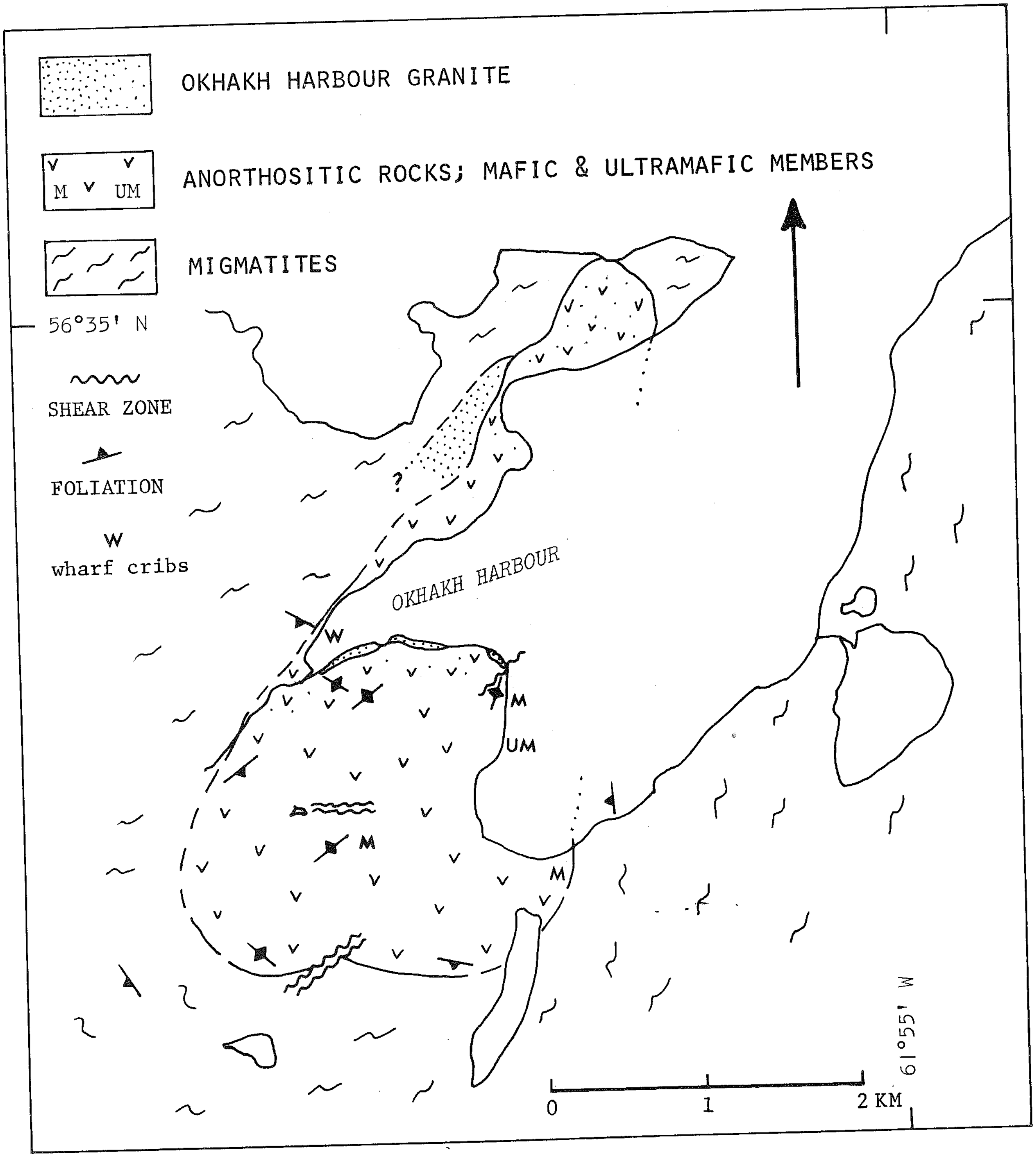

Fig. 2. Geologic sketch map of the Okhakh Harbour area, Labrador. Where symbols are mixed, anorthositic rocks are heavily invaded by granite, and occur as xenoliths. Samples of granite and anorthosite used for age determinations were taken on the shore SE of the old wharf cribs. Base: airphoto LAB 59-83.

REGIONAL GEOLOGY AND GEOCHEMISTRY

ARCHAEAN ANORTHOSITE IN LABRADOR

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D. E. Runkle, Mount Holyoke College
M. J. Saunders, Mount Holyoke College
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". . . . the only region where Archaean anorthosites have not yet been found is Labrador."

- Bridgwater et. al., 1973, p. 501.

Introduction

During the 1972 field season, plagioclase-rich material from the east shore of Okhakh Harbour was collected (Farhat and Hurst, FR 1972, p. 18) which proved on examination to be granular anorthosite. Aware of the growing literature on Archaean anorthosite in Greenland and elsewhere (Bridgwater, 1967, p. 1010; Windley, 1970; Bridgwater et. al., 1973), Hurst immediately sought and obtained a yield of zircon from this material sufficient for a Pb-Pb age of 2.6 Gyr, reported below. This age, and the 2.4 Gyr Rb-Sr isochron age reported herein by Barton (p. 23) for granite cutting the anorthosite, are sufficient to confirm that this is an Archaean anorthosite. The 2.6 Gyr age is conceivably a minimum, and there remains a possibility that the Okhakh Harbour anorthosite can be correlated with certain of those in Greenland, supposed to be at least 3 Gyr old (McGregor, 1973; Black et. al., 1973). In order to evaluate this possibility further, and to investigate the field relations of the plagioclase-rich material, the Okhakh Harbour area was resampled and mapped during brief visits in the 1973 field season.

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

Owing to the excellence of Wheeler's records of earlier reconnaissance work, and to the very distinctive appearance of the "(Siberian) tiger-striped gneiss" variety of anorthositic material, we have been able to locate eight additional localities south of Okhakh where similar material occurs. These are mentioned below, with the expectation that some of them, at least, will receive further attention in the near future.

Petrography

The distinctive "tiger-striped gneiss" occurs abundantly around the shores of Okhakh Harbour, and forms a large component of the wharf cribs and building foundations of the former Moravian Mission establishment in Okhakh. The distinctive appearance is due to discontinuous double-tapered black streaks, typically 1-3 cm wide and 10-30 cm long, of olive-green hornblende set in a matrix of fine to medium grained granular, pale gray or white plagioclase. The few Okhakh samples examined in oil immersion show plagioclase with An in the high 70's. The "tiger-striped gneiss" is a foliated hornblende anorthosite, with a typical color index (C.I.) near 25. Locally this grades into patches of pure anorthosite (C.I.<5), or into more hornblende-rich areas warranting the name hornblende gabbro or melagabbro gneiss.

A sample of tiger-striped gneiss (UCLA L-52) collected in 1972 was examined in thin section. This sample, in hand specimen, is similar to the sample (UCLA L-50) with a ^{207}Pb - ^{206}Pb age of 2.6 Gyr except for the occurrence of biotite, which is visible in hand specimen. Green hornblende, in places partially rimmed by biotite, is set in a bytownite matrix. Both mafics are in turn locally enclosed in poikiloblastic fashion by hypersthene. Remnants of hornblende in hypersthene are oval or rounded, or rarely subhedral rhombs rounded at the edges. The growth of younger hypersthene, while conceivably a contact metamorphic effect of the younger granite, may reflect partial recrystallization in a regional granulite facies metamorphism similar to that found in Greenland.

A mafic to ultramafic zone lies on the southeast side of the point east of Okhakh Hr. This zone appears to be more or less completely serpentinized, but in places the ultramafic rock is composed mainly of laminated rectangular tablets 1 x 3 cm of what might have been cumulus enstatite, accompanied by a small amount of interstitial plagioclase. The relationship of this zone to the hornblende anorthosite has not as yet been established, but field relations do not appear to prohibit the interpretation that this may be an ultramafic cumulate grading upward through gabbroic compositions to anorthosite. The anorthosite, in other words, may be a metamorphosed remnant of a basic sill or layered intrusion of the Bushveld-Stillwater type. This mode of origin has been suggested for Archaean anorthosite in Greenland (Windley, 1973, p. 326).

Field Relations

A brief reconnaissance establishes the general relations shows in Fig. 2 . The country rock is acid to basic Archaean migmatite in the amphibolite facies. The contact of anorthositic rocks with migmatite is poorly exposed, and chloritized shear zones intervene where the two rock types are seen as close as several meters apart. Although the general trend of foliation in migmatite and anorthosite is NE, there are local deviations from this strike in both units, and it is not clear whether the anorthosite intrudes the country rock or is interlayered with it. The strike in both units swings to SE, parallel to the contact, south of Okhakh Hr. The contact is locally gradational in the sense that the migmatite is leucocratic, possibly quartz-poor near the contact, and is succeeded northward by mesocratic hornblende-plagioclase gneiss, followed by "tiger-striped gneiss" (hornblende anorthosite). The mesocratic hornblende-plagioclase gneiss appears again at the eastern contact of anorthosite with migmatite, and could either be a basal layer within a continuous stratigraphic sequence from migmatite to anorthosite, or a border facies of an intrusive anorthositic body.

The apparently cumulate ultramafic body mentioned above has been seen over such a limited area that its status relative to anorthosite is moot.

The entire perimeter of Okhakh Harbour is heavily invaded by the younger, massive, medium grained Okhakh Harbour granite (2.4 Gyr; Barton, this report). This forms a spectular agmatite with blocks of tiger-striped gneiss and related anorthosite, especially along the NW shore of the center parts of the Harbour, and along the south shore. Large blocks of anorthositic rocks have been rotated by the granite, so that structural continuity is destroyed. The massive granite also invades the regional migmatite very extensively in places.

Age

A zircon concentrate of 5 mg was obtained from 10 kg of the tiger-striped gneiss at Okhakh Harbour. The individual grains are translucent with hyacinth coloration. Zircon morphology ranges from euhedral grains, showing the (110) prism and the (111) tetragonal dipyramid, to anhedral grains which are broken and in some cases corroded. One euhedral zircon is a euhedral overgrowth on a smaller, anhedral zircon. The majority of the zircons were anhedral.

The single zircon fraction yields a ^{207}Pb-^{206}Pb age of 2.6 Gyr. Samples collected from the Okhakh Harbour body this summer will be separated in order to obtain a zircon U-Pb age on the body. The opportunity also exists to use the Pb-Pb whole rock method on the body. Black et al. (1973) have demonstrated the feasibility of using the Pb-Pb method as an indicator of granulite facies metamorphism when supported by Rb-Sr ages.

The zircon data from tiger-striped gneiss are shown in Fig. 3. Since there is but one datum point at present, the 2.6 Gyr age is a ^{207}Pb-^{206}Pb age, i.e. the chord through the datum point and origin is dependent only on the isotopic composition of the Pb which defines the ^{207}Pb-^{206}Pb age. The concentrations of ^{235}U and ^{238}U have been determined for this sample and will be used in conjunction with other zircon fractions to determine the U-Pb age of the body.

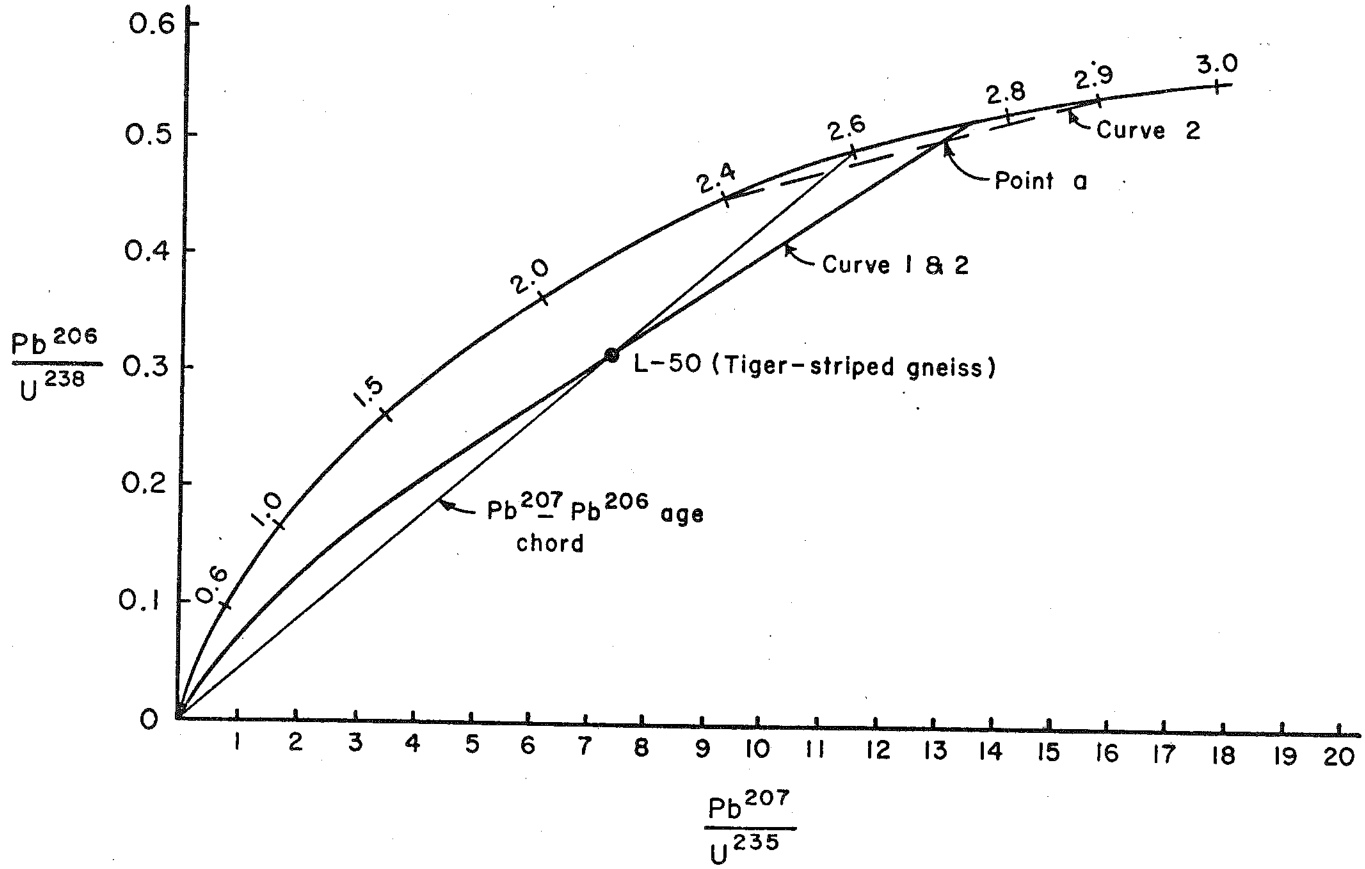

Fig. 3 . ^{207}Pb-^{206}Pb age of Okhakh Harbour zircons from tiger-striped gneiss. Curve 1 is model 1 in text: zircons lose Pb by diffusion from 2.75 Gyr to present. Curve 2 is model 2 in text: zircons experience episodic event at 2.4 Gyr which leaves the once-concordant zircons at point _a_; the zircons then diffuse Pb from this time on, following curve 1.

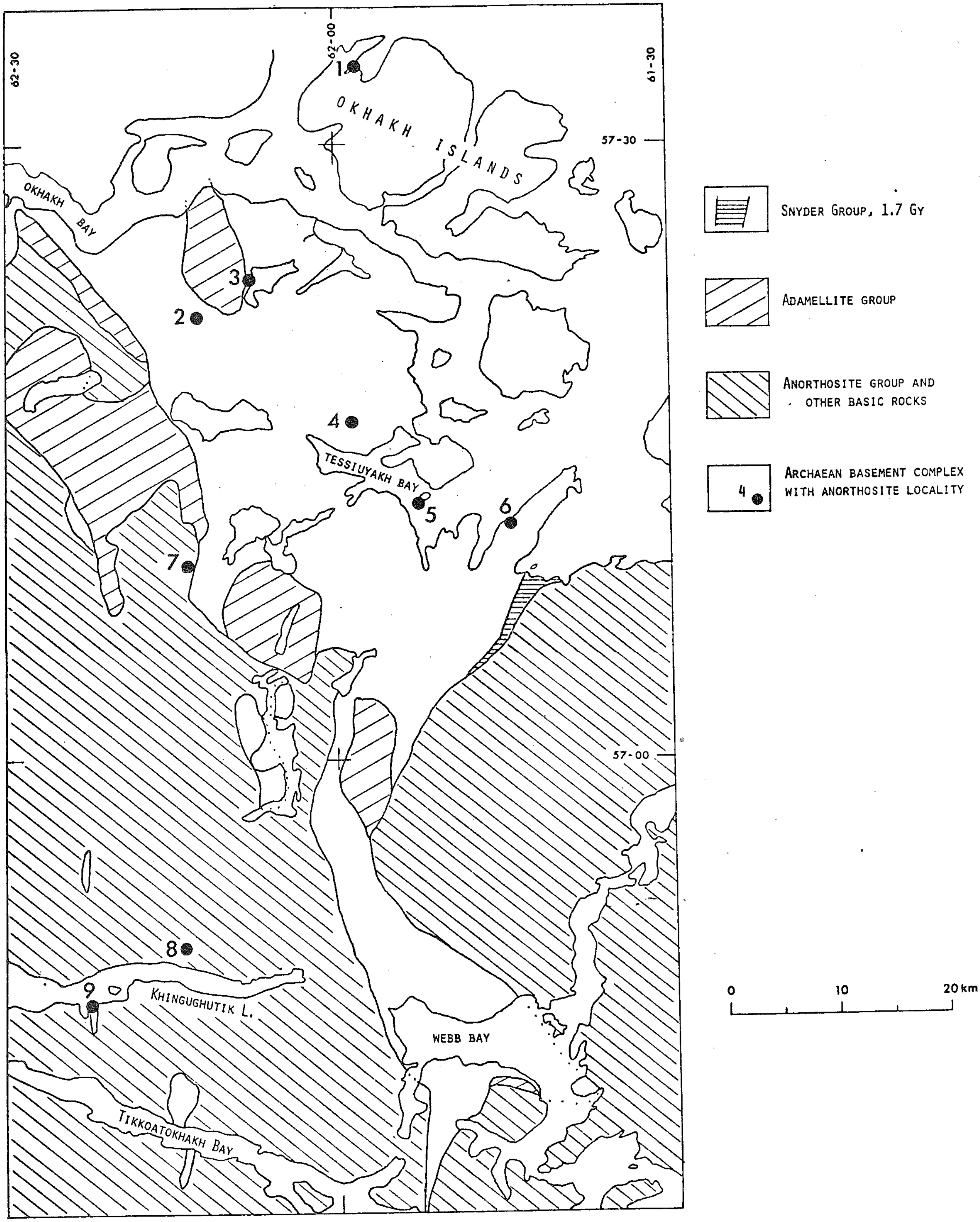

Fig. 4. Distribution of tiger-striped gneiss in the Nain-Okhakh area of Labrador. These occurrences are lithologically similar to the dated Archaean anorthosite at Okhakh Harbour. Identifications: 1. Okhakh Harbour, 2-6. Nakharvik Brook linear system, 7. Aupalukitak Mountain, 8-9. Khingughutik Lake.

The interpretation of the ^{207}Pb-^{206}Pb age is dependent on the zircon morphology and the effect, if any, of the younger granitic intrusion on the U-Pb systematics of the tiger-striped gneiss zircons. Possible interpretations of the 2.6 Gyr age are of the following types: (1) the zircons have lost Pb by diffusion since their formation, ∿ 2.75 Gyr ago, and have not been affected appreciably by younger events; (2) the 2.4 Gyr old granite resulted in an episodic event which partially reset the U-Pb clock of the older tiger-striped gneiss zircons. These zircons have diffused Pb since that time. Fig. 3 shows these relationships with the number (1) or (2) relating the above models. Note that the upper intercept for model (2) is arbitrary until further data become available. Davis et al. (1968) studied the effects of the Eldora Stock on the U-Pb systematics of zircons from Precambrian metasedimentary rocks and granites which it intruded. Zircons in the metasedimentary rocks and granites become more euhedral, due to recrystallization, as the stock is approached. ^{207}Pb-^{206}Pb ages in the metasedimentary rocks and granite are least affected by the stock relative to ^{238}U-^{206}Pb and ^{235}U-^{207}Pb ages. The zircon suite from the granite yields an upper intercept on a Concordia plot which agrees with the Rb-Sr crystallization age and a lower intercept indicative of an episodic event which coincides with the known age of the stock. The lower intercept of the metasediment zircon suite is also consistent with an episodic event at the time of the Eldora Stock intrusion.

The tiger-striped gneiss zircons in this study are from part of the Okhakh Harbour body which is 2-3 m from the intrusive granite. The 2.6 Gyr age of the tiger-striped gneiss is a minimum age which may be dating the metamorphism of the anorthosite. The anhedral nature of the zircons suggests, however, that the granite did not recrystallize the zircons or cause an episodic loss at 2.4 Gyr, therefore model (2) above is not favored. The anhedral morphology also suggests that if the Okhakh body began as a layered igneous complex (igneous rocks tend to have euhedral zircons), there has been a change in morphology by some mechanism since that time. The foliation seen in the tiger-striped gneiss due to the alignment of hornblende pods and tight folding in the more mafic part of the body implies that the Okhakh Harbour body has experienced intense deformation, probably accompanied by amphibolite or possibly granulite facies metamorphism.

If a continuous Pb diffusion model is assumed for the Okhakh Harbour body, an upper intercept of 2.77 Gyr is obtained. This would be consistent with the Pb-Pb whole rock ages found by Black et al. (1973) on the Nordland and Fiskenaesset anorthosite complexes in West Greenland.

Other Occurrences

Outcrops of tiger-striped gneiss which may represent additional occurrences of Archaean anorthosite are indicated on Fig. 4 . A photograph taken at locality No. 5 shows rock closely resembling the distinctive Okhakh rocks. In it, tiger-striped gneiss appears as blocky to irregular xenoliths in a leucocratic granular rock. The plagioclase composition in these hornblende-plagioclase rocks, where determined, runs around An_{60}. Relict cores of hypersthene (and augite?) occur in hornblende at one locality, in contrast to the relationship described above at Okhakh Harbour for sample L-52. No simple succession of metamorphic events can as yet be worked out for the rocks as a group.

These localities have only been noted in passing, and no detailed study has been made of them. The southernmost occurrences lie within areas mapped as Nain anorthosite, and may not be Archaean. The distribution of occurrences is such that rocks resembling Archaean anorthosite may occur along a sinuous belt at least 60 km long. This rock may serve as a stratigraphic marker which can clarify the structure and stratigraphy of the regional migmatites.

Conclusions

There is Archaean anorthosite in Labrador which closely resembles the occurrences reported from Greenland. Similarities exist in the extreme deformation and fragmentation of the anorthositic rocks, in petrography dominated by calcic plagioclase and green hornblende, and in age, which is at least 2.6 Gyr in Labrador and estimated at 2.85 Gyr or older in Greenland. The extent of the Labrador occurrences is poorly known, but probably exceeds 60 km in strike length. The anorthositic rocks may be remnants of layered basic sills. The present metamorphic grade is amphibolite facies, but relict cores of hypersthene in hornblende suggest either an earlier granulite facies metamorphism or an initial crystallization as leuconorite.

The discovery of Archaean anorthosite in Labrador greatly strengthens the known similarities between the oldest rocks of Labrador and West Greenland. These now include a 3.5 Gyr U-Pb age for gneisses at Lost Channel, Labrador (Hurst, this report), to be compared with the 3.7 Gyr age of Amitsoq gneisses in Greenland (OIGL and MacGregor, 1971; Black et. al., 1973), and the Okhakh Harbour anorthosite dated here at >2.6 Gyr, to be compared with a Pb-Pb whole rock age of 2.85 Gyr for anorthosites in Greenland (Black et. al., 1973).

Acknowledgment

The assistance of Mr. J. S. Farhat of U.C.L.A. during the 1972 field season is greatly appreciated. Discussions with Dr. David Bridgwater of the Greenland Geological Survey have been most helpful.

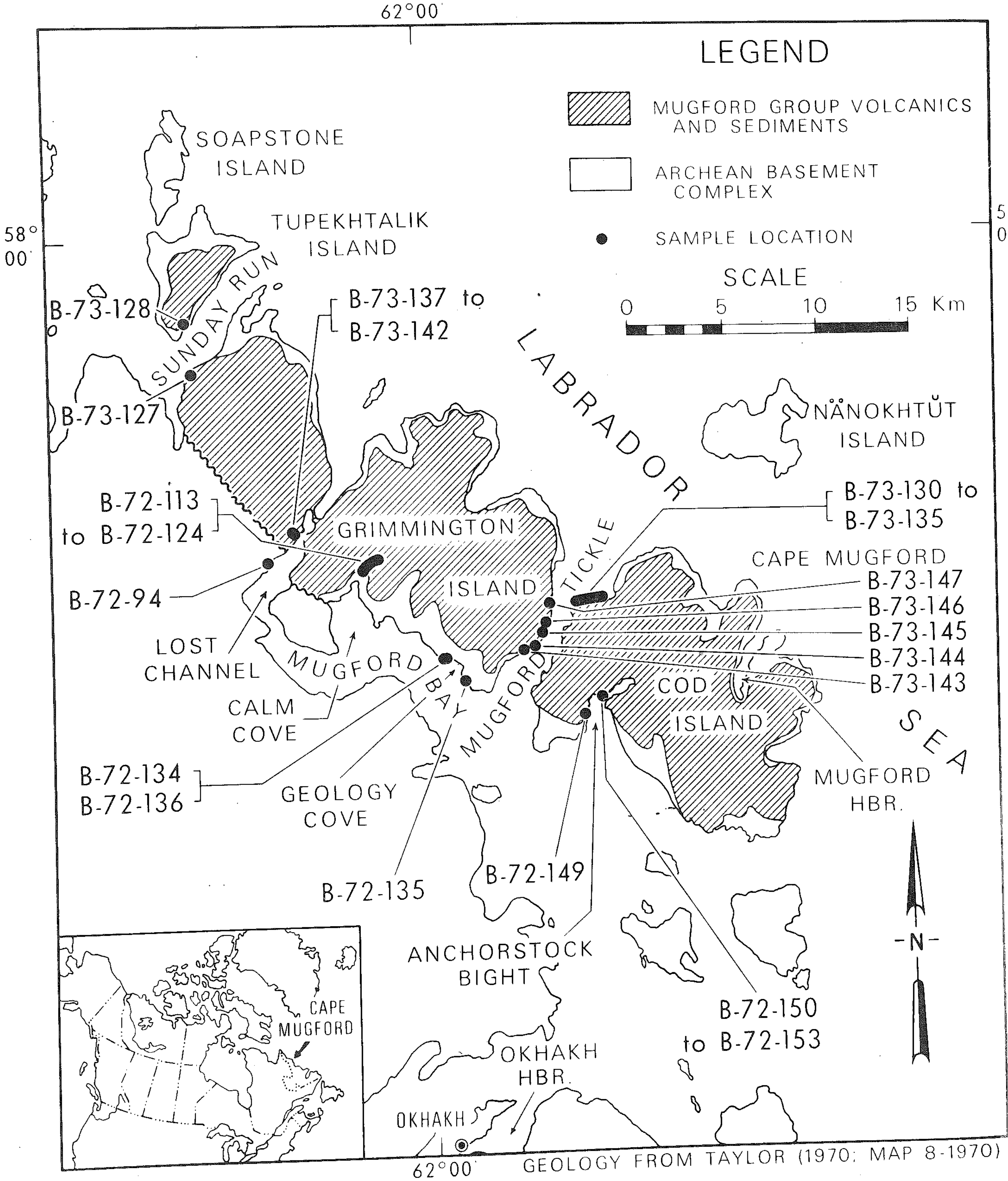

Fig. 5. Geologic map of the Khaumayät Mountains, Labrador, showing the distribution of the Mugford Group and the sampling localities.

PROGRESS OF ISOTOPIC AND GEOCHEMICAL INVESTIGATIONS, COASTAL LABRADOR, 1973

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The Snyder Group

The Snyder Group is a sequence of metasedimentary rocks preserved as a wedge along the northwestern margin of the Kiglapait layered intrusion. It unconformably overlies migmatites of presumed Archaean age and was metamorphosed by the emplacement of the Kiglapait intrusion (Morse, 1969; Speer, FR 1972, p. 21; Barton, FR 1972, p. 13). Prior to this deformation, the Snyder Group and the underlying migmatites were intruded by dikes and sills of what is now a gray breccia containing rounded xenoliths of migmatites similar to those underlying the Snyder Group (Speer, FR 1972, p. 21; Morse, 1969).

The mean chemical composition and C.I.P.W. norm of twelve samples of the matrix from the gray breccia are shown in column 1 of Table 1. These data suggest that the matrix was originally the intrusive equivalent of a high-alumina andesite, perhaps a granodiorite. Preliminary Rb-Sr isotopic data indicate an age of 1.75 Gyr for these dikes and sills with an initial $^{87}Sr/^{86}Sr$ ratio of about 0.704. Because the emplacement of the Kiglapait intrusion deformed these dikes and sills, this intrusion must be younger than 1.75 Gyr. 1.75 Gyr is also the minimum age of the deposition of the Snyder Group and this raises the possibility that these rocks may be contemporaneous with the sediments to the west in the Labrador Trough which were intruded by igneous rocks about 1.85 Gyr ago (Fryer, 1972).

The Mugford Group

The Mugford Group is a mixed sequence, 1000 to 1200 meters thick, of volcanic, pyroclastic and sedimentary rocks which form the Khaumayät (Kaumajet) Mountains (Fig. 5). These rocks are nearly flat lying and

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

unmetamorphosed, and they are separated from the underlying migmatitic basement complex by a profound angular unconformity.

The stratigraphy within the Mugford Group is as yet poorly understood. In most places, the base of this sequence is marked by black to green shales of variable thickness up to about 100 meters. Overlying these shales or resting directly on the migmatitic basement complex is a sequence of up to twelve tholeiitic and olivine tholeiitic flows. In addition, a flow of basaltic komatiite of the Geluk-high-Al type (Viljoen and Viljoen, 1969) has also been identified within these flows. East-facing flow fronts exposed in the cliffs along Sunday Run and Mugford Tickle indicate that the source of these flows was to the west. However, no source locality has yet been recognized. Where these flows overlie shales, the lowest ones are in many places mineralized along fractures with pyrrhotite, chalcopyrite and bornite, suggesting that these sulfides were derived from the underlying shales. Pillows are uncommon in the lower flows, indicating that they were extruded into a subaerial environment. Higher up the sequence however, the lavas become almost exclusively pillowed and are interfingered with water-lain sediments and pyroclastics, implying an aqueous environment.

K-Ar dates measured on hornblende separated from the migmatites underlying the Mugford Group at Lost Channel, Calm Cove and Anchorstock Bight yield a spectrum ranging from 2600 to 2735 Myr , demonstrating an Archaean age for these rocks. Evidence presented by Hurst in this report shows that the rocks at Lost Channel contain zircons at least 3.5 Gyr old. If these zircons formed in situ and are not detrital, then these rocks are substantially older than the K-Ar ages indicate.

K-Ar dates measured from whole-rock vesicle free samples of the lower flows of the Mugford Group exposed at Calm Cove and Anchorstock Bight yield values of 1361, 1484 and 1488 Myr , suggesting a minimum age for these rocks of about 1490 Myr , substantially older than previously believed (Wanless et. al., 1966). Incomplete Rb-Sr studies indicate an initial $^{87}Sr/^{86}Sr$ ratio of about 0.7035 for these same flows and suggest the possibility that these rocks may be as old as 2.3 Gyr (Fig. 6).

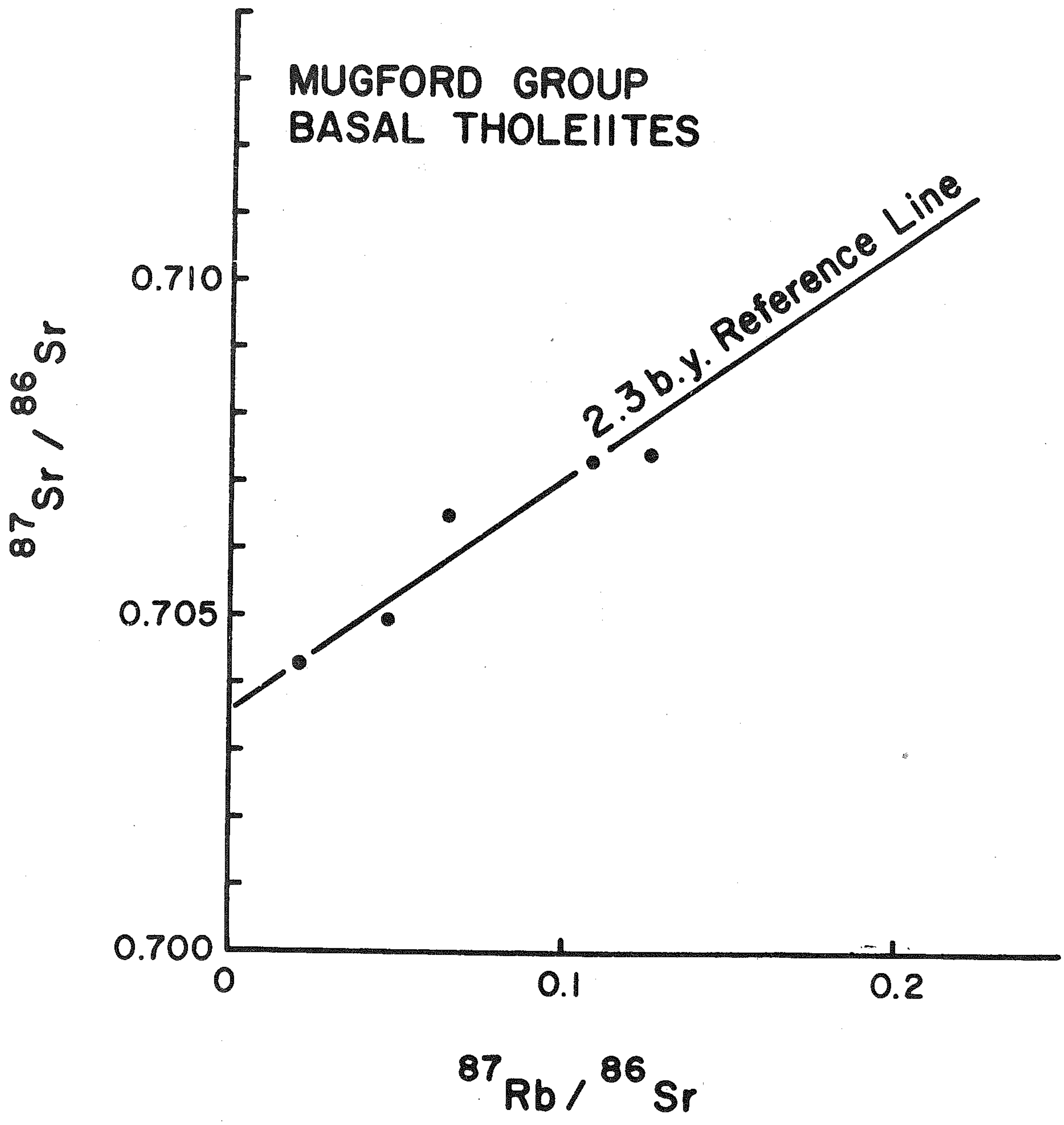

Fig. 6. Isochron plot for samples from the Mugford Group.

Table 1

CHEMICAL ANALYSES*

	1	2	3	4	5	6
SiO_2	57.06	70.12	55.56	49.20	76.51	54.10
Al_2O_3	18.35	14.85	25.83	3.60	12.74	28.28
TiO_2	.591	.292	.155	1.242	.096	.065
Fe_2O_3**	8.17	1.16	1.54	17.84	.72	.07
MnO	.171	.037	.021	.308	.011	.005
MgO	2.75	.82	.83	13.87	.37	.59
CaO	7.13	1.90	10.20	12.80	.94	11.82
Na_2O	2.88	4.33	5.25	.99	7.22	4.69
K_2O	2.547	6.400	.588	.092	1.388	.384
P_2O_5	.34	.10	.03	.07	.01	.00
Total	99.989	100.009	100.004	100.012	100.005	100.004
Ni (ppm)		6.9				
Cu (ppm)		0.0				
Rb (ppm)	84.5	201.82***	2.13***	2.15***	32.35***	.9
Sr (ppm)	523.7	183.81***	612.76***	37.66***	54.40***	657.4
Ba (ppm)	578.5	1209.8				
Pb (ppm)		32.6				
Th (ppm)		26.3				
S (ppm)		50.8				
Cr (ppm)		39.7				
K/Rb	256.	263.	2292.	355.	365.	3630.

C.I.P.W. NORMS****

	1	2	3	4	5	6
QZ	9.37	16.58			27.82	
OR	15.05	37.83			8.20	
PLAG	53.99	38.82			59.35	
(% An)	53.4	5.3	48.9		0.0	
DI	3.12	5.31			4.03	57.6
HY	12.96	.06			0.0	
MT	3.03	.56			.35	
IL	1.12	.55			.18	
AP	.74	.22			.02	

FOOTNOTES AT THE BOTTOM OF NEXT PAGE

1 Average of 12 analyses of the matrix of the gray breccia intruding the Snyder Group.

The Okhakh Granite

The Okhakh Granite is a medium grained undeformed leucocratic granite which sharply intrudes both the migmatitic basement complex surrounding Okhakh Harbour and the Okhakh Harbour hornblende anorthosite (see Hurst, this report; Hurst et al., this report). The average chemical composition and C.I.P.W. norm of 6 samples of this unit are shown in column 2 of Table 1. Rb-Sr analyses yield an isochron of 2386 ± 30 Myr and an initial $^{87}Sr/^{86}Sr$ ratio of 0.7154 ± 0.0010 for this rock (Fig. 7). This age probably closely approximates that of the intrusion of the granite and the high initial $^{87}Sr/^{86}Sr$ ratio suggests but does not prove that it was derived from crustal sources.

The Nain Anorthosite Complex

Within the Nain Anorthosite Complex but near the contact with the Ford Harbour Formation on the peninsula separating Higher Bight from Lower Bight on Paul Island are lensoid bodies of coarsely crystalline (pegmatoidal) plagioclase and clinopyroxene with some interstitial trondhjemitic granophyre. These bodies appear to be late crystallizing portions of the anorthosite complex and may represent either simple residual magma from the anorthosite complex or magma which has been contaminated by the

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2 Average of 6 analyses of the Okhakh Granite.

3 Plagioclase megacryst in pegmatoidal body near Higher Bight, Paul Island.

4 Clinopyroxene megacryst in pegmatoidal body near Higher Bight, Paul Island.

5 Trondhjemitic granophyre in pegmatoidal body near Higher Bight, Paul Island.

6 Plagioclase from anorthosite surrounding pegmatoidal body near Higher Bight, Paul Island.

FOOTNOTES FROM TABLE 1:

* Analyses calculated volatile free by X-ray fluorescence spectrometry in the laboratory of Dr. B. M. Gunn at the Université de Montréal.

** Total iron expressed as ferric iron.

*** Analyses done by isotope dilution in the laboratory of Dr. C. Brooks at the Université de Montréal.

**** If % Fe_2O_3 is greater than 5, % Fe_2O_3 in norm calculated as % TiO_2 + 1.5. If % Fe_2O_3 is less than 5, % Fe_2O_3 in norm calculated as 0.2 x Fe_2O_3.

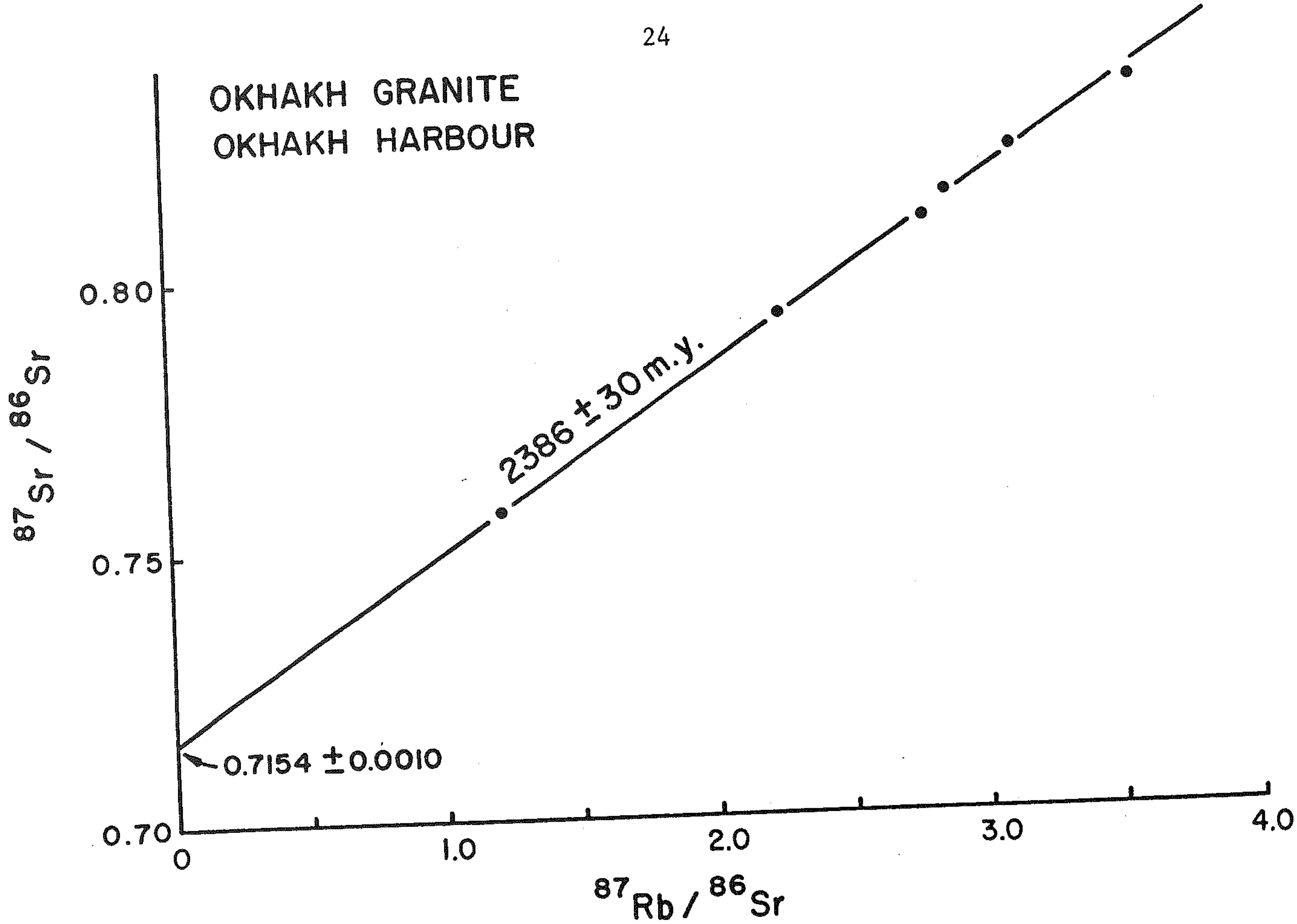

Fig. 7. Isochron plot for samples from the Okhakh Granite, Okhakh Harbour, Labrador.

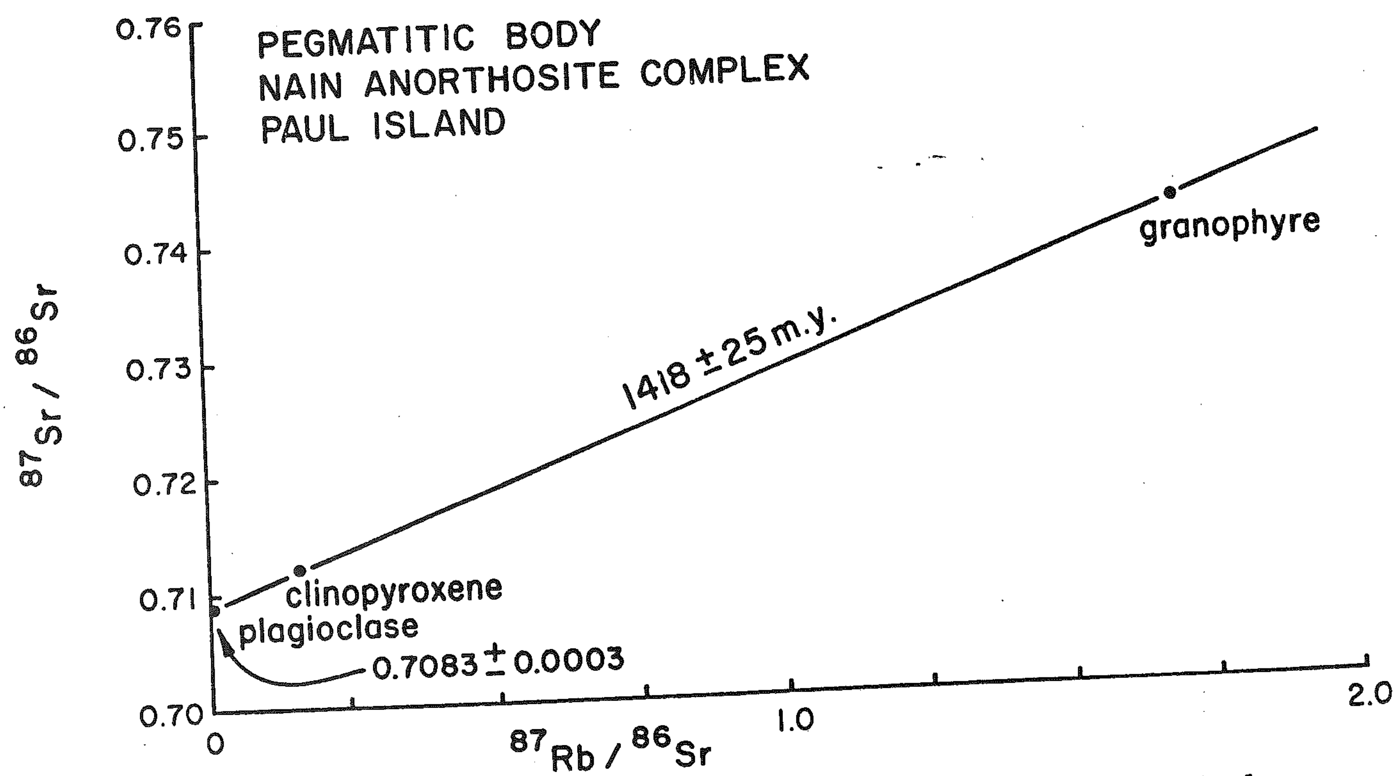

Fig. 8. Isochron plot for samples from a pegmatoidal lens of plagioclase, clinopyroxene and trondhjemitic granophyre within the anorthosite on the peninsula separating Higher Bight from Lower Bight on Paul Island, Labrador

surrounding Ford Harbour Formation. Chemical analyses of the plagioclase, clinopyroxene and trondhjemitic granophyre from one of these bodies are presented in columns 3 through 5 of Table 1. For comparison, the average composition of 6 samples of plagioclase from the anorthosite about 50 meters away is presented in column 6. From these analyses, it may be seen that the plagioclase in the pegmatoidal body is more sodic and potassic than that in the surrounding anorthosite. It also is richer in iron and titanium.

Rb–Sr studies on the minerals found in this body yield an isochron of 1418 ± 25 Myr with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7083 ± 0.0003 (Fig. 8). The age is taken to be that of crystallization of the body and probably closely approximates the age of the surrounding anorthosite complex. The initial $^{87}Sr/^{86}Sr$ ratio is substantially higher than the mean value of 0.7055 reported by Heath and Fairbairn (1968) for the Nain anorthosite complex, suggesting that in fact the magma yielding the pegmatoidal body was contaminated.

The Manvers Granite

The Manvers Granite is a fine to medium grained (locally pegmatitic) granite intruded as dikes and stocks along the northern margin of Port Manvers Run and at Topaz Point (Morse, 1969). It is undeformed and clearly post-dates the intrusion of the Kiglapait layered intrusion. One of the distinctive characteristics of this granite is the widespread occurrence of amazonite megacrysts within its pegmatitic varieties.

Beall et al. (1963) published a K-Ar age of 1140 ± 40 Myr measured on biotite from the Manvers Granite. Another sample of biotite analyzed during this study yielded a K-Ar age of 1240 Myr and a sample of amazonite yielded a Rb-Sr age of 1274 Myr. These ages suggest that at least part of the Manvers Granite crystallized about 1274 Myr ago and cooled below the threshold temperature for Ar retention in biotite about 1240 Myr ago. The younger age of Beall et al. (1963) may indicate that the Manvers Granite does not reflect a single igneous episode. As the Manvers

Granite intrudes the rocks of the Kiglapait layered intrusion, this body must have crystallized prior to 1274 Myr ago.

Sampling For Isotopic And Geochemical Studies: 1973

Sampling for further geochemical and Rb-Sr and K-Ar isotopic studies was undertaken primarily north of Cape Kiglapait and south of Kangalaksiorvik Fiord this year (Fig. 9). In conjunction with ongoing studies of the Archaean rocks of the Labrador Coast (Barton, FR 1972, p. 11; Farhat and Hurst, FR 1972, p. 16), migmatites were sampled at nine new localities:

(1) Kangalaksiorvik Fiord
(2) Delabarre Bay
(3) Ramah Bay
(4) BearsGut Fiord
(5) Branagin Island, Säglekh Fiord
(6) Anchorage Cove, Säglekh Fiord
(7) Hebron Fiord
(8) Rifle Bay, Napartokh Bay
(9) Khikkertakh Island, Okhakh Bay

In general, these migmatites, especially those samples at Hebron Fiord (the Hebron gneisses) and those sampled at Rifle Bay (the Tuktuk gneisses) are very similar to the Amitsoq gneisses of West Greenland (Bridgwater, Watson and Windley, 1973; McGregor, 1973; Bridgwater, McGregor and Myers, 1973; Bridgwater, personal communication, 1973). These migmatites are tonalitic to granitic in composition, intensely deformed and cut by numerous iron-rich diabase dikes which may correlate with the Ameralik dikes of the Godthaab region. The regional metamorphic grade along this portion of the Labrador Coast is upper amphibolite and except at Okhakh Hr. (Hurst et al., this report) there is no evidence yet to suggest that the migmatites were ever metamorphosed to the granulite facies. No supracrustal rocks similar to the Isua or Malene gneisses of the Godthaab region have been recognized yet in this area, but meta-anorthosite has been found on Okhakh Island and other localities to the southwest (see

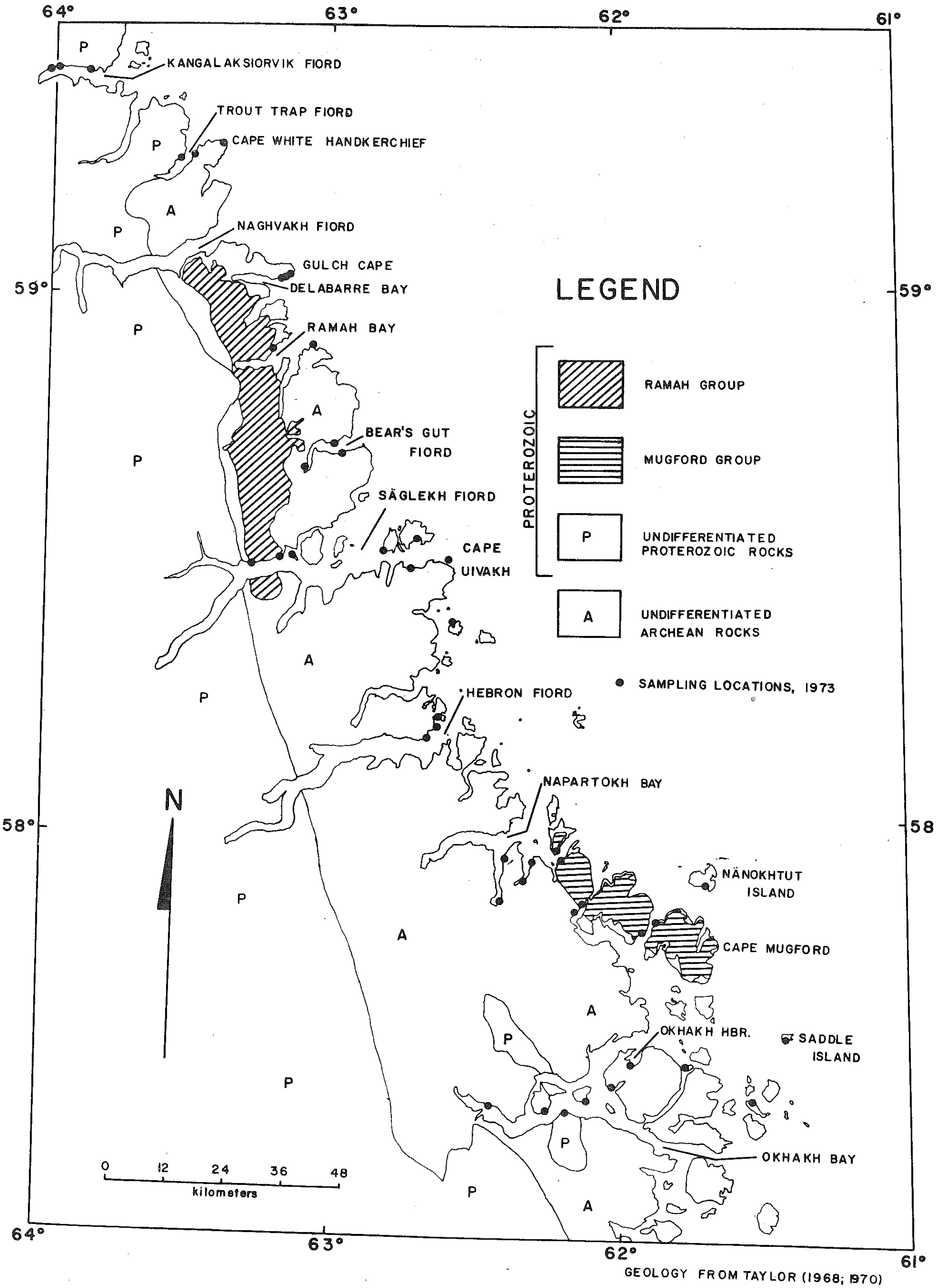

Fig. 9. Geologic map of the Labrador Coast between Okhakh Bay and Kangalasiorvik Fiord, showing the sampling localities for 1973.

Hurst et al., this report). Rocks similar to the Nuk gneisses have also not been identified.

Additional sampling was also done for continuing projects involving the Mugford Group and diabase dikes along the Labrador Coast (Barton, FR 1972, p. 11). In hopes of ascertaining a clearer picture of the age of the Ramah Group, a volcanic flow of tholeiitic composition and a shale unit were sampled from the basal section of this sequence exposed at Ramah Bay. A second tholeiitic flow was sampled within the Ramah Group exposed at Säglekh Fiord. Finally, the undeformed granite bodies exposed on Nänokhtut and Saddle Islands were also sampled for age determinations.

Acknowledgements

The Rb-Sr isotopic data mentioned in this report was obtained in the laboratory of Dr. Christopher Brooks in the Département de Géologie, of the Université de Montréal. Field expenses were defrayed by grants from the Geological Society of America.

THE EARLY ARCHAEAN OF COASTAL LABRADOR

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University of California, Los Angeles[1]

Introduction

Geophysical studies in the Labrador Sea between Labrador and Greenland (Le Pichon, et. al., 1971) indicate that Greenland separated from the North American continent ∿65-80 Myr ago. This rifting was suggested by Bullard (1965) based on a geometrical reconstruction of the North Atlantic region. The geophysical evidence is supported by geological similarities among Labrador, Baffin Island and West Greenland (Clarke and Upton, 1971; FR 1971; FR 1972; Sutton, 1972; Sutton, et. al., 1972).

The discovery of 3.75 Gyr old gneisses in West Greenland (Black, et. al., 1971; Moorbath, et. al., 1972; Baadsgaard, 1973), in the light of the Labrador-Greenland rifting, suggests that gneisses of a similar age may occur on the coast of Labrador. Due to uncertainties in the reconstruction of these land masses exact correlations are not yet possible.

Sampling of the Archaean basement complex in Labrador from Tessiuyakh Bay to Mugford Tickle (Farhat and Hurst, FR 1972) has now been extended to Kangalasiorvik Fjord in order to apply Rb-Sr and U-Pb isotopic dating techniques to the following problems:

1. To determine the existence of rocks in Labrador which may be correlative with the 3.75Gyr old Amitsoq gneisses in West Greenland.
2. To clarify the regional geochronology and Precambrian stratigraphy in Labrador and thereby contribute to the geology of Labrador as well as the predrift reconstruction of the North Atlantic craton in this region.

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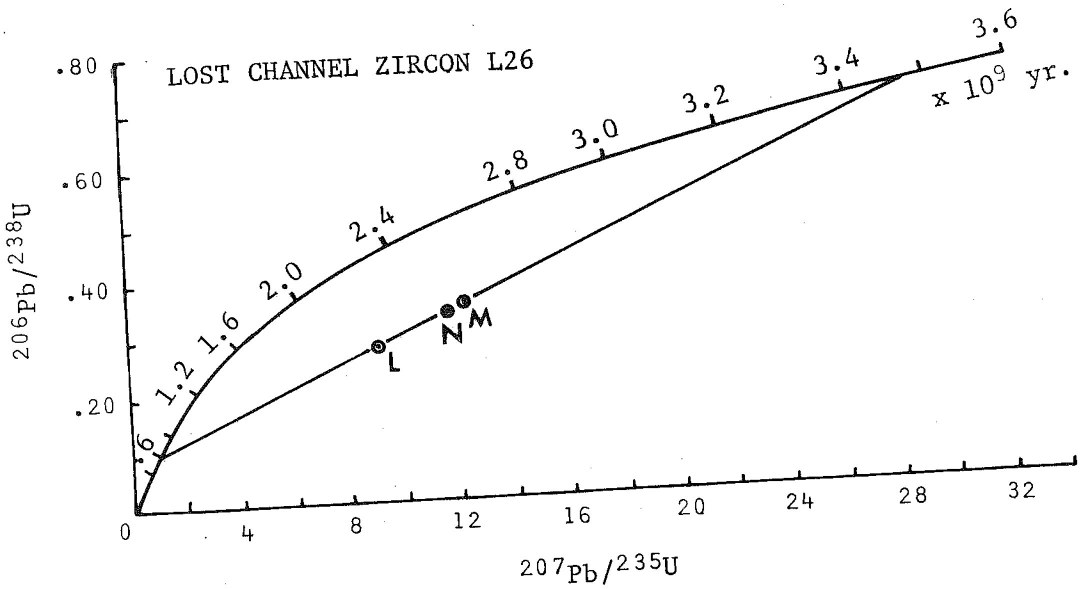

Fig. 10. U-Pb measurements on zircon sample L26 from Lost Channel.

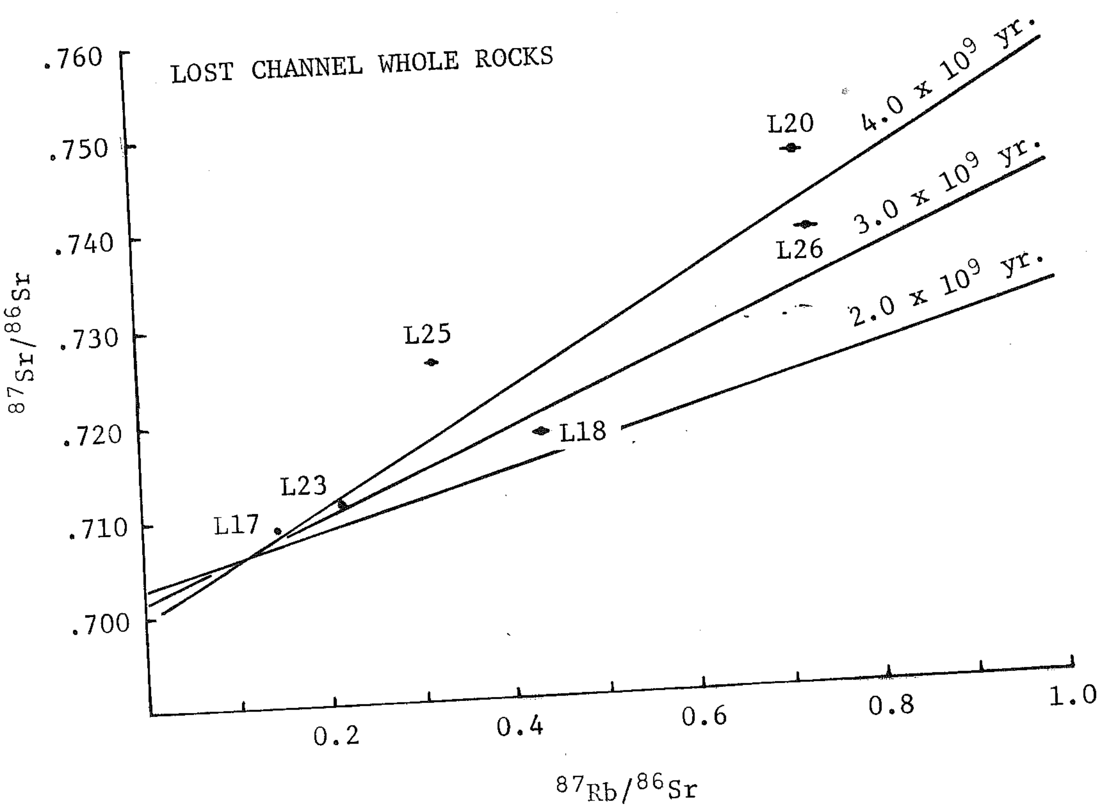

Fig. 11. Rb-Sr data on whole rocks from Lost Channel.

1973 Sampling

Approximately 800 kg of basement and related rocks were collected from the following areas (locations shown in Fig. 9):

1. Kangalasiorvik Fjord (garnet-mafic gneiss)
2. Trout Trap Fjord (felsic gneiss, basalt dikes)
3. Ramah Bay (quartzofeldspathic gneiss)
4. Bear's Gut (banded gneiss)
5. Delabarre Bay (feldspar-mafic gneiss)
6. Säglekh Bay (Branagin's I., feldspar-mafic gneiss;
   Shuldham I., granitic gneiss;
   Säglekh Domes, feldspar-mafic gneiss)
7. Maidmont's I. (feldspar-mafic gneiss)
8. Hebron Fjord (banded gneiss)
9. Rifle Bay (feldspar-biotite gneiss)
10. Finger Hill I. (basalt)
11. Nänokhtut I. (granite)
12. Mugford Tickle (basalt)
13. Lost Channel (granite gneiss)
14. Okhakh Harbor (meta-anorthosite)
15. Khikkertakh I. (migmatitic gneiss)
16. Saddle I. (granite)
17. Amitokh I. (felsic gneiss)

Preliminary Results

Rb-Sr and U-Pb data indicate the following:

1. The basement complex in Lost Channel was metamorphosed $\sim$3.5Gyr ago.
2. Archaean anorthosites are present in Labrador (see Hurst, et. al., this report).

The data for Lost Channel are shown in Figs. 10 and 11. The Rb-Sr data on the Lost Channel gneisses, Fig. 11, indicate that these gneisses have been open systems with respect to Rb or Sr, or both.

Samples L17 (granitic gneiss), L20 (granitic gneiss) and L18 (mafic gneiss) were collected within 50 m of the Mugford Group - basement contact. The basement in this portion of the outcrop is sheared. Secondary hydrothermal alteration is evident in the field and in the thin sections of these gneisses (sericitization, cloudy plagioclase), in addition to deformation features (subgrains and undulose extinction in quartz). Samples L23 (mafic gneiss), L25 (mafic inclusion in gneiss) and L26 (granitic gneiss) were collected 200m from the sheared zone. These rocks show minimal secondary alteration and less deformation than the gneisses in the shear zone.

The U-Pb results in Fig. 10 , from 3 zircon magnetic separates from L26, indicate an age of 3.46 Gyr for the Lost Channel area. The majority of the zircons are euhedral, implying that they have been recrystallized. The mafic gneiss, L23, may have experienced granulite facies conditions, judging from its mineralogy (plagioclase, orthopyroxene, clinopyroxene, hornblende, quartz, opaques). Based on this evidence, the 3.46 Gyr age is interpreted as the time of metamorphism.

One interesting observation is the Rb-Sr whole-rock "age" of samples L23 (mafic gneiss) and L26 (granitic gneiss) taken together. These two samples yield an age of 3.7Gyr, with $(^{87}Sr/^{86}Sr)_o = 0.6999$. It is possible that these less altered rocks have remained closed systems, inasmuch as the initial Sr isotopic composition is reasonable for rocks 3.7 Gyr old. More samples were collected in the vicinity of L26 (possibly the same outcrop) in order to test this hypothesis.

K-Ar dates on amphiboles from Lost Channel Inlet indicate ages in excess of 2.6 Gyr (Barton, this report). Partial Ar loss would explain the lower K-Ar ages but the event which caused this loss (metamorphism, weathering, shearing) is not obvious. K-Ar ages on coexisting biotites would be of interest along with petrographic control, since this writer has seen secondary amphiboles, possibly actinolite, replacing primary hornblende in the Lost Channel gneisses.

Conclusions

Preliminary geochronologic studies indicate that sections of the Labrador Archaean may be 3.5 Gyr old or older. On a regional scale, the Okhakh I.--Lost Channel area resembles the Godthaab area in West Greenland with its early Archaean ages and anorthosites. Far more data are required before geologic similarities become meaningful predrift reconstructions. Correlations in the North Atlantic and the history of the Archaean crust in this area will be contingent on continued research in the Precambrian terrain along the coast of Labrador and related areas.

Acknowledgment

This research has been supported by NSF Grant GA-12701 to Dr. George W. Wetherill.

MINERAL ASSEMBLAGES IN THE CONTACT AUREOLE OF THE HETTASCH INTRUSION: P-T ESTIMATES

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University of Massachusetts[1]

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Introduction
Ultramafic Rocks
Aluminous Rocks
Deviations From the MASH Model
Temperatures
Discussion

Introduction

The Archaean rocks of the Webb Valley metamorphic complex are described in FR 1972 (p. 51-56). The discussion here will be centered on a few interesting mineral assemblages formed during the contact metamorphism produced by the Hettasch intrusion (FR 1972, p. 49-64), the purpose being to indicate limits on the pressures and temperatures obtaining during the crystallization of this part of the Nain anorthosite complex.

Ultramafic Rocks

Numerous ultramafic bodies occur in the Webb Valley metamorphic complex at or near the contact of the Hettasch intrusion. One such outcrop located within a few hundred meters of the contact (point D on Fig. 30 , north of Webb Bay) displays the mineral assemblage pargasite-olivine-orthopyroxene-spinel-plagioclase-ilmenite. This assemblage can be approximately modelled

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

in the system MASH ($MgO-Al_2O_3-SiO_2-H_2O$). Significant by its absence is the mineral pair cordierite-olivine (see Fig. 12a). The absence of the tie line cordierite-olivine and the coexistence of orthopyroxene and spinel indicate that the assemblage formed at higher pressures than the natural analog of the reaction enstatite + spinel $\rightleftharpoons$ forsterite + cordierite (Fig. 12a). This reaction was studied by Fawcett and Yoder (1966), and it is nearly insensitive to temperature. Regardless of what temperature one might infer, the stability of orthopyroxene and spinel suggests a minimum pressure (P_{H_2O}) of approximately 3 kbar (see Fig. 13).

Obviously, this natural ultramafic sample has a composition which is not strictly in the system MASH. Most notably ignored are the component FeO and the possibility of $P_{H_2O} < P_{TOTAL}$. The effect of ignoring these factors will be discussed below.

Aluminous Rocks

Two outcrops which are in immediate contact with the Hettasch intrusion (Fig. 30 : point E, north of Webb Bay and point F, south of Deep Lake) consist of rocks which are extremely rich in Mg and Al. Many of these rocks contain more than 70% cordierite (Cord), which is deep bluish purple in hand specimen and pleochroic lavender in thin section. Other minerals include hypersthene (Hyp), quartz (Q), sillimanite (Sill), spinel (Sp), corundum (C), sapphirine (Sa), plagioclase, and opaques (mainly sulfides). The common assemblages are (1) Cord-Hyp-Q, (2) Cord-Hyp, (3) Cord-Sp, (4) Cord-Sp-Sill, (5) Cord-Sp-C, and (6) Cord-Sp-Sill-C (all assemblages contain plagioclase). Sapphirine has been identified in grain mounts, but has not yet been observed in thin section. Model chemographic relations are shown in Fig. 12b.

The most crucial assemblage for indicating pressure limits is the intimate, ubiquitous association of cordierite and spinel. Experimental work of F. Seifert (in press) shows that the breakdown of cordierite and spinel (Cord + Sp $\rightleftharpoons$ En + Sa) is nearly insensitive to temperature and nearly parallel to the previously discussed reaction En + Sp $\rightleftharpoons$ Cord + Fo (see Fig. 13). Again regardless of the temperature inferred, cordierite

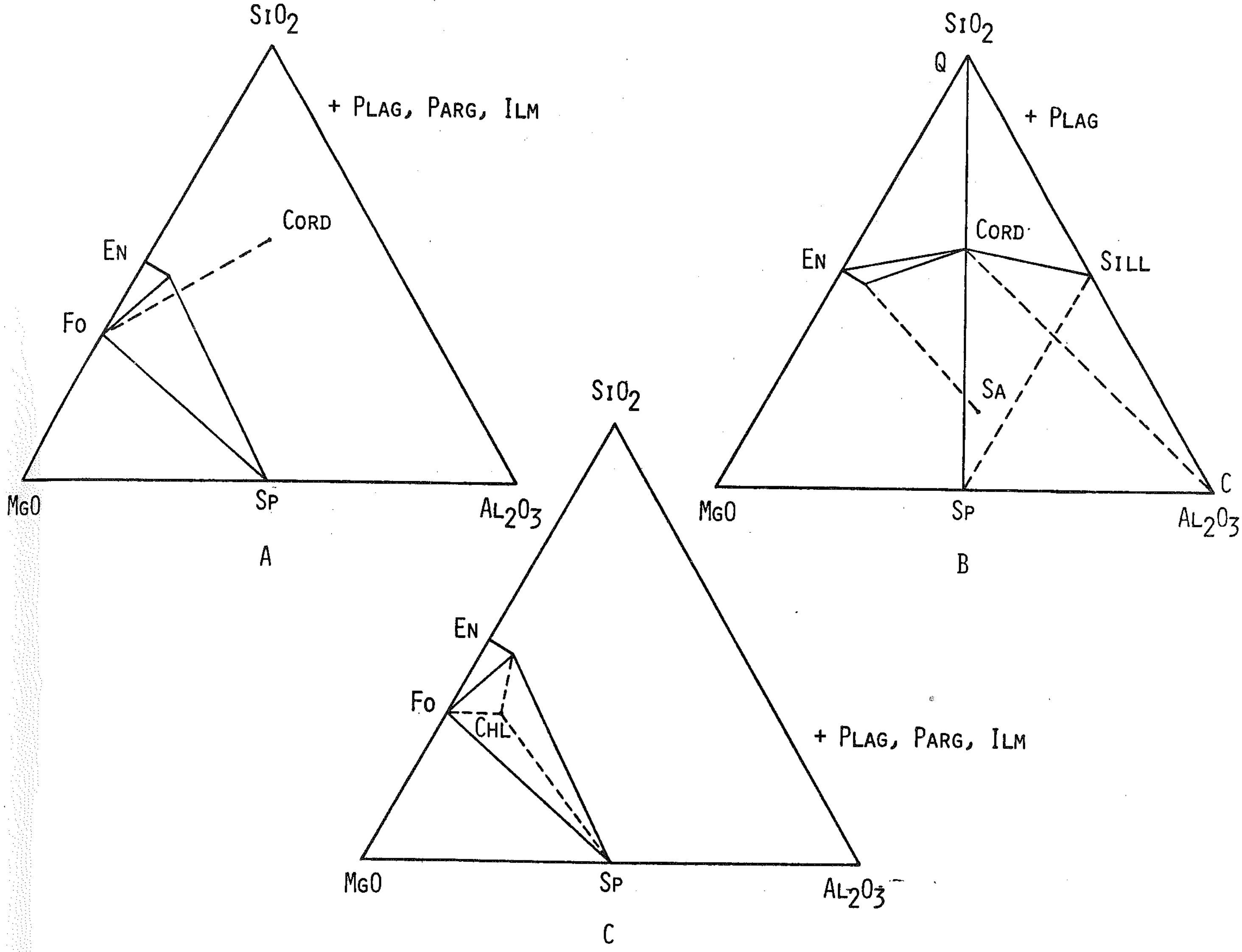

Fig. 12. Chemographic relations of selected mineral assemblages in the Hettasch contact aureole.

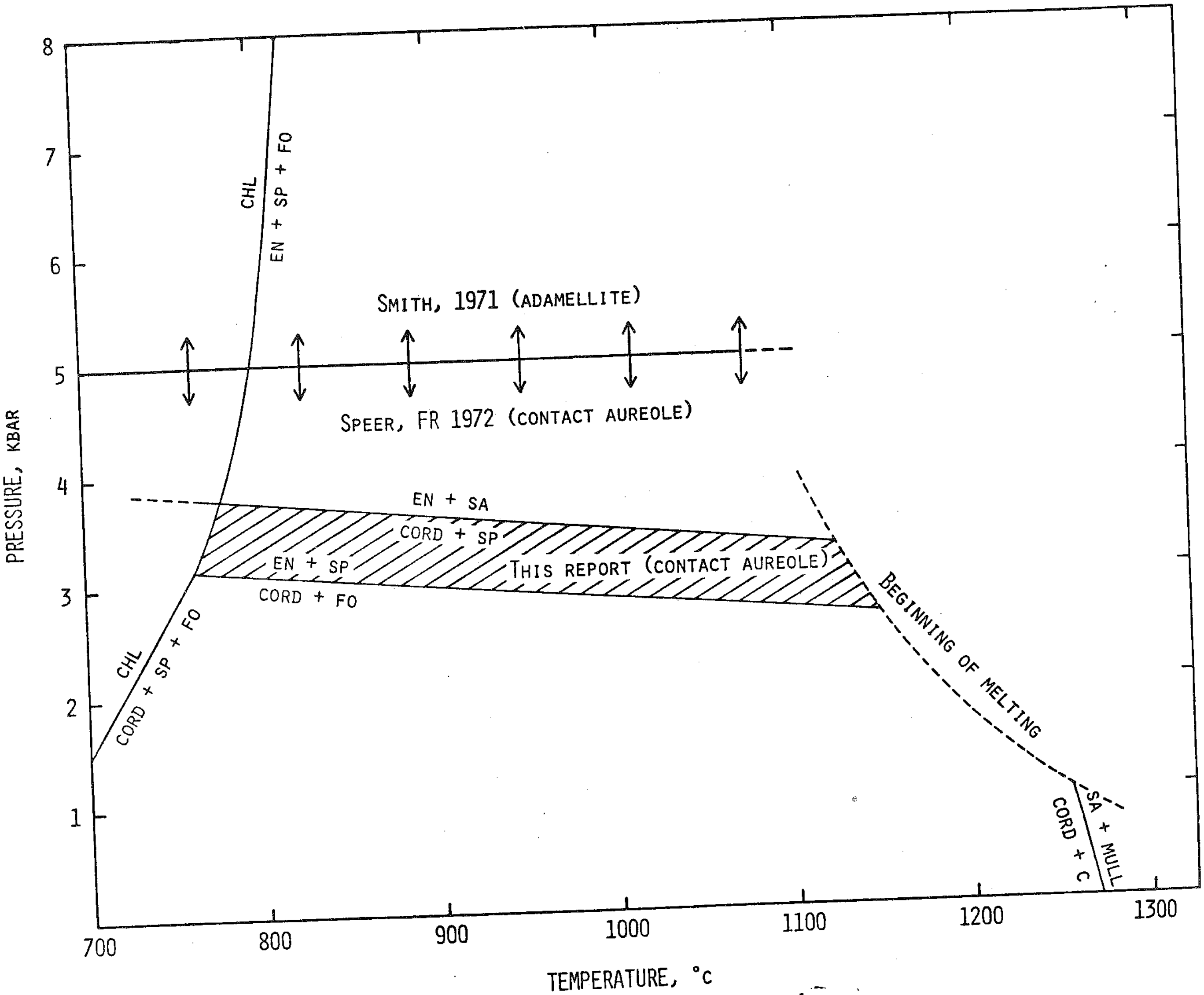

Fig. 13. Pressure-temperature plot showing univariant equilibria and various estimates of P-T conditions for parts of the Nain complex. Experimental data from Fawcett and Yoder (1966) and Seifert (in press).

and spinel could not have coexisted relative to enstatite and sapphirine above approximately four kbar $\underline{P}_{H_2O}$.

Deviations From the MASH Model

Although these assemblages are Mg-rich, there is enough Fe to alter the phase relationships and to render the experimental data not directly applicable. Hensen and Green (1973) show that an increase in Fe causes reactions involving cordierite and garnet to occur at lower pressures. What effect the addition of Fe has on the ultimate stability of Co + Sp and En + Sp is unknown; however it is clear that the reactions will become divariant rather than univariant in $\underline{P}$-$\underline{T}$ space.

It seems likely that near the anorthosite contact $\underline{P}_{H_2O}$ could be considerably less than $\underline{P}_{TOTAL}$. Because cordierite, below about 850°C, probably contains water (Schreyer and Yoder, 1964; Newton, 1972), H_2O should be included on the high-pressure side of the two reactions thus far considered. Therefore, if the $\underline{P}_{H_2O}$ was indeed less than $\underline{P}_{TOTAL}$, the reactions would likely be shifted to lower pressures. At temperatures above 850°C the cordierite is probably anhydrous, and the reactions would likely be unaffected by conditions of $\underline{P}_{H_2O} < \underline{P}_{TOTAL}$.

Temperatures

Temperatures, which must have varied considerably, are not easily defined by these assemblages. However, the absence of Mg-chlorite from the ultramafic rocks near the Hettasch contact (see Fig. 12c) indicates that temperatures were above those of the reaction Mg-chlorite $\rightleftharpoons$ Fo + En + Sp (Fawcett and Yoder, 1966; and Fig. 13). This suggests that temperatures were at least greater than about 775°C although this reaction would probably shift to lower temperatures with the presence of a small amount of Fe and with $\underline{P}_{H_2O} < \underline{P}_{TOTAL}$.

Textures suggest that at one time sillimanite and sapphirine may have coexisted stably. This would appear to have been the highest temperature assemblage attained here, there being no textural evidence that cordierite ever broke down to produce sapphirine and quartz (see Schreyer and Seifert, 1969). In thin section sillimanite is commonly rimmed by cordierite, spinel, and corundum. The suggestion is that, taking into account the presence of a small amount Fe in the natural system, the reaction Sill + Sa → Cord + C + Sp occurred. The analogous reaction in the pure system MASH would be Al-silicate (mullite) + Sa → Cord + C (Seifert, in press; and Fig. 13). Seifert (personal communication, 1973) suggests that the reaction Sill + Sa → Cord + C + Sp would be sub-parallel to the reaction Mull + Sa → Cord + C, but of course the former would certainly lie at lower temperatures. This would be a retrograde reaction attendant upon slight cooling or possibly a release in pressure.

Discussion

The hachured area of Fig. 13 indicates the best estimate at this time of P-T conditions during the emplacement of the anorthositic Hettasch intrusion. The zone may be shifted slightly to lower pressures by the condition $P_{H_2O} < P_{TOTAL}$. Evaluation of the effect of Fe awaits future experimental study.

Regionally, the not uncommon coexistence of cordierite and spinel (E. P. Wheeler, II, personal communication, 1973) suggests that much of the Nain anorthosite complex may have been emplaced at pressures similar to that of the Hettasch intrusion. Cordierite + garnet assemblages are also common in the region (Wheeler, de Waard, Speer in FR 1972; Wheeler, Davies in this report). Supposedly, this assemblage could indicate higher pressure, lower temperature, or same conditions with a more Fe-rich bulk composition (Hensen and Green, 1973). The documented break-down of garnet near anorthosite contacts (Wheeler, FR 1972; 1968; 1955) implies that throughout the Nain region temperature, not pressure, determines whether or not garnet is stable, assuming similar bulk compositions. The local occurrence of garnet and cordierite assemblages near anorthosite contacts would then be most easily explained as having formed from a more Fe-rich bulk composition.

These estimates are consistent with those of Speer (FR 1972, p. 28). He concludes that pressures obtaining during the emplacement of the Kiglapait layered intrusion were less than about 5 kbar based on the andalusite - sillimanite transition (i.e., pressures below the Al-silicate triple point; Richardson, et. al., 1969) within the Snyder Group meta-sedimentary rocks in the Kiglapait contact aureole (see Fig. 13).

The presence of iron-rich orthopyroxenes in adamellitic rocks associated with the Nain anorthosite complex and experimental data on the reaction orthopyroxene $\rightleftharpoons$ olivine + quartz (Smith, 1971) indicate pressures greater than 5 kbar during crystallization of adamellite. These estimates conflict with the evidence from contact aureoles discussed above (see Fig. 13). If both methods of evaluating pressure are indeed valid, this disagreement would imply that some adamellite crystallized or was emplaced at greater depth than anorthosite.

It was once commonly believed that massif-type anorthosites were emplaced at "great depths". Now it appears most likely that one classical massif-type anorthosite (Nain) was not emplaced at great depths, but instead at quite shallow depths near 10-13 km. Somewhat similar conclusions are drawn by Emslie, et. al. (1972, p. 10-11).

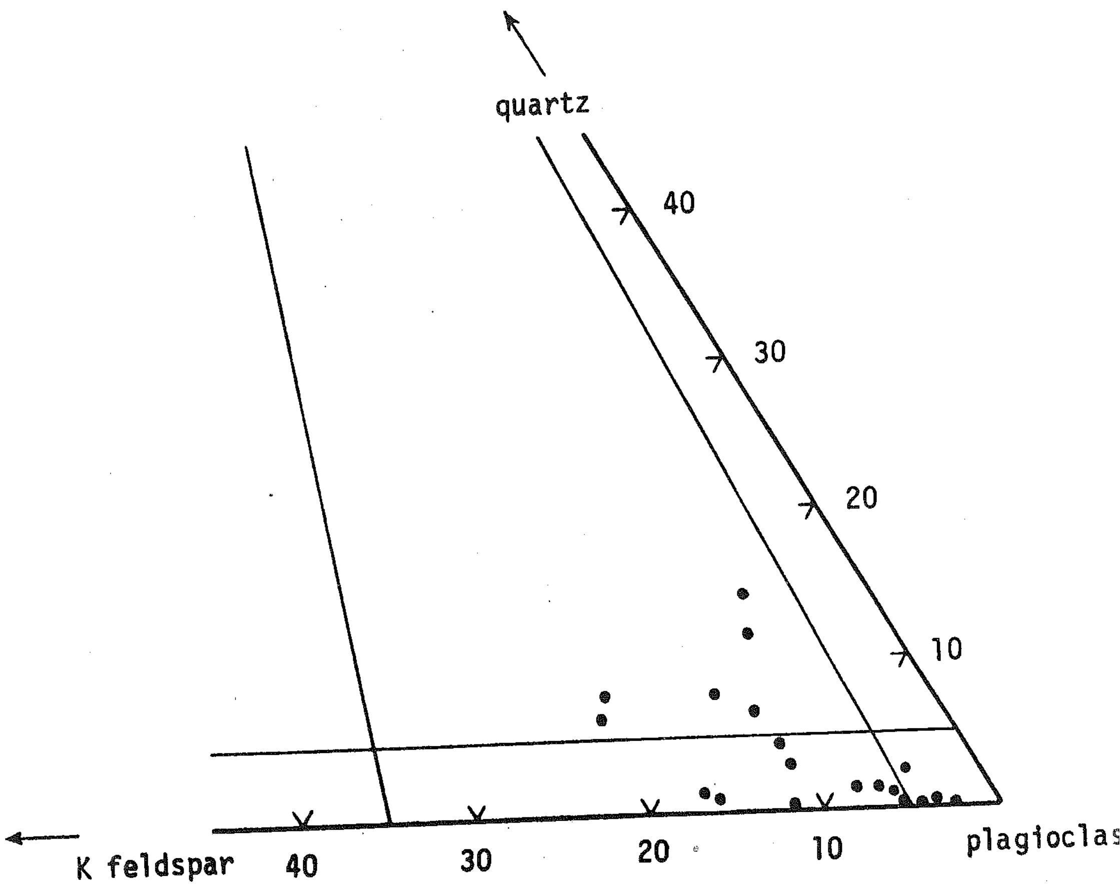

Fig. 14. Volumetric proportions of quartz, K feldspar, and plagioclase in monzogabbroic rocks from Dog Island, from the dike north and northeast of Nain, and from rocks associated with the Barth layered structure. Compositions range from gabbroic to granodioritic with a median for these 19 samples in the monzogabbroic field.

NAIN COMPLEX: GENERAL

ON THE NOMENCLATURE AND CLASSIFICATION OF ROCK GROUPS IN THE NAIN ANORTHOSITE COMPLEX (CONTINUED)

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Rocks of the Nain anorthosite massif are traditionally divided into three major groups: the anorthositic, the adamellitic, and the troctolitic rock series or groups (for example, see map, Fig. 1). They are the principal components to be taken into consideration in petrogenetic models of the massif. This three-fold division also provides a convenient field terminology and simple rock classification: the anorthositic rocks are coarse to very coarse grained, leucocratic plagioclase-pyroxene (-olivine) rocks; the adamellitic rocks are coarse grained quartz feldspar rocks, typically with ovoidal feldspars; and the troctolitic rocks are coarse to fine grained plagioclase-olivine-pyroxene rocks in which the olivine is fairly easily identifiable in the field. The three rock groups are widely distributed in the Nain massif, and each of them may be subdivided on local field or microscopic characteristics.

It may be advantageous to recognize a fourth major group of rocks which in my experience is also widely distributed, though generally in smaller occurrences than those of the other three groups. The rock is typically a fine to medium grained, dark plagioclase-pyroxene rock which generally also contains variable amounts of quartz and K feldspar. It occurs, for instance, in a zone around the Barth layered structure (Rubins, FR 1971, p. 40-41; de Waard and Mulhern, FR 1972, p. 75), in a dike about 20 km long and 30 m wide (de Waard and Hancock, this FR), as part of a layered intrusion on Newark Island (Woodward, FR 1972, p. 44), in the Ikkinikulluit headwaters (Wheeler, this FR), and in a zone between adamellitic and anorthositic rocks on Dog Island (de Waard, this FR). This rock type is too fine grained and too mafic to be part of the anorthositic group or the adamellitic group, and though it is closest in general appearance to rocks of the troctolitic group, it does not contain olivine. Depending on the amounts of quartz and K feldspar in the rock, and on the

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kind of ferromagnesian minerals present, the rock may have any of the following names: gabbro, norite, tonalite, enderbite, monzodiorite, jotunite, granodiorite, and opdalite (see de Waard, FR 1972, p. 7-9). Considering the compositional distribution of examined specimens the median could be called either monzogabbroic, thus stressing the abundance of pyroxene and the scarcity of hornblende, or monzodiorite, indicating the general presence of andesine rather than labradorite in these rocks. The name monzogabbroic is chosen here, because it probably conveys better the gabbroic appearance of the rock.

A similar nomenclatural problem exists with respect to the term adamellite which in the Nain massif is used for a group or series of rocks, including diorite, monzodiorite, granodiorite, adamellite, and granite (Wheeler, 1955). The 'adamellitic rock' of Dog Island is a granodiorite in most places (de Waard, this FR).

As a fifth group may be considered gabbroic rocks occurring in major bodies. The rocks are medium to coarse-grained, generally mesocratic plagioclase-pyroxene rocks in which olivine may be present. They are characterized by plagioclase of high An percentages. Examples are the North Ridge Gabbro with An percentages ranging from 83 to 55 (Berg, FR 1972, p. 56) and the Bridges Layered Group, where An percentages range from 81 to 64 (Planansky, FR 1972, p. 83).

In summary it is suggested that in the Nain anorthosite complex five main groups can be recognized of rocks occurring in major bodies. They are briefly defined as follows:

1. Anorthositic rocks: very coarse and coarse-grained anorthosite, leuconorite, leucogabbro, and leucotroctolite.

2. Gabbroic rocks: medium to coarse-grained bytownite or labradorite-bearing gabbros and olivine gabbros.

3. Troctolitic rocks: fine to coarse-grained troctolite and associated olivine-bearing rocks.

4. Monzogabbroic rocks: fine to medium-grained, mesocratic, gabbroic to grandioritic rocks.

5. Adamellitic rocks: coarse-grained quartz-feldspar rocks of granodioritic to granitic composition, commonly with ovoidal feldspar.

It should be emphasized that this grouping represents a broad division of rocks of the Nain anorthosite complex, largely based upon field characteristics. Though it indicates gross lithologic differences, it tends to obscure petrologic details of possible genetic significance, which are only brought out by detailed mapping and systematic sampling.

Appendix: Figures 14 and 15 show the distribution of plots representing mineralogical compositions of rocks of the Nain anorthosite complex.

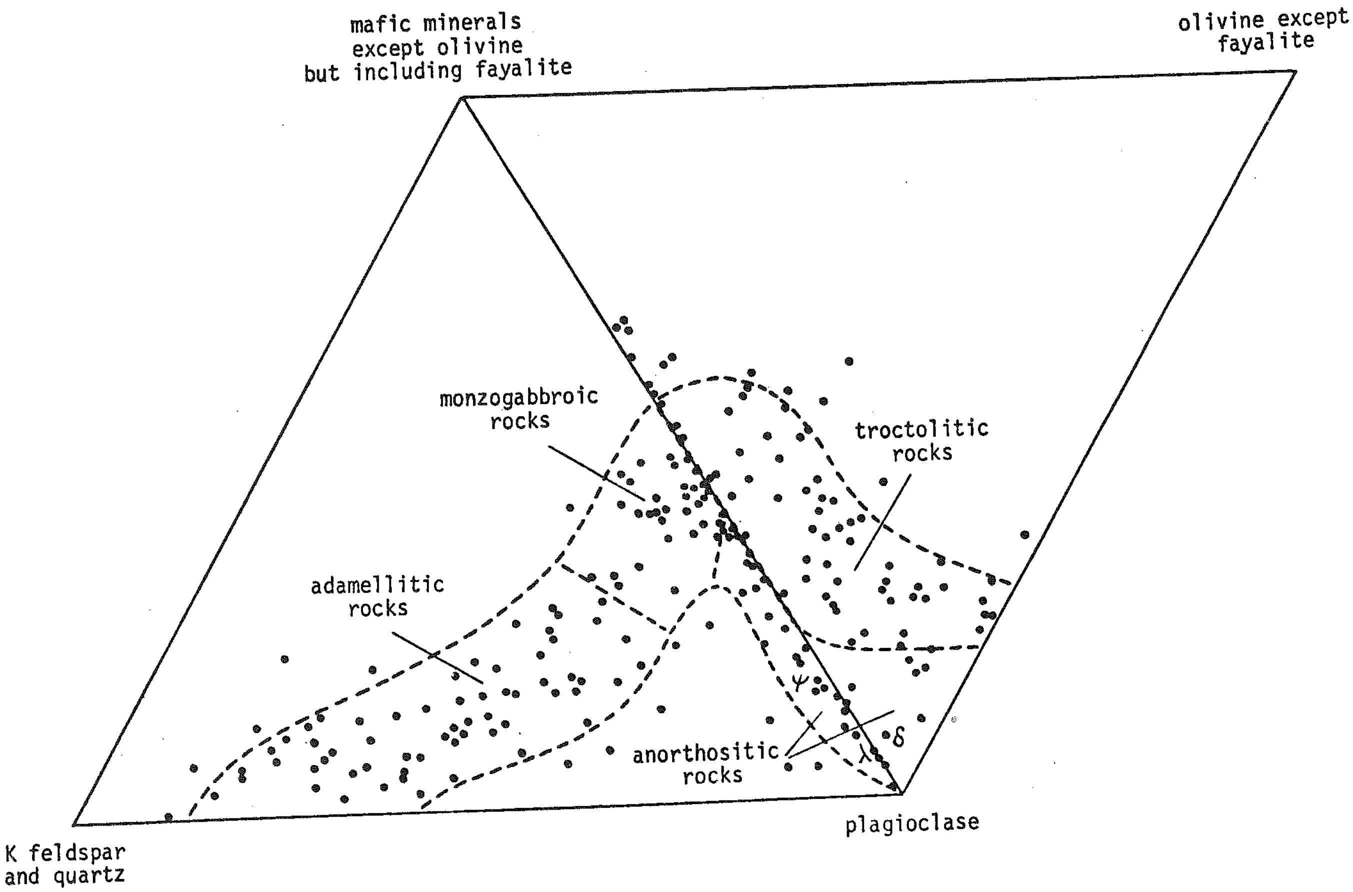

Fig. 15. Compositional variation of rocks occurring in the Nain anorthosite complex. The diagram is based upon 206 published and unpublished modal analyses. The double triangle represents volumetric proportions of quartz plus K feldspar, plagioclase, mafic minerals minus olivine except fayalite, and olivine minus fayalite. Fayalite is here excluded from olivine as it substitutes for iron-rich orthopyroxene in quartz-bearing rocks. There is an almost continuous distribution of compositions from adamellitic rocks, through monzogabbroic rocks, to anorthositic and troctolitic rocks. Dashed lines between these fields indicate the general area of overlap and transition between rock groups. In the field of anorthositic rocks compositions are shown of buff-weathering (ψ), pale (λ) and dark (δ) facies anorthosite. Modal compositions of gabbroic rocks are lacking; their field would lie near the boundary between the troctolitic and monzogabbroic groups.

NAIN COMPLEX: CONTACT ZONES OF ANORTHOSITE AND ADAMELLITE

PLUTONIC AND METAMORPHIC ROCKS OF IKKINIKULLUIT HEADWATERS

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Cornell University[1]

Introduction

The field work of 1972 in the Ikkinikulluit area (FR 1972, p. 65-70) failed to close the gap between previous coastal and interior geologic mapping, and correlation between the rock units as mapped in the different areas was not obvious. Therefore a special effort was made in the 1973 field season to close the gap. An upland camp was established by air lift from which the previously mapped areas were accessible.

The area of operation proved to be a complex zone between major rock units: anorthosite to the east, basement rocks to the north, and adamellite to the west. The resulting pattern of rock-unit distribution is so irregular that many details of occurrence and relationship must be symbolized in a reconnaisance map at the scale of Fig. 16. To indicate areas of minor inclusions or intrusions, small rock-unit symbols are interspaced with the larger symbols of what is judged to be the prevailing unit in a given area. More detailed work will doubtless necessitate some shifting of even major boundaries.

Petrology

The descriptions of the map units given in FR 1972, p. 65-67 require some modification and amplification on the basis of laboratory work and additional field work.

Table 2 gives tentative field criteria for recognition of the principal units.

Basement complex. Cordierite is widely distributed in the basement rocks of the present map area, and they are presumably in large part of sedimentary origin. The prevalance of cordierite dissipates any suspicion that these rocks might be layered fragments of the plutonic complex. Table 3 , Columns 1 and 3 give modal analyses of cordieritic rocks in

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

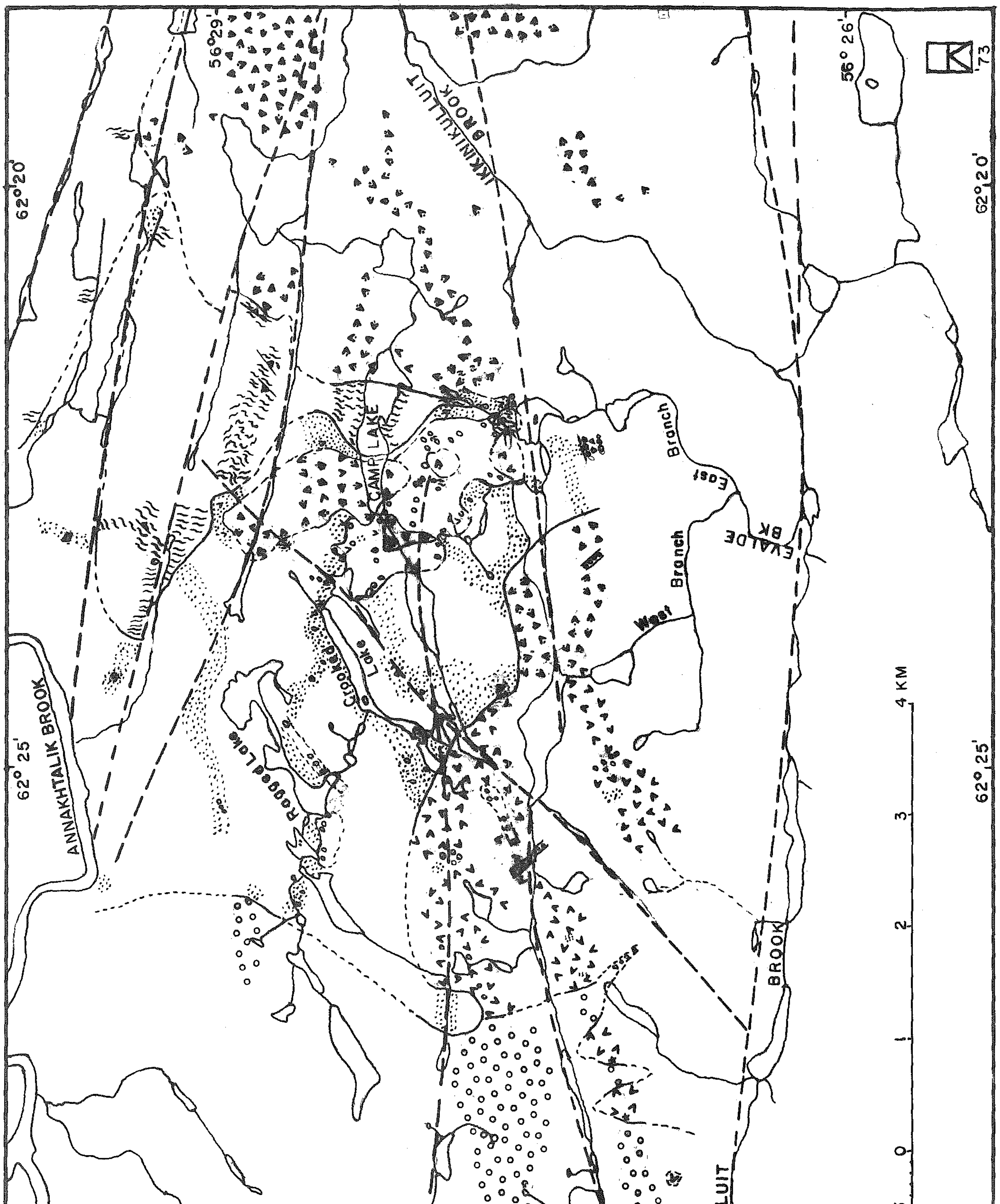
ANNAKHTALIK BROOK
CAMP LAKE
Crooked Lake
Ragged Lake
IKKINIKULLUIT BROOK
IKKINIKULLUIT
BROOK
East Branch
West Branch
EVALDE BK
62°20'
62°25'
56°29'
56°26'
'73
0
.5
1
2
3
4 KM

Fig. 16.

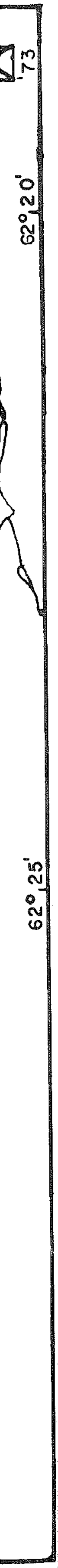

Fig. 16. Geologic sketch map of Ikkinikulluit Headwaters

Explanation

* Mafic end-stage derivatives of ovoidal rapakivi

Ovoidal rapakivi

Intermediate rocks

Buff-weathering anorthosite

Pale anorthosite

Basement complex

Rock unit boundary, determined and inferred

Foliation or layering, dips greater than 45° and less than 45°

Linear

Small unbounded rock unit symbols within the area of larger bounded rock units indicate small inclusions or intrusions

Table 2. Field criteria for major rock types in the Ikkinikulluit headwaters area.

Feature	Pale Anorthosite	Buff-weathering Anorthosite	Intermediate Rocks	Ovoidal Rapakivi
Grain Size	Medium to very coarse	Medium to very coarse	Medium. Few 1-cm megacrysts	Ovoids to 4 cm
Fresh Color	Pale gray to white	Dark charnockitic greenish to brownish gray	Moderate gray feldspar	Dark charnockitic greenish to brownish gray
Bleach Color	Pale gray to white	Variable medium gray	Pale gray	Ovoids bleach pale gray to pinkish
Pale Minerals	Blocks and laths of feldspar. Long cleavage reflections	Blocks and laths of feldspar. Long cleavage reflections	Short blocks of plagioclase	Ovoids most prominent. Give equant cleavage reflections
Mafics	Low pyroxene	Medium to coarse subophitic crystals	Intergranular to allotriomorphic granular	Medium-fine-grained interstitial aggregates
Weathering Character	Fresh, even to local retention of glacial polish	Angular shards	Glacial surface retained	Ovoid pebbles

and near this map area.

The garnet in Column 3 occurs as residual cores in the cordierite. In the Voisey Bay area (56-15 N, 62-10 W), myrmekite-like plumes of cordierite with vermicular orthopyroxene penetrating the garnet have been found at a suitable distance from the anorthosite-adamellite complex in the pale garnet granulite formation (Wheeler, 1955, Fig. 6 opposite p. 1051). Such data and the field associations point to derivation of the cordieritic rocks from the pale garnet granulite formation that extends northward from Voisey Bay west of the anorthosite. Thus on the geologic map of Labrador by the Government of Newfoundland and Labrador (1972), the cordieritic rocks represented by the yellow A?Wr rock unit on Annakhtalik Brook (56-30 N, 62-30 W) are the contact metamorphosed equivalent of the green A?Wy unit farther west. It seems likely that the same equivalence exists elsewhere in the region.

Enderbitic granulites were suspected in the field and their presence is corroborated by modal analysis 2, Table 3 . Similarly some layers appear to be noritic in composition in the field. One near anorthosite has medium-grained granoblastic texture but megacrysts of iridescent plagioclase. The iridescent plagioclase in this layer indicates it is probably an anorthositic intercalation in the paragranulite series, but other layers that appear to be noritic do not necessarily have the same origin. Locally the granulite is high in mafic minerals, but ultramafic material has not been recognized.

Anorthositic rocks. Anorthosite as a field name is used in a very wide sense, including rocks that may contain over 20% dark minerals, especially in the buff-weathering facies. In the present map area the mafics in pale-facies anorthosite are locally abundant enough to define a clotted fabric (Wheeler, 1955, Fig. 3 opposite p. 1050). They are generally finer grained than the feldspar, and giant pyroxenes appear to be less common than in the pale anorthosite farther east. Petrographic studies of pale anorthosite have yielded confusing results, perhaps because they do not fit preconceptions. The facies remains a field concept including rocks that weather with a pale, sound, marble-like surface.

Table 3. Modal analyses, Ikkinikulluit area.

Mineral Data	1	2	3	4	5	6	7	8
Plagioclase	33.5	41.5	29.6	88.5	68.4	82.6	78.4	34.9
K-feldspar	2.6		7.7	1.4	0.4	1.3	2.0	32.8
Quartz	5.4	20.8	0.5	0.6	0.2	1.3	0.7	21.9
Olivine								3.9
Orthopyroxene	15.4	26.5	1.2	5.0±	25.5±	9.0±	9.0±?	
Clinopyroxene		P		2.0±	5.0±	4.0±	7.3-?	5.0
Hornblende								0.3
Biotite		0.2	0.7		0.1	0.4	0.9	
Opaque	<0.1	1.3	1.6	0.3	0.2	0.9	1.4	1.0
Graphite	3.9		P?					
Apatite		<0.1	0.1?	0.2	0.2	0.3	0.3	0.2
Zircon	P?		<0.1?					<0.1
Cordierite	32.4		49.9					
Garnet			0.2					
Spinel	<0.1		3.4					
Alteration	6.8	9.7*	5.1	2.0		0.2		
Pc An meg				52±4	52±4	57±6	56±4	
ground	56	67±11	37	43±4	50±3	51±5	49±8	32
dark rods				P		P	P	
antiperthite	S	S	S	P		P	P	P
zoning				P		P	P	
Opx En	54	57	?	48±4	53-65	48?	40	
Stillwater				P	P		P	
Bushveld				P	P		P	
Cpx β		1.710			1.713		1.706	1.735
lamellae					P	P	P	
Max grain width	4.5Qz	2.8Qz	2.1Ga	20Pc	20Pc	10Pc	7 Pc	20Kf
AGI	.312	.230	.168	.783	2.30	.344	.441	.594

--continued

Table 3 Comments

* includes 4.2% amphibole from orthopyroxene and 2.3% carbonate.

AGI: Average Grain Intercept: a traverse length, generally about 100 mm, divided by the number of major-constituent grains encountered in the traverse. It, like the maximum grain width, is expressed in millimeters.

An: anorthite content of plagioclase.

Cpx: clinopyroxene.

En: enstatite content of orthopyroxene

Kf: K-feldspar.

Max: maximum, measured in hand specimen.

Meg: megacrysts.

P: present

S: sparse.

Column 1 is Specimen 2-1817, orthopyroxene-cordierite enderbitic paragranulite, 238/12 (Johannsen) from granulite zone east side 2.0 km north of Camp Lake outlet (56-28.8 N, 62-21.1 W). It is granoblastic, with mineral lumps, and two kinds of cordierite, one of which is poikilitically developed while the other forms mosaic grains.

Column 2 is Specimen 2-1816, enderbitic paragranulite, 238 (Johannsen) from granulite zone east side, 2.0 km north of Camp Lake outlet (56-28.8 N, 62-21.1 W). It is granoblastic, layered, slightly foliated, with poikilitic orthopyroxene.

Column 3 is Specimen 2-1833, cordierite melasyenodioritic paragranulite, 3212 (Johannsen) from north of lower Ikkinikulluit Brook (56-28.2 N, 62-14.4 W). It is granoblastic with cordierite lumps and rough layering.

Column 4 is Specimen 2-1804, buff-weathering anorthosite, 2/13/212 (Johannsen) from Ikkinikulluit lowest lake SW corner (56-27.9 N, 62-17.6 W). It is bimodal with subophitic texture.

Column 5 is Specimen 2-1805, anorthositic norite, 23/212 (Johannsen) from Ikkinikulluit lowest lake SW corner (56-27.9 N, 62-17.6 W). The texture is bimodal, very coarsely ophitic.

--continued

Table 3 Comments

Column 6 is Specimen 2-1808, noritic anorthosite, 2312 (Johannsen) from the massif top in Ikkinikulluit lowest lake south side (56-27.2 N, 62-16.8 W). The texture is bimodal, ophitic.

Column 7 is Specimen 2-1838, dioritic anorthosite, 22/312 (Johannsen) from north of Usighanyat north branch lowest lake (56-26.8 N, 62-15.8 W). It is bimodal, subophitic. Quartz is localized in the thin section, and may be low in the mode.

Column 8 is Specimen 2-1834, wiborgitic ferroadamellite, 227"/6" (Johannsen) from Annakhtalak Bay south shore near the bay head (56-27.5 N, 62-12.6 W). The field classification would be ovoidal rapakivi. Intergrown irregular plagioclase and K-feldspar crystals are in optical continuity, and myrmekite is common.

They are generally low in mafics.

Buff-weathering anorthosite shows a wide range of grain size and mafic content. Blocky feldspar megacrysts with ill-defined margins are common: the fresh rock is dark charnockitic gray. The finer grained, more mafic varieties contain perhaps as much as 20% pyroxenes and black oxides, and become difficult to distinguish from the rock unit called finer grained intermediate rocks. The anorthosites are perhaps distinguishable from these because they have more definitely subophitic, less granular pyroxene crystals between the plagioclase laths. Some very coarse patches contain plagioclases to 1 dm across. Such rocks rarely contain much pyroxene, and the pyroxene grains are usually smaller.

Locally, near the paragranulite, irregularly sinuous veins of graphite that taper to streaky tips occur in buff-weathering anorthosite. The absence of such concentrations in the granulites, from which the graphite is presumably derived, suggests that they are vein fillings or the result of some other concentrating process in the anorthosite.

Table 3 , Columns 4 and 5 give modes of typical buff-weathering anorthosite. Plagioclase megacrysts cause wide variations in modal analyses.

Petrographic study of these and other specimens of buff-weathering anorthosite from the Ikkinikulluit region suggest the following features are characteristic of the group:

1. Rounded apatite crystals over 0.4 mm across. Cumulus?
2. Orthopyroxene with En less than 55.
3. Accessory quartz. (Larger concentrations accompanied by carbonate.)
4. Accessory interstitial K-feldspar.
5. Turbid alteration of plagioclase (saussurite?).
6. Fibrous alteration of orthopyroxene (amphibole and biotite?).
7. Low proportion of clinopyroxene among the mafics.
8. Plagioclase with wide range of An values.
9. Zircon accompanying concentrations of quartz-carbonate.
10. Stillwater exsolution lamellae in orthopyroxene.

These features are not universally present in the specimens examined, but the list should prove useful in efforts to define the characteristics of the different anorthosite facies.

Dark-facies anorthosite was not recognized in the present map area.

Intermediate rocks. This group was called finer grained diorite in FR 1972 (p. 67). However, the rocks appear to be part of a group in which K-feldspar and quartz, together or separately, are generally more prominent than in the anorthositic rocks and exceed 5% in some material. Therefore some more inclusive name than diorite seems indicated. They appear to form a group with compositions intermediate between anorthositic and adamellitic rocks. They form a zone between these rocks in the present map area, and apparently similar rocks do so in other parts of the Nain region. Thus from several points of view they are intermediate between the two groups, and are designated as intermediate rocks in this note. It is not necessary that they fall within the 54-65% silica range specified for intermediate igneous rocks in the Glossary of Geology. One could designate certain rocks as intermediate in a group of rhyolites, or of basalts, that obviously would not fall within such limits. They may prove to be analogous to the rock group called monzogabbroic by de Waard in this Field Report (p. 42). Rocks of this group are much more abundant in the present map area than in the 1972 map area (FR 1972, Fig. 13, p. 66).

Modal analyses 6 and 7, Table 3 are of rocks from the 1972 area. Preliminary work on rock powder from an even-grained specimen within the 1973 map area indicates a rough mode of plagioclase with minor K-feldspar 65%, orthopyroxene 20%, clinopyroxene 10%, opaque with a little apatite, pale amphibole and biotite 5%. The plagioclase is chiefly An41±4, possibly with a little as calcic as An56. Orthopyroxene is En46 and clinopyroxene 100En/En+Fs ≈ 64 (β = 1.702). There appears to be little variation in the composition of the pyroxenes. These data suggest there may be a considerable composition range in the group as a whole, even in the Ikkinikulluit area. Detailed study of material collected in this area and comparison with similar rocks in other parts of the Nain Complex should give information about the extent of such variations.

The intermediate rock group is characterized by medium grain and intergranular texture. The short blocky feldspar crystals show up well on bleached surfaces, but on fresh surfaces the dark gray of the feldspar and the granular character of the pyroxene make the blocky forms less obvious. Commonly there are cleavage reflections from a poikilitic dark mineral, perhaps orthopyroxene, several centimeters across.

Even-grained texture occurs, but is rare. Generally megacrysts to several centimeters across are present. Some of these are single blocky dark plagioclase crystals that look like anorthositic plagioclase. More frequently they are pale "maggots" that appear to be compound feldspar crystals with small dark inset grains, suggesting the pearly megacrysts in adamellitic rocks. They may be widely scattered, or aggregated into tapering streaks suggesting accumulations along flow lines. Rarely dark minerals form aggregate streaks or small clusters. Distinct thin layers of dark minerals are even less common.

Weathered surfaces commonly retain their glaciated form though any polish they may have had is lost. Below this surface there is a thick zone of rust-stained and friable material, and entirely fresh rock is hard to find.

Adamellite complex nomenclature. Like the term anorthosite, adamellite has been used very loosely in discussing rocks of the Nain plutonic complex. This situation can be rectified to some extent while at the same time calling attention to the close parallelism between certain rocks of the Nain region and Scandinavia in composition, texture, and field characteristics. Rapakivi is a Finnish word meaning disintigrating rock. It became applied to Precambrian, post-tectonic, granitic rocks characterized by the ease with which they disintigrate into rusty grus.

Many of the so-called adamellites of the Nain region fit this definition, but do not fall within the compositional limitations imposed by the Johannsen classification, to which I try to conform, at least when convenient to do so. Thus use of the term rapakivi, where applicable will avoid ambiguity and at the same time emphasize significant peculiarities of the rock. Adamellite would remain applicable where petrographic analysis justifies its use. Ultimately, when the petrography of the Nain plutonic complex is sufficiently well known, the Johannsen nomenclature might be used to the exclusion of the term rapakivi, and rapakivi might be retained only as a field term.

Rapakivis have been subdivided on the basis of texture. So many of them contain ovoidal K-feldspar megacrysts that the term rapakivi alone is often used for such rocks. Wahl (1925, p. 24) notes that there are types of rapakivi in which the ovoids are lacking, and this is thought to be the case in the present map area. It therefore seems desirable to be precise and use the term <u>ovoidal rapakivi</u> where the ovoids occur.

Rocks in which the ovoids are mantled by plagioclase were called wiborgite by Wahl (1925, p. 24) after the city of Wiborg, Viborg, or Viipuri (depending on the language of the writer). He defined wiborgite on the basis of texture and Sederholm (1928, p. 88) took exception to the name partly because the definition of igneous rock names is customarily based on composition rather than texture. The texture occurs in the Nain region as well as different areas in Scandinavia, and Wahl (1925, p. 6) mentions other parts of the world where it is found. Thus it is a general phenomenon deserving nomenclatural recognition. If we speak of <u>wiborgitic texture</u> instead of wiborgite, it will be possible to retain a precedent without straining the principles of igneous rock nomenclature. This usage also accommodates the fact that the granitic rocks with K-feldspar ovoids may have fayalite and clinopyroxene as the mafic minerals in Scandinavia (Savolahti, 1962, p. 43) and Labrador (see the next section) instead of the hornblende and biotite indicated in Wahl's description (1925, p. 55). Though the native spelling of the name was Viborg, Wahl's original German-text spelling of wiborgite (pronounced with a v) has precedence.

<u>Ovoidal rapakivi</u>. These rocks contain abundant ovoids of K-feldspar to 4 cm across, studded with granules of light and dark minerals. The groundmass between the ovoids is a medium-grained aggregate of feldspars, quartz, pyroxene, olivine, and hornblende. The mafic content of the whole rock is not high because the ovoids are so abundant. The minerals are difficult to recognize in the field, and this summary is based on

microscope study of similar rock from the south side of upper Annakhtalak Bay (south side) (56-26 N, 62-12 W). The mode of a rock from there is given in Table 3 , Column 8. The section shows wiborgitic texture which is detectable in the field only under the most favorable conditions.

The fresh rock is charnockitic gray and few minerals are recognizable in it. Even the ovoids are dark so that it resembles megacrystic buff-weathering anorthosite. The megacrysts are more blocky in the anorthosite. Commonly steep surfaces weather to a rich orange brown, very rough and disintigrating, while flatter surfaces are covered by a grus in which the ovoids dominate. They bleach pale gray to faintly pink.

Locally the ovoids are not well developed. Instead, there are leucocratic areas several centimeters across between which there is a reticulation of more mafic material. The mineralogy does not appear to differ from that of the ovoidal rapakivi, and this rock may tentatively be called reticulate rapakivi.

Locally mafic material appears to be highly concentrated and ovoids are lacking. Some pockets appear to be very mafic. R. E. Hodgson examined such material in refractive index liquids. His rough estimate of composition was plagioclase An43, 40%; blocky antiperthite 6%; clino-pyroxene 100 Mg/Mg+Fe =28, 35%; olivine Fo 10, 5%; brown hornblende 4%; magnetite and other opaques 10%; traces of apatite, large zircon crystals, and biotite. The high Fe:Mg ratio indicates advanced differentiation, implying a late-stage crystallization. The rock occurs in anorthosite at and near contacts with ovoidal rapakivi towards the southwest edge of the mapped area. Similar rocks with similar relationships have been found in other parts of the Nain complex.

Structural Relations

Basement rocks form a tongue on the east side of the complex zone between the main mass of buff-weathering anorthosite on the east and the ovoidal rapakivi on the west. The tongue tapers southward and ends in the divide region between Evalde Brook and the lower end of Camp Lake (56-28 N, 62-22 W). It is flanked by the main buff-weathering anorthosite body along most of its east side, and where foliation attitude has been measured in the granulite near this contact, it is near parallel to the contact trend. A few granulite inclusions have been recognized in the buff-weathering anorthosite east of the granulite zone.

Some buff-weathering anorthosite occurs west of the granulite tongue, but the two are generally separated by a zone of the intermediate rock which is wide in some places, but narrow enough to approach the vanishing point at others. It appears to wrap around the tip of the granulite zone, and contains recognizable granulite inclusions at many places.

Iridescent plagioclase in a noritic layer of the granulite indicates anorthositic material is interlaminated with the granulite, but no transgressive anorthosite was noted in it.

There is a suggestion that the buff-weathering anorthosite underlies the granulite zone in the east-draining gorge 0.7 km north of Camp Lake (56-29 N, 62-22 W), but its walls have only been seen from the ridge tops, and a treverse up the gorge is needed to confirm long-range appearances.

A traverse part way across the granulite zone 1 km north of Camp Lake (56-29 N, 62-22 W) shows a progressive change in the character of the layering. On the west side of the zone it appears to be extensively fragmented and disoriented. The rock is too rusty to determine readily if this is an agmatite of granulite invaded by the west-boundary intermediate rock. The latter contains numerous granulite inclusions near the granulite zone, and the prominent rusting suggests intermediate rock may well be present. Layering has become continuous and rusting minor 500 m from the west margin of the granulite, but it is contorted into great swirls with axial planes that do not appear to have a uniform attitude. The layering has become essentially uniform at 800 m from the west margin, with attitude 048Az, steep west, and a little farther east the dips are steep easterly. At the east margin, layering is also uniform with northeasterly strike and steep dip. The intervening zone has not been examined. This apparent gradation in layering character suggests the need for a detailed structural study to determine its exact nature and cause.

The main body of pale anorthosite lies towards the west side of the complex zone. Eastward, the only occurrence of pale anorthosite is as inclusions in the buff-weathering facies. Thus here pale anorthosite is older than buff-weathering anorthosite, though the inclusions may well be cognate, and the age difference not large.

Besides the pale-facies inclusions in buff-weathering anorthosite, there are also indistinct, raft-like masses of very coarse anorthosite in coarse noritic anorthosite. Inclusions of finer grained anorthosite in coarser, such as those described by de Waard (FR 1971, p. 20) were not noted in this area.

Relations between intermediate rocks and anorthosite are ambiguous. At some contacts, as at the southwest end of Crooked Lake and the lake below it (56-28 N, 62-25 W), the intermediate rock appears to be a little finer grained near the contact, possibly showing faint foliation or layering parallel to it. Here the anorthosite is thought to be the pale facies, but with characteristics obscured by contact effects of the intermediate rock.

North of the middle of Camp Lake (56-28 N, 62-22 W), definite inclusions of buff-weathering anorthosite occur in the margin of intermediate rock. In other areas, as around the head of Camp Lake (56-28 N, 62-23 W) and 1 km NE of Crooked Lake (56-29 N, 62-23 W) it is often difficult to decide whether a given rock is buff-weathering anorthosite that is finer grained and more mafic than usual, or intermediate rock that is coarser and less mafic than usual. Difficulty in finding boundaries between rocks that appear to belong on either side of this dichotomy suggests that the change between them is gradational. More detailed work on suites of specimens across such zones is indicated.

Ovoidal rapakivi occurs near the south tip of the granulite wedge, but has not been found cutting the wedge. It is undoubtedly younger than the granulite since it cuts younger rocks. Rocks of the adamellite group, if not ovoidal rapakivi, cut similar granulites elsewhere in the complex.

Definite dikes of unchilled ovoidal rapakivi are not uncommon in the anorthosite. They undoubtedly occur in buff-weathering anorthosite, and are thought to occur in pale anorthosite also.

Here again there is a suggestion that the characteristics of pale anorthosite are modified by contact effects of ovoidal rapakivi. On several traverses from pale anorthosite to ovoidal rapakivi, the anorthosite seemed more like buff-weathering anorthosite as the rapakivi was approached. Since the rapakivi is clearly the younger rock, systematic changes in the anorthosite as the rapakivi is approached are more likely to be products of rapakivi action than inherent in the anorthosite.

There is no question that but unchilled ovoidal rapakivi forms dikes cutting intermediate rock in many places throughout the complex zone. At the contact between these units 2.15 km southwest of Ragged Lake (56-28 N, 62-27 W), the ovoidal rapakivi forms an agmatite with included angular blocks of intermediate rock. Some of these blocks have curved outlines indicating they were at least slightly plastic when the agmatite formed, though brittle enough to break into angular fragments at their point of origin. Some of the ovoidal dikes in the intermediate rock near this contact form raised, weather-resistant surfaces, and the rock might better be called ovoidal granite.

Layering is occasionally detectable, especially in rock-fall blocks, but is rarely well enough developed to measure. It has been suspected in buff-weathering anorthosite, and definitely observed in the intermediate rock. None has been observed in pale anorthosite or ovoidal rapakivi. Deep weathering in the latter would make it especially difficult to detect, even if well-developed.

Linears

Numerous linears cross the map area and affect the topography profoundly. Most of them appear to be segments of major linears belonging to the linear family that approaches east-west in the region from north of Nain perhaps to Davis Inlet, or even farther south. Lateral displacement up to several kilometers has been demonstrated along some members of the family, but the linears in the present map area do not appear to have affected the geological boundaries appreciably. Possibly the complexity of the geology hides their effect. At the few places where bedrock could be found along their course, neither diabase nor indications of faulting were encountered.

The well-exposed walls of the east-west gorges in the area occasionally show prominent fracture sets crossing them at high angles, and producing little topographic effect. This suggests that linears approaching east-west are disproportionately emphasized by their near approach to parallelism with the direction of Pleistocene glacier movement, promoting ice erosion along them.

Discussion

Probably the greater confusion of rock units near Camp Lake portrays the character of the complex zone between major anorthosite and rapakivi units better than the apparently simpler conditions farther from the lake. The coverage near camp was more detailed because all long traverses started from there, and numerous short traverses were made in that area when weather was not suitable for long traverses.

There is a clear time sequence among the rock units of the area. Listed from the oldest to the youngest they are: 1, Basement granulite. 2, Pale anorthosite. 3, Buff-weathering anorthosite. 4, Intermediate rock. 5, Ovoidal rapakivi. In contrast to this clear sequence, there are zones in which evenly medium-grained intermediate rock grades towards ovoidal rapakivi by increase in number and size of "maggots", and their development into more recognizable ovoidal form, and other zones in which the intermediate rocks appear to grade into buff-weathering anorthosite. Also anorthosite-like plagioclase megacrysts definitely occur in the intermediate rock.

It appears that the intermediate rock is in some way a derivative of the buff-weathering anorthosite, and a progenitor of the ovoidal rapakivi. As a working hypothesis to account for these relations, one might assume that anorthosite formed in a magma chamber by concentration of plagioclase crystals. If we assume that the plagioclase crystals floated, this might account for lack of layering in the anorthosite. There must have been enough movement during or before this stage for incorporation of the pale anorthosite inclusions in the buff-weathering facies. Subsequently an accumulation of K-feldspar crystals developed in the residual magma. It is difficult to account for separate accumulations of K-feldspar and plagioclase unless one floated and the other sank. The plagioclase would be the one to sink, contrary to the suggestion above, possibly because the magma density had decreased by this time. At this point, the residual magma, from which much of the K-feldspar and more calcic plagioclase had crystallized, rose to higher levels, entraining some of the plagioclase and K-feldspar crystals. It was chilled enough to crystallize with a finer grained texture. It was followed by the final mush with a large content of feldspar ovoids and a high iron:magnesium ratio in the interstitial liquid. It penetrated both the anorthosite and the finer grained intermediate rock.

It is to be hoped that petrographic and chemical studies of material collected from these rocks and other parallel suites in the Nain region will result in a more satisfactory hypothesis to explain their origin and relationships.

Acknowledgements

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ANORTHOSITE-ADAMELLITE CONTACT ON DOG ISLAND, LABRADOR

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Introduction

Field research dealing with the contact relationships between anorthositic and adamellitic rocks, was initiated last year in the northern part of Dog Island (de Waard, FR 1972, p. 37-41), and was continued this year with observations on contacts in the central and eastern parts of the island. The results of the field study are shown in Fig. 17. It is of interest that in the mapped area the anorthositic and adamellitic rocks were found to be not in direct contact with each other, but separated by an 'intermediate' rock type.

Rock units

Based on field characteristics, the following rock units are recognized in the map area:

1. Anorthositic rocks, which include anorthosite, leuconorite and leucogabbro, commonly containing megacrysts of dark plagioclase. Thin sections of specimens collected in 1972 show that intercumulus quartz and K feldspar may be present.

2. The 'intermediate' rock is a fine to medium grained dark rock, consisting largely of plagioclase and pyroxene, but also containing K feldspar or quartz, or both, commonly in more than trace amounts.

Last year the term fine-grained norite was used for this rock, which is incorrect, because thin sections have shown that orthopyroxene is commonly not the predominant ferromagnesian mineral. Also the quartz and K feldspar content varies from place to place to the extent that rock compositions range from gabbroic to granodioritic. The use of the term "intermediate" for this rock is appropriate as far as its location between anorthosite and adamellite is concerned, but inappropriate with regard to its composition, since this rock has a considerably higher mafic mineral content than either anorthosite or adamellite. The rock will be

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

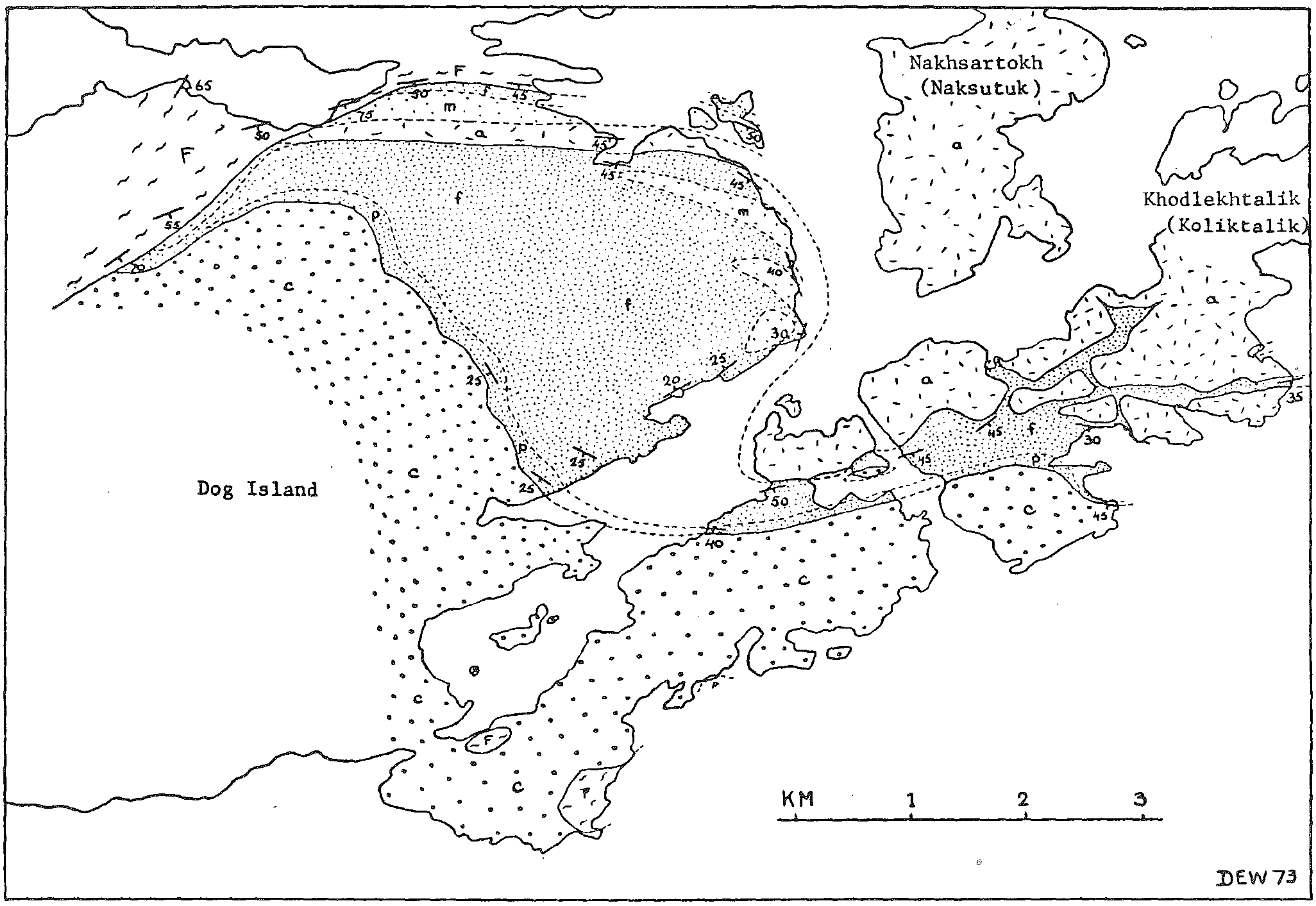

Fig. 17. Map showing contact relations between anorthositic, monzogabbroic, and adamellitic rocks in the eastern part of Dog Island and adjacent islands.

Explanation: F: Ford Harbour Formation, country rock consisting of interlayered enderbitic and mafic granulites; a: anorthositic rocks, including anorthosite and leuconorite, commonly containing dark plagioclase megacrysts; m: medium-grained leuconoritic rocks, locally containing dark plagioclase megacrysts; f: fine to medium-grained, dark, gabbroic to granodioritic rocks, locally containing large, dark plagioclase crystals, or locally having a porphyritic or cumulophyric texture with phenocrysts or clusters of grains of plagioclase, of K feldspar, or both; p: porphyritic 'monzogabbro', i.e., monzogabbroic rocks with abundant ovoidal phenocrysts or clusters of grains of plagioclase and K feldspar; c: coarse-grained quartz-feldspar rock of granodioritic to adamellitic composition, containing ovoidal feldspars or clusters of feldspar grains, and large, round quartz grains.

referred to here as monzogabbroic, after the probable center of the distribution of its petrographic varieties. The name also stresses the abundance of pyroxene in the rock, and its gabbroic appearance. A similar rock group is discussed by Wheeler (this FR) under "Intermediate Rocks."

Besides homogeneous monzogabbroic rock, which may have locally a streaky appearance due to concentration in layers of mafic or leucocratic minerals, three other types can be distinguished, viz., (1) monzogabbro containing dark, 1 to 3 cm large plagioclase crystals; (2) monzogabbro containing spottily distributed phenocrysts or clusters of grains of feldspars, either plagioclase, or K feldspar, or both; (3) porphyritic monzogabbro in which abundant ovoidal phenocrysts or clusters of grains of plagioclase and K feldspar occur in a fine-grained, dark, matrix. In the field, areas consisting largely of porphyritic monzogabbro, and of monzogabbro with dark plagioclase crystals, were mapped separately from those areas containing the other two types of monzogabbro which generally occur intermingled.

3. The adamellitic rock is a coarse grained quartz-feldspar rock, containing 2 to 3 cm large, ovoidal feldspars or clusters of feldspar grains, and conspicuous, round quartz grains. Possible ferromagnesian minerals are biotite, hornblende, orthopyroxene, and fayalite. Hornblende commonly occurs in 10 cm large poikilitic crystals (in one place crystals up to 40 cm large were measured). The composition of the rock varies in the Nain area, and is probably mostly granodioritic on Dog Island.

Field Relations

The monzogabbroic rocks generally have intrusive relationships with the anorthositic rocks. The map shows large dikes of monzogabbro in anorthosite forming a mega-agmatite along the eastern part of the contact. In detail the contacts are generally sharply defined. However, there are also features which speak for a transition between the two rock types. Along the east coast of Dog Island, for instance, there are zones and lenses of a transitional rock occurring at or near the contact between monzogabbro and anorthosite. The rock is a medium-grained leuconorite, containing small amounts of quartz and K feldspar, and locally megacrysts of dark plagioclase. In the field the rock resembles the anorthositic rock with plagioclase megacrysts, but is finer grained with smaller and fewer plagioclase megacrysts. Mineralogically it seems to have a more sodic plagioclase than the anorthosite. On the other hand the transitional rock resembles the monzogabbro with the large, dark plagioclase crystals, which is finer grained and more mafic, but which occurs adjacent to it and is transitional with it.

The relationship between the monzogabbroic rock and the adamellitic rock is generally transitional within 10 to 20 meters. Typically, a zone of porphyritic monzogabbro occurs along the contact. The monzogabbro becomes increasingly porphyritic towards the contact, and grades into the porphyritic monzogabbro, which in turn grades into adamellite with the disappearance of the fine-grained matrix and the appearance of the conspicuous, round quartz grains. Poikilitic hornblende appears in about 3 cm size in the porphyritic monzogabbro, and increases in size to about 10 cm in adamellite. Although this contact appears transitional in a general sense, in detail there is abundant evidence for intrusive relationships between the two rock units. Near the contact, dikes of adamellite occur in monzogabbro and inclusions of monzogabbro are common near the contact in adamellite.

In summary, there is evidence for monzogabbro intruding anorthosite, and adamellite intruding monzogabbro, yet there are indications that all three units form one transitional sequence. This seeming contradiction may be resolved by assuming that the transitional sequence developed first, and was disturbed in a later phase, resulting in transverse relationships between neighboring units.

Structural Relations

Field relations show that the anorthositic rocks behaved structurally rigid with respect to the intruding monzogabbroic magma. The monzogabbro contains streaks of light and dark minerals, and schlieren of feldspar phenocrysts or clusters of feldspar grains, which have a consistent orientation in a given locality, demonstrating the direction of flow during intrusion. Fig. 17 shows that, according to flow structures, monzogabbroic rocks overlie anorthositic rocks at angles between 20° and 50°. The presence of flow structures indicates that the monzogabbro was in a state of thick crystal much during its emplacement.

In adamellite the evidence of flow is absent, except for a weakly developed orientation near the contact with monzogabbro. Even for numerous inclusions of various composition, which are common throughout the adamellitic body, show no discernible preferred orientation indicative of intrusive flow. This indicates that the rock was either a liquid or perhaps a thin crystal much during its intrusion, and crystallized undisturbed, or it may have been a thick crystal much in which little or no internal movement occurred during intrusion. The adamellitic body is the uppermost rock unit in the map area. It overlies at medium to low angle the relatively thin zone of monzogabbro which separates it from the anorthosite.

Conclusions

Three rock units are found in systematic order. The earliest to consolidate is overlain by the next, which in turn is overlain by the last to solidify. One possible interpretation is that the two intrusions are unrelated and occurred at different times. However, the general structural order, and the evidence of different structural mobility of the units, speak for a single magmatic event in which emplacement occurred of a monzogabbroic crystal mush and an adamellitic magma in an anorthositic environment. The presence of intermediate rock types, which form transitions between anorthosite and monzogabbro, and between monzogabbro and adamellite also indicates a congenetic relationship between the three rock units.

It may be argued that the order in which the rock units occur represents the sequence in which they were formed: a bottom layer of anorthosite, followed upward by a layer of monzogabbro, which was overlain by adamellite. If that was the case, external forces need to be invoked to disturb this order, to induce flow in the monzogabbro, and to inject it, downward, into anorthosite.

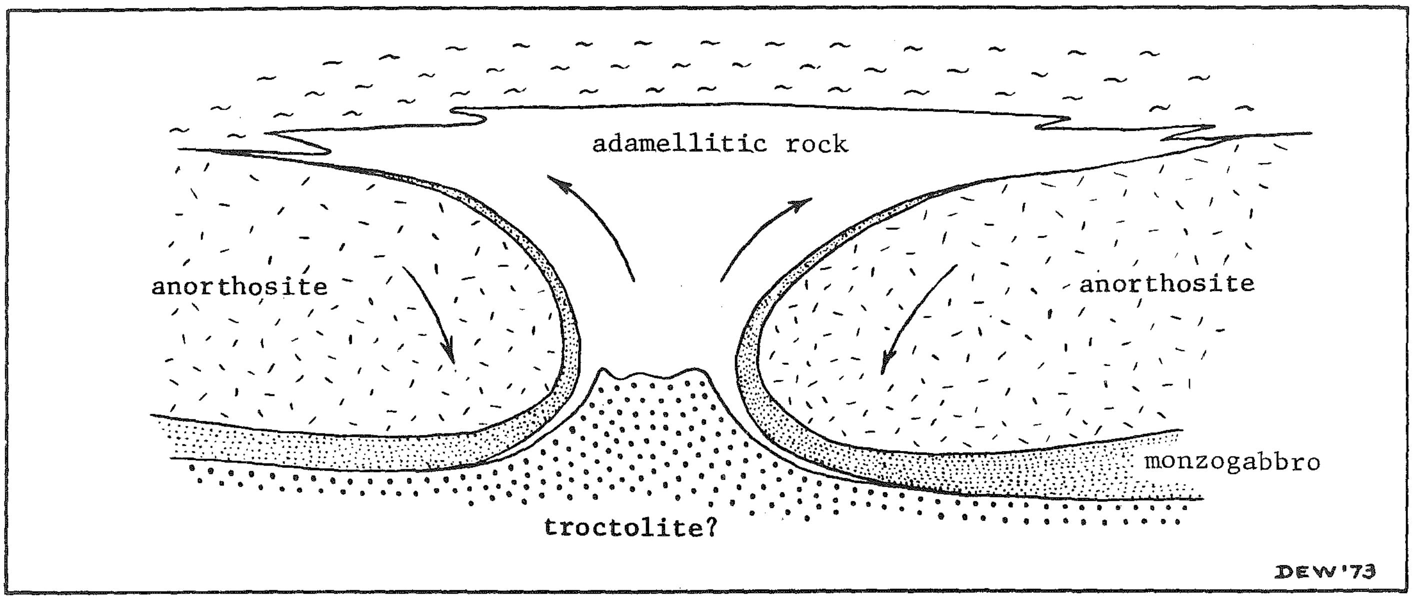

Fig. 18. Schematic section illustrating possible mechanism involved in producing structural relationships as found between anorthositic, monzogabbroic, and adamellitic rocks on Dog Island. Density instability caused overturn by subsidence of anorthosite masses and ascent of residual magma. The intermediate layer of crystal mush was dragged upward and smeared out along anorthosite contacts. Troctolite may form the lowermost unit.

The other possibility is that the order in which the rock units occur represents an inverted sequence, with solid anorthosite as the upper layer, followed downward by monzogabbroic crystal mush, and by adamellitic magma as the lower structural unit. In that case, the forces of deformation were of internal origin, caused by density overturn. The instability resulted from decrease in the density of magma during fractional crystallization. Large blocks of the heavier anorthositic rock subsided into the lighter adamellitic magma, which flowed upward between the blocks, dragging along and spreading out a thin, intermediate layer of monzogabbroic crystal mush (Fig. 18). The finer grain size of the monzogabbroic rocks may be indicative of the relatively cool environment in which the rock solidified. The adamellitic magma, having a lower temperature of crystallization, solidified after its emplacement in a relatively calm structural environment.

Acknowledgements

I thank Susan Hancock for superior assistance in the field, and for her share in evolving petrogenetic ideas.

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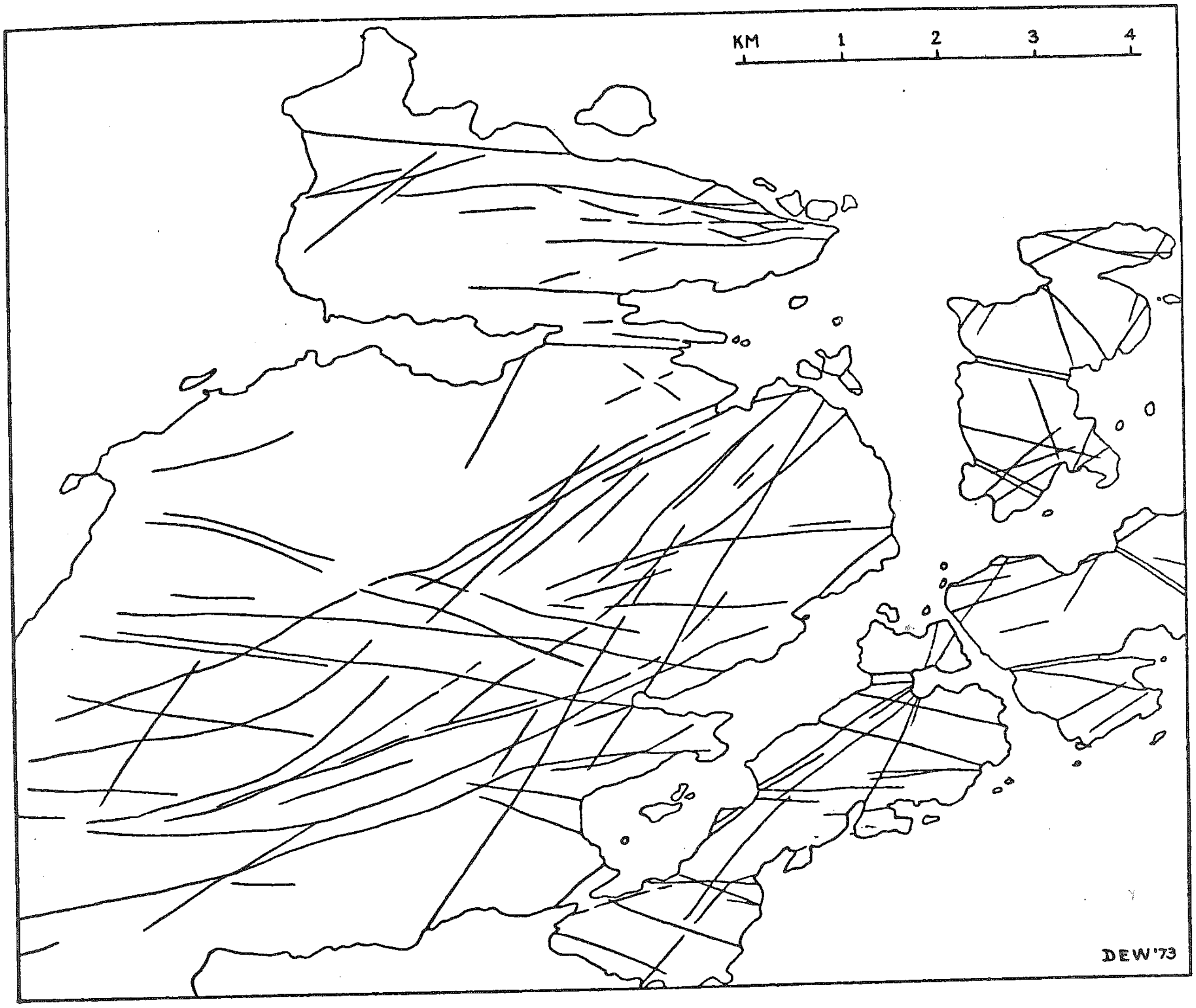

Fig. 19. Map of Dog Island and neighboring islands showing linears traced from aerial photographs.

Appendix: Linears of Dog Island

Air photos show a large number of conspicuous linears traversing Dog Island and the islands east of it (Fig. 19). Though linears occur throughout the Nain area they appear clearer and more abundant nearer the coast, because there is less overburden and vegetation. Linears are most sharply defined in the almost bare and rocky islands east of Dog Island. There is more overburden on Dog Island, and it is possible that the direction of Pleistocene ice flow produced here an effect on the pattern of linears.

In the topography the linears generally represent valleys and trench-like depressions. A search for the nature of the linears revealed that diabase dikes occur in about 10% of those observed. About another 10% were well enough exposed to prove that no dike material was present. The other linears were insufficiently exposed at the points of observation to determine their nature.

Linears of this kind may represent fractures with or without dike filling, and with or without displacement. Whereas considerable left-lateral strike-slip movements along E-W faults have been noted in the Nain area (e.g., de Waard and Mulhern, FR 1972, p. 72), no displacement has become evident in the geologic map pattern of Dog Island. The linears appear to transect all rock units, and contacts are not discernibly offset in the field or on the map. In a few cases it could be ascertained by the presence of heterogeneities in the rock, intersected by a well-exposed linear, that no displacement had taken place.

The map shows a predominance of E-W and NE-SW oriented linears. If these fracture sets are considered coeval, representing a conjugate system of shear planes, the maximum compressive stress would have been oriented ENE-WSW, or the maximum tensile stress NNW-SSE.

A more intensive study of the linears of Dog Island and neighboring islands is planned for next summer.

Appendix II: Modal compositions of monzogabbroic and adamellitic rocks of Dog Island

The following table shows modal and mineral compositions of specimens collected in 1972 on Dog Island.

The monzogabbroic rocks are subophitic, fine to medium-grained, and dark colored. DI-50-G, H, and D have a cumulophyric (maggoty) texture with small, sparse clusters of feldspar grains. DI-50-E has a porphyritic texture with large feldspar grains or clusters of feldspar grains. DI-50-D and E are coarser grained than DI-50-F, G, and H.

The adamellitic rocks are coarse grained and leucocratic, with abundant ovoidal feldspars and round quartz grains. DI-50-I occurs at the contact with porphyritic monzogabbro, DI-50-J was taken about 100 m from the contact, and 2-888, given here for comparison (de Waard and Wheeler, 1971, no. 15), was collected about 750 m from the contact.

Table 4. Modal analyses, Dog. Island.

	MONZOGABBROIC					ADAMELLITIC		
	DI-50-F	DI-50-G	DI-50-H	DI-50-D	DI-50-E	DI-50-I	DI-50-J	2-888
quartz	-	3.9	4.6	9.6	9.2	20.1	16.1	13.7
K feldspar	2.9	6.4	7.3	4.7	6.5	13.5	14.4	11.0
plagioclase	49.7	48.9	46.4	52.4	62.2	50.3	51.5	50.5
biotite	1.1	0.5	0.5	0.1	0.1	0.2	0.4	-
hornblende	0.5	4.1	6.0	1.1	3.8	6.4	9.5	6.2
clinopyroxene	11.9	16.2	17.5	13.0	2.9	3.0	1.9	6.6
orthopyroxene	23.7	11.6	8.6	9.4	8.6	2.3	2.0	6.7
apatite	0.8	1.1	1.2	2.0	1.3	1.0	0.5	1.1
zircon	-	-	0.2	-	-	-	0.2	0.1
calcite	0.1	0.3	0.1	0.4	0.3	0.6	0.2	0.1
opaque minerals	9.3	7.0	7.6	7.3	5.1	2.6	3.3	4.0
mafic %	47.4	40.8	41.7	33.3	22.1	16.1	18.0	24.8
An %	38.5 ± 1	38 ± 0.5	37 ± 1	42.5 ± 3	38 ± 1	37.5 ± 1	27 ± 1.5	18
En % op	37.5 ± 1.5	37 ± 1.5	38 ± 1.5	32 ± 1	36 ± 1	27.5 ± 1	22.5 ± 0.5	24
name	jotunite	opdalite	opdalite	opdalite	opdalite	opdalite	opdalite	opdalite

THE GEOLOGY OF THE LOWER KHINGUGHUTIK RIVER AREA

Stephen Brand
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Introduction

The lower Khingughutik (Kingurutik) Brook area is located approximately 60 km northwest of Nain, Labrador. Previous mapping of this area has been done by Wheeler (1942, 1960, 1968). The purpose of this study is to examine part of the buff-weathering facies of the Nain anorthosite massif. Emphasis is placed on establishing the relation of the present structural position of the buff anorthosite rocks to the overall petrogenesis of the anorthosite-adamellite complex. The area of interest, as mapped by Wheeler (1972), occurs at the western contact of the anorthosite and adamellite with the country rock. During 1973, the country rock, the anorthosite and the adamellite were mapped (Fig. 20) and systematically sampled in this region.

Country Rock

The country rock in the area is a gneiss characteristically having widely distributed garnet throughout. Not present in this area is the fine-grained granulite that occurs at some of the other contacts.

The occurrence of subhedral garnet in the major gneiss body varies. In the northern part of the body the garnets are more pronounced, larger (8-9 mm), and are highly disseminated through the outcrop. In the southern part of the body and in the other minor gneissic bodies the garnet is restricted to bands and the size of the individual crystals is smaller (1-2 mm).

Some layers of the gneiss consist almost wholly of quartz. Biotite is scarce and where present occurs as an accessory mineral. The foliation tends to be fairly uniform with steep dips and a northwest trend, parallel to the trend of the gneiss zone.

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

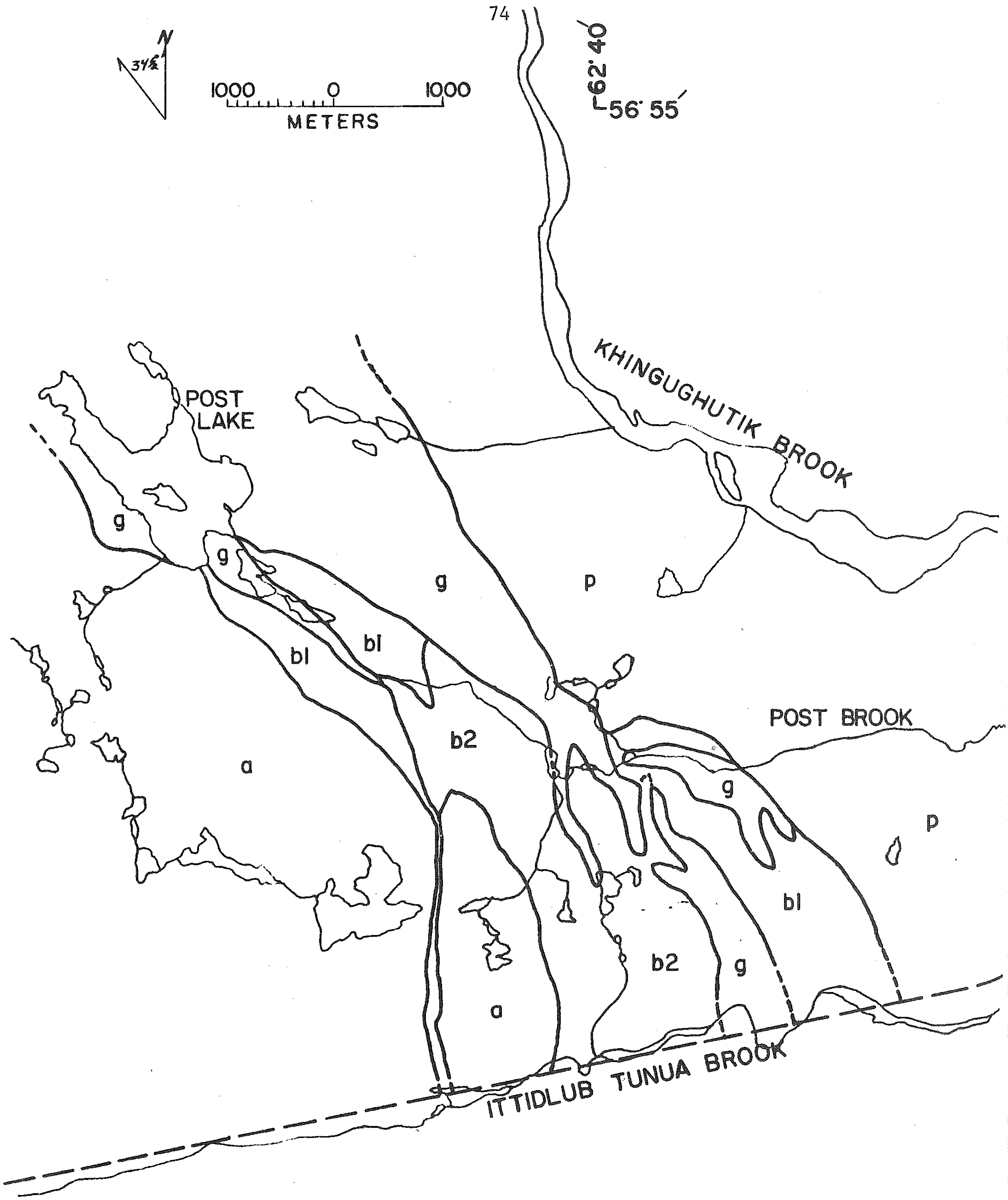

Fig. 20. General geology of the Lower Khingughutik Brook area, Labrador. KEY, from youngest to oldest: a, adamellite; b1, first phase of buff-weathering anorthosite; b2, second phase of buff-weathering anorthosite; p, pale anorthosite; g, gneiss. Large dashes represent possible fault.

Anorthosite Group

Two facies of anorthosite occur in the area: the pale facies lies on the eastern side of the gneiss body and the buff-weathering facies lies to the west of the gneiss body.

The pale anorthosite rocks are characterized by the marble-like whiteness of the weathered surfaces. The fresh surfaces are light blue-gray in color and show medium- to coarse-grained plagioclase. The mafic mineral content of most of the pale anorthosite is very low and locally the rock is almost completely devoid of mafics. The mafics that are present occur in subophitic texture.

Current work tends to indicate at least two phases of the buff-weathering facies. The earlier of the two phases (b1) is readily identifiable in the field. It has the distinctive buff colored weathered surface and a texture that is very similar to that of the pale anorthosite in the area. The plagioclase is coarse-grained and there is a relatively high percentage of subophitic mafics. The second phase (b2) of the buff-weathering facies tends to be buff colored on the weathered surface, but rust colored on a fresh fracture. This phase is very easily weathered, commonly disintegrating into a rusty gravel that is more characteristic of the adamellite than the anorthosite. This phase contrasts with the previously mentioned types of anorthosite. It is a fine- to medium-grained rock composed of plagioclase phenocrysts set in a matrix of plagioclase and scattered mafics which constitute over 20% of the rock. These mafics do not display the subophitic texture as in the other phase of the buff anorthosite; rather they have a granular texture. The color on a fresh surface is a dark charnokitic green and, using the color index as the guide, the rock is not strictly anorthosite. Instead, it is probably more of an anorthositic diorite or gabbro. Recognition of the anorthosite units is made using criteria similar to those of Wheeler (this report, Table 2).

Occurring within the buff anorthosite, especially near the adamellite contact, there are large strips of gneiss (see Fig. 20). The foliation in these gneiss strips tends to conform with the major gneiss body. Also conforming to the foliation direction of the gneiss is a slight foliation in the first phase (b1) of the buff-weathering anorthosite.

Adamellite

The adamellite has a light buff color on the weathered surfaces and except in limited areas, which is probably a function of freshness, is rust colored on the fractured surfaces. The grain size varies from fine to coarse with chilled margins occurring at the contact of the anorthosite and the country rock. On moving away from the contact to the west one finds an increase in the grain size and phenocrysts of feldspar become predominant.

At the contact with the anorthosite, quartz is not evident in hand specimen even on the bleached surfaces, but to the west, away from the contact, quartz can be seen in hand specimen.

Granitic dikes

In the northwestern part of the map area there are several northeast-southwesterly trending granitic dikes. They range from 15 cm to 2 meters in width. The dikes are light pink, medium-grained and contain quartz, K-feldspar and biotite which occurs as books in some of the dikes.

These dikes weather differentially faster than the rock type in which they are found.

General Relations

Evidence gathered through the season's field work indicates that the coarse-grained phase b1 buff-weathering anorthosite is older than the fine-grained phase b2 buff anorthosite. It must be noted that phase b2 may be a transitional or intermediate rock between the anorthosite and the adamellite similar to the intermediate rocks of the Ikkinikulluit area of Wheeler (this report, p. 54). Definite contacts were seen between the adamellite and the phase b1 buff anorthosite, but between the adamellite and phase b2 the contact is very obscure. Near or at the latter contact there is an increase in the rusty weathering and the rock becomes virtually impossible to identify in hand specimen. This contact appears to be more of a transitional zone between the two rock types (phase b2 - adamellite) than a definite contact.

Near the gneiss - b1 buff anorthosite contact at Post Brook in the southeastern area of the map there is graphite coating the joint surfaces. Occurrences like this are reported by Wheeler (this report, p. 53) in the buff-weathering anorthosite near the paragranulite in the Ikkinikulluit area. In one of the samples the graphite is disseminated throughout the anorthosite. Also within the same area of the map, except closer to Ittidlub Tunua Brook and in the b2 buff anorthosite, is positive evidence indicating that two ages of anorthosite -- pale and buff-weathering -- do exist. In this region one encounters inclusions of the pale facies in the buff-weathering facies.

Summary

It has been proposed by de Waard and Wheeler (1971) that a single magma may have formed both the troctolite-syenite suite and the anorthosite-adamellite suite, whereas Morse (1972) proposes a two-parent model; the anorthosite series being formed from a tholeiitic suite and the adamellite series forming from a calc-alkaline suite.

Further work is needed to determine whether the buff-weathering anorthosite is a possible basic member of a calc-alkaline suite (adamellite series), a fractionation product of tholeiitic suite (anorthosite) or a representative of both types of origin. It appears as though one can distinguish between the two models on the basis of field evidence; phase b2 buff-weathering anorthosite is transitional to adamellite. However, establishment of some method to distinguish between the two models by petrographic or chemical methods is needed.

Clarification of these problems should be provided by future laboratory research and field work on the buff-weathering anorthosite and the adamellite. This investigation will provide a rewarding basis for defining the relationship of the buff anorthosite rocks to the overall petrogenesis of the Nain anorthosite-adamellite complex.

A COMMENT ON FIELD RELATIONS AT IKKINIKULLUIT, KHINGUGHUTIK, AND DOG ISLAND

An onlooker's overview on the anorthosite/adamellite relationship may be permitted. Still lacking definitive Sr isotopic data, we have few constraints as yet on models for this relationship. Perhaps this is a good thing for the moment, as hypothesis continues to flourish from the field evidence. Much is made of the transitional yet transgressive contact relations between younger adamellitic rocks and older intermediate rocks, and so on back to anorthosite. Both de Waard at Dog I. and Wheeler at Ikkinikulluit describe convincing examples of transitional properties in rocks having clearly cross-cutting relationships. In addition, Brand suggests a transitional contact between an intermediate rock and adamellite in the lower Khingughutik Brook area. Although these descriptions are persuasive, problems arise with the fine grain size of intermediate rocks if these are to be consanguinous differentiates of a magma producing everything from anorthosite to ovoidal rapakivi.

Field evidence seems not to encourage the view that the various rock types could represent separate magma batches from the mantle. Nevertheless, this simplistic idea has some merit. In particular, it would permit certain intermediate (dioritic) rocks to be identical in bulk composition to buff-weathering anorthosite, yet differing in grain size due to timing and path from the mantle source. Some "transitional" similarities, such as those of plagioclase megacrysts in different units, could be a result of similar rather than identical processes. Transitional contacts could arise from partial or complete physical mixing of magmas where they came in contact. Xenoliths could be formed at the same time where an older magma had solidified sufficiently to fracture as a rock. Finally, the spectrum of rock types and their apparently close relationship in time could be a plutonic equivalent of an oft-noted volcanic phenomenon, namely the contemporaneous eruption of basalt and rhyolite. Yoder (1972) has discussed such occurrences and has offered the outline of a solution involving mantle melts only which has a credible experimental basis. The solution suffers, to some extent, from what may be called the "parking problem", in that an early rhyolitic melt must be stored (parked) somewhere while the source temperature rises toward the basalt solidus. The parking problem becomes a boon, however, in the case of ovoidal rapakivi, since a period of storage in mantle or crust would help explain the large size of K feldspar ovoids, and abrupt emplacement would explain the bimodality of grain sizes observed.

This is not the place to dwell on these matters, but it does seem appropriate to call attention to the opposite pole of speculation and to urge its evaluation along with the hypotheses which flow more directly (but not necessarily more convincingly) from the field evidence.

The Editor

GEOLOGY OF NUKASORSUKTOKH ISLAND

H. M. Davies

University of Massachusetts [1]

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Introduction

Nukasorsuktokh Island is located approximately 17 miles SE of Nain, Labrador at 56°21' N, 61°17' W. Previous work includes reconnaissance mapping of the island by E. P. Wheeler II and mapping of parts of the troctolite intrusion by S. A. Morse and J. A. Speer (FR 1971, p. 60-64). Petrographic work on board R. V. *Pitsiulak* in 1971 and 1973, as well as petrographic work by R. E. Hodgson, in the spring of 1973, was extremely helpful in delineating several ambiguous rock types which are discussed below and in FR 1971, p. 60-64.

A great variety of igneous and metamorphic rock types is exposed on the island. They may be categorized as follows: 1) metamorphic basement rocks of the Ford Harbour Formation, 2) anorthositic rocks, 3) troctolite of the Wyatt Harbour intrusion, 4) diorites and monzonites.

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

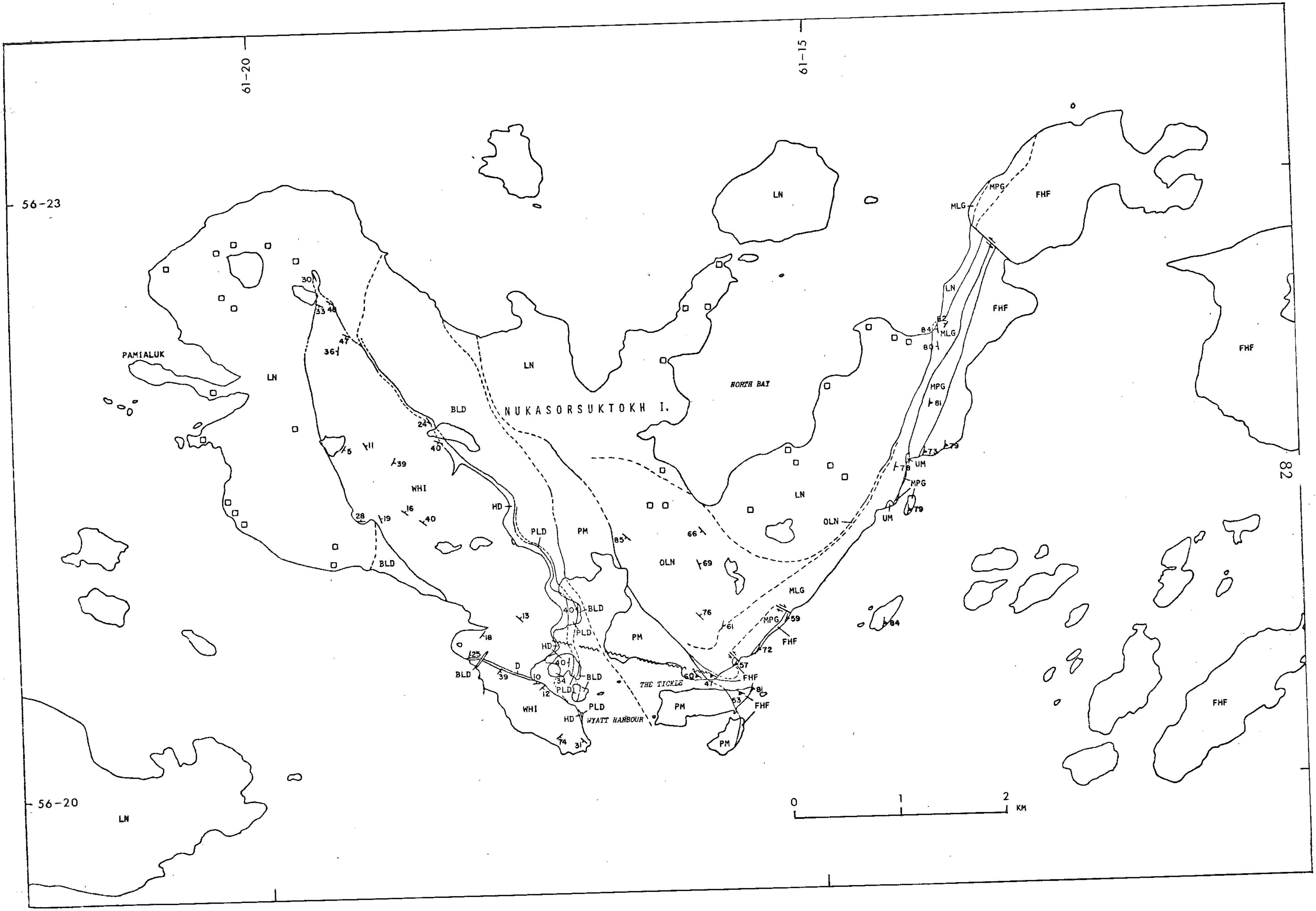
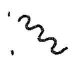


Fig. 21. Geologic map of Nukasorsuktokh I. Enlargements of this map are shown beyond.

Geologic Key for Fig. 21.

FHF	Ford Harbour formation
MPG	Marginal pyroxene granulite
MLG	Marginal layered gabbro
OLN	Olivine leuconorite
LN	Leuconorite
HD	Hypersthene diorite
PLD	Pale leucodiorite
BLD	Black leucodiorite
PM	Pyroxene monzonite
WHI	Wyatt Harbour intrusion
UM	Ultramafic body (pyroxenite)
D	Dike
	layering
	foliation
	shear zone
	fault
□	block structure

Nukasorsuktokh I. provides an excellent locality to study the relations between anorthosites, diorites and troctolites of the Nain Complex, within a limited, well exposed and easily accessible area.

Ford Harbour Formation

Granulite facies Archean rocks of the Ford Harbour Formation (de Waard, FR 1971, p. 16) are exposed along the eastern arm of Nukasorsuktokh I., and on islands to the east, and along the eastern side of two islands immediately south of The Tickle (Fig. 22). The predominant rock type is an enderbitic quartz-plagioclase gneiss containing minor pyroxene. This gneiss commonly contains pods and lenses several cm. thick of pyroxenite. Interbedded with enderbite are fine grained mafic pyroxene granulites 50-75 meters thick. Other rock types found were quartzite, amphibolite, aluminous granulite, and an ultramafic lens consisting of diopside, orthopyroxene, and plagioclase. The following mineral assemblages were noted in the aluminous granulites: cordierite-garnet, cordierite-pyroxene, cordierite-sillimanite-garnet, and garnet-hornblende.

The major structural trend of the Ford Harbour Formation is consistently NNE. Occasional kinks in the foliation have amplitudes of approximately 40-50 meters. Minor folds are common and have axial planes which parallel the major foliation and fold axes which are steeply plunging.

An exception to the dominant NNE trending foliation occurs along the southern shore of Nukasorsuktokh where an isolated wedge of basement rocks strikes NW. This area may represent a large fold in basement rocks whose foliation is conformable with the marginal anorthosite contact. This structural interpretation is shown on the map (Fig. 22). An alternate interpretation is that the wedge of basement rocks is a large inclusion in the anorthosite body. Both basement foliation and the anorthosite contact are cut by intermediate rocks.

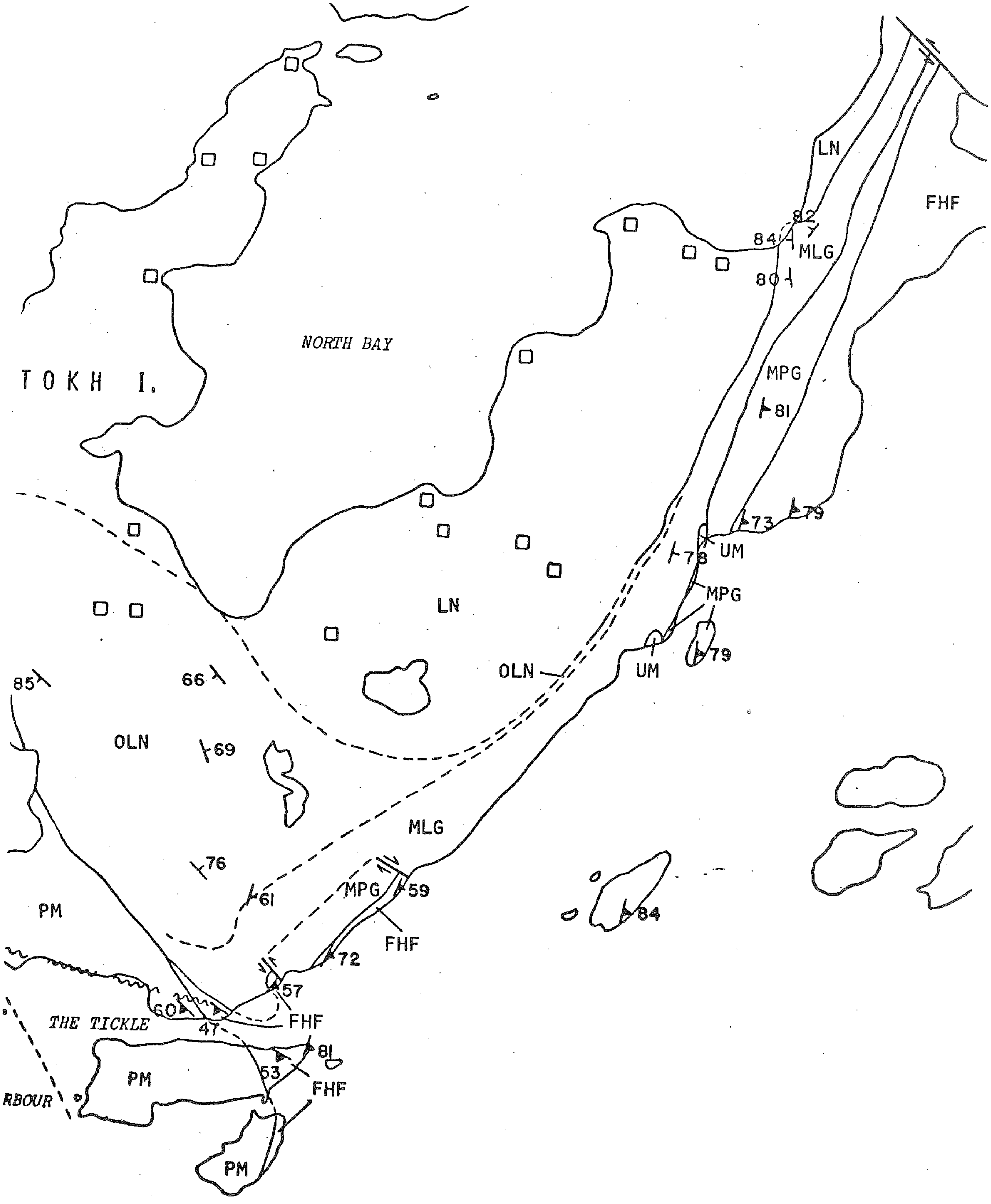


Fig. 22. Geology of the eastern part of Nukasorsuktokh I.

Marginal Pyroxene Granulite

Along the western contact of basement rocks is a mafic pyroxene granulite which persists in contact with anorthositic rocks to the west. This is the "granulite of uncertain origin" of Wheeler (1968). de Waard (FR 1971) includes this granulite in the Ford Harbour Formation. The granulite is approximately 250 meters thick and the mineralogy and general appearance in the field are indistinguishable from pyroxene granulites elsewhere in the basement. Foliation is well developed and consistently parallels foliation in the Ford Harbour Formation. Concordance of basement foliation with anorthosite contacts and marginal anorthosite structures is common along anorthosite margins elsewhere in the Nain region and cannot be used in the classic sense to interpret age relations. That is, parallelism of marginal pyroxene granulite foliation with basement foliation is not adequate evidence to equate the two units in time. However, marginal gabbros related to the anorthosite intrude the marginal granulites. Field relations suggest that the granulite should be classified with basement rocks; however, its persistence adjacent to anorthosite margins on Nukasorsuktokh I. leaves the origin of the pyroxene granulite unresolved at this time.

Anorthositic Rocks

Wheeler (1960 and 1968) reports that most of the island is underlain by pale facies anorthosite. Leuconorites occur on both the eastern and western sides of the island. They are separated by intermediate rocks and the Wyatt Harbour intrusion.

Marginal layered gabbros. A medium- to fine-grained olivine gabbro lies in contact with the marginal pyroxene granulite along the east arm of Nukasorsuktokh I. Within a meter this rock takes on a distinct subophitic texture. The gabbro becomes coarse grained and maintains its subophitic texture westward from the contact. This rock is part of a unit approximately 400 meters thick consisting of layered gabbro and olivine gabbro, which locally show intense rusty weathering. Layering is parallel to the contact with the pyroxene granulite and parallel to foliation in the granulite and basement rocks.

A fine-grained troctolite was found near the bend in the structure on the east arm (Fig. 22). It has been included in this zone of olivine gabbros based on the presence of olivine. Two large, mappable pyroxenitic inclusions occur within the gabbro and close to the contact with the pyroxene granulite. The mineralogy of the ultramafics is predominantly clinopyroxene with minor orthopyroxene and plagioclase.

Transitional olivine leuconorite. Marginal olivine gabbro grades into leuconorite through a transitional unit of medium grained olivine leuconorite characterized by interesting textures. The rock consists of 10-12 cm. diameter circular patches of plagioclase and subophitic olivine surrounded by subophitic leuconorite. Within this patchy or clotted olivine leuconorite occur 20 X 30 meter blocks of medium grained pale anorthosite as well as 1 X 3 meter blocks of layered fine grained pale anorthosite containing minor pyroxene. The layering in these blocks shows an unexpectedly consistent orientation parallel to the regional layering trend in leuconorite noted by Runkle and Saunders (this report, p. 121), and shown in Fig. 34.

Internal leuconorite. Olivine leuconorite grades into gray weathering, medium to coarse leuconorite with subophitic pyroxenes. This rock is characterized by iridescent plagioclase and block structure. Blocks of many varieties of anorthosite are found within leuconorite country rock (see Runkle and Saunders, this report). The distribution of block structure is shown on the map (Fig. 22) by an open square symbol.

All the above anorthositic rocks appear to be the product of one magma which first produced olivine gabbro at the base, followed by olivine leuconorite and leuconorite. A stratigraphic column (Fig. 23) illustrates this proposal.

Blocks of fine- to medium-grained pale anorthosite are abundant in the leuconorite in the western part of the island. No mafic margins are associated with these leuconorites.

Intermediate Rocks

The following four major intermediate rock types occur on Nukasor-

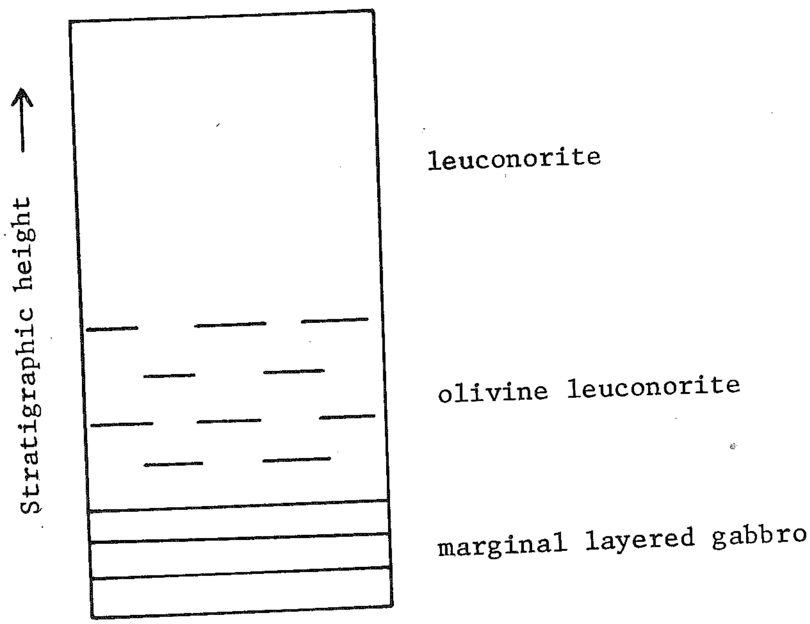


Fig. 23. Proposed stratigraphic column for the anorthosite intrusion at Nukasorsuktokh I.

suktokh I.: 1) fine grained hypersthene diorite, 2) pale leucodiorite, 3) black leucodiorite, and 4) pyroxene monzonite.

Layered, fine-grained hypersthene diorite with granular texture is exposed along much of the eastern contact of the Wyatt Harbour intrusion. Some layers weather red and contain minor olivine. The rock contains antiperthitic plagioclase which ranges from An_{37} to An_{44}. The mafics are predominantly orthopyroxene, with minor clinopyroxene.

In contact with the fine grained hypersthene diorite to the east is a pale leucodiorite which grades into a pale quartz-bearing leucodiorite. Both pale leucodiorites are mapped as one unit. The mafics are hornblende, hypersthene and augite. The quartz occurs as pale violet rounded phenocrysts measuring 1/2 to 3/4 cm. The plagioclase compositions of pale leucodiorites range from An_{32} to An_{47}.

To the east, quartz-bearing pale leucodiorite grades into black leucodiorite with the persistence of quartz phenocrysts for approximately 1 meter. Prior to petrographic work on board R. V. *Pitsiulak*, this rock was mapped as dark anorthosite (Morse and Speer, FR 1971). It consists predominantly of plagioclase ranging in composition from An_{32} to An_{38}. The dark color of the rock is due to fine opaque rods in the plagioclase. The mafics are minor; however, they locally represent 20-30% of the rock. The mafic mineral consists of very coarsely exsolved subcalcic ferroaugite. The subcalcic bulk composition of these pyroxenes is inferred optically from the subequal proportion of augite and orthopyroxene lamellae. Such pyroxenes have only recently been recognized in nature. They are described by Smith (1974) from the Nain area. Formation of a pyroxene of this composition requires very high temperatures in order for initial crystallization to occur above the pyroxene solvus. Such temperatures would require a dry magma.

The texture of black leucodiorite changes from a medium grained rock in the southern and central part of the island to a coarse grained rock with 7-10 cm. black plagioclase megacrysts in the northern part of the island near the contact with the leuconorite body to the west.

Black leucodiorite is in contact with fine to medium grained pyroxene

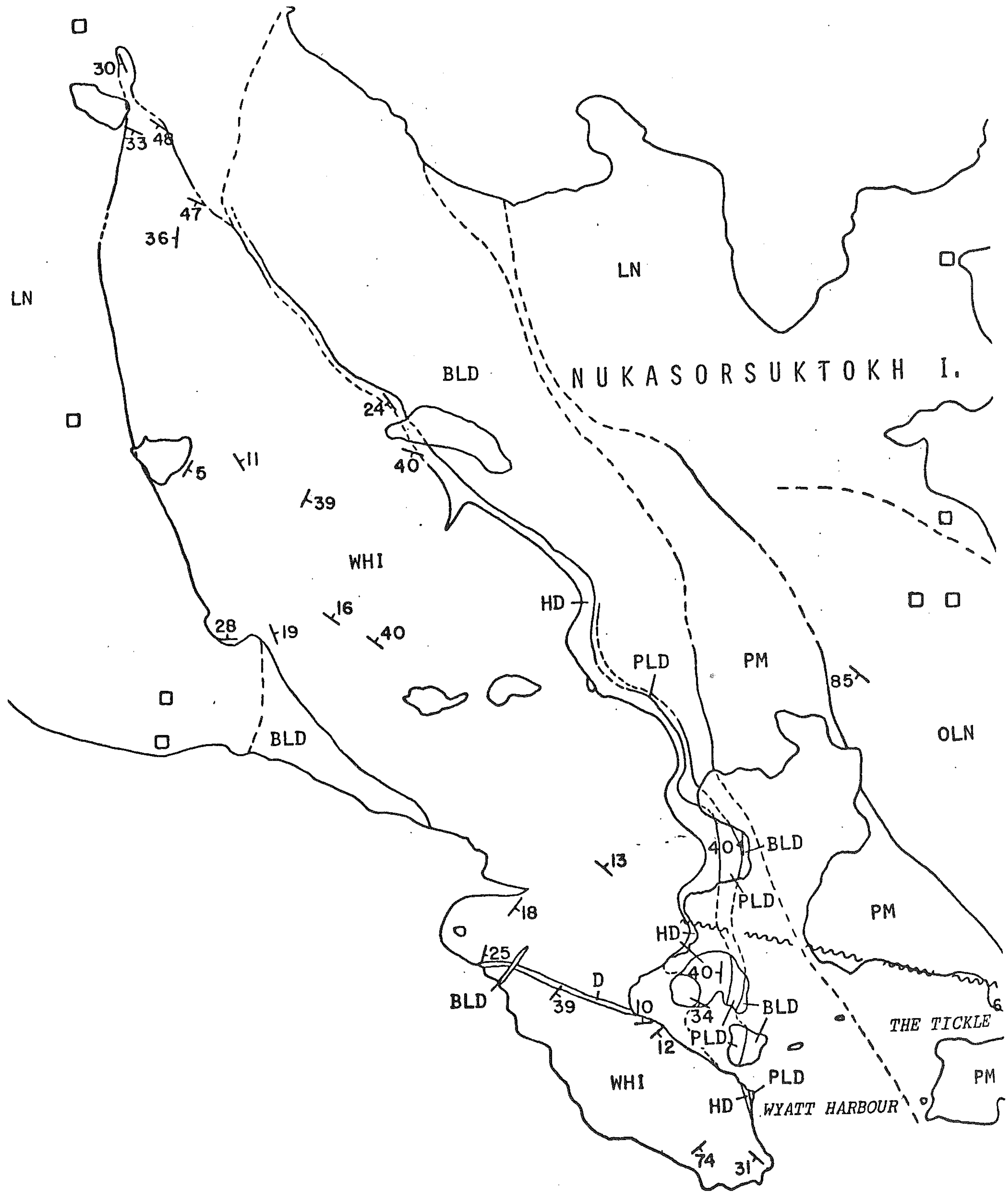


Fig. 24. Geology of the western part of Nukasorsuktokh I.

monzonite. The 2-4 cm. black plagioclase megacrysts occur in both rocks at the contact. The pyroxene monzonites can be divided into two groups, based on the presence or absence of finely exsolved 1 cm mesoperthite phenocrysts. Both rocks contain twinned plagioclase ranging from An_{25} to An_{41}, perthite, and exsolved subcalcic ferroaugite.

Age relations. Foliation and contact attitudes show that the intermediate rocks dip steeply to the SW, presumably beneath the Wyatt Harbour intrusion. The contact is not sharp between troctolite and fine grained hypersthene diorite. One exception is discussed later. The fine grained hypersthene diorite is, however, in sharp contact with the pale leucodiorite. The leucodiorite consistently cuts fine grained hypersthene diorite, and blocks of the latter are found in the former. Pale leucodiorite intrudes troctolite. In one instance a dike containing both leucodiorite and fine grained hypersthene diorite cuts layering in the Wyatt Harbour intrusion. Contacts among all types of leucodiorites are gradational. The contact between black leucodiorite and pyroxene monzonite is more distinct but transitional with interlayering of the two rock types over a zone of approximately 15 meters.

Distinct contacts between the hypersthene diorite, leucodiorites, and pyroxene monzonite suggest there may have been 3 different periods of intrusion. However, petrographic similarities between the leucodiorites and monzonites suggest they may have originated from the same parent magma, perhaps in different stages of differentiation. This hypothesis may apply to the hypersthene diorite as well. Fig. 25 shows a stratigraphic column illustrating the hypothesis that all the intermediate rocks are comagmatic. Assuming this hypothesis, mineralogical data suggest that the time sequence from oldest to youngest is diorite, leucodiorite, monzonite.

If all the intermediate rocks are related to each other, the fine grained hypersthene diorite may be considered a chill rock of the intermediate

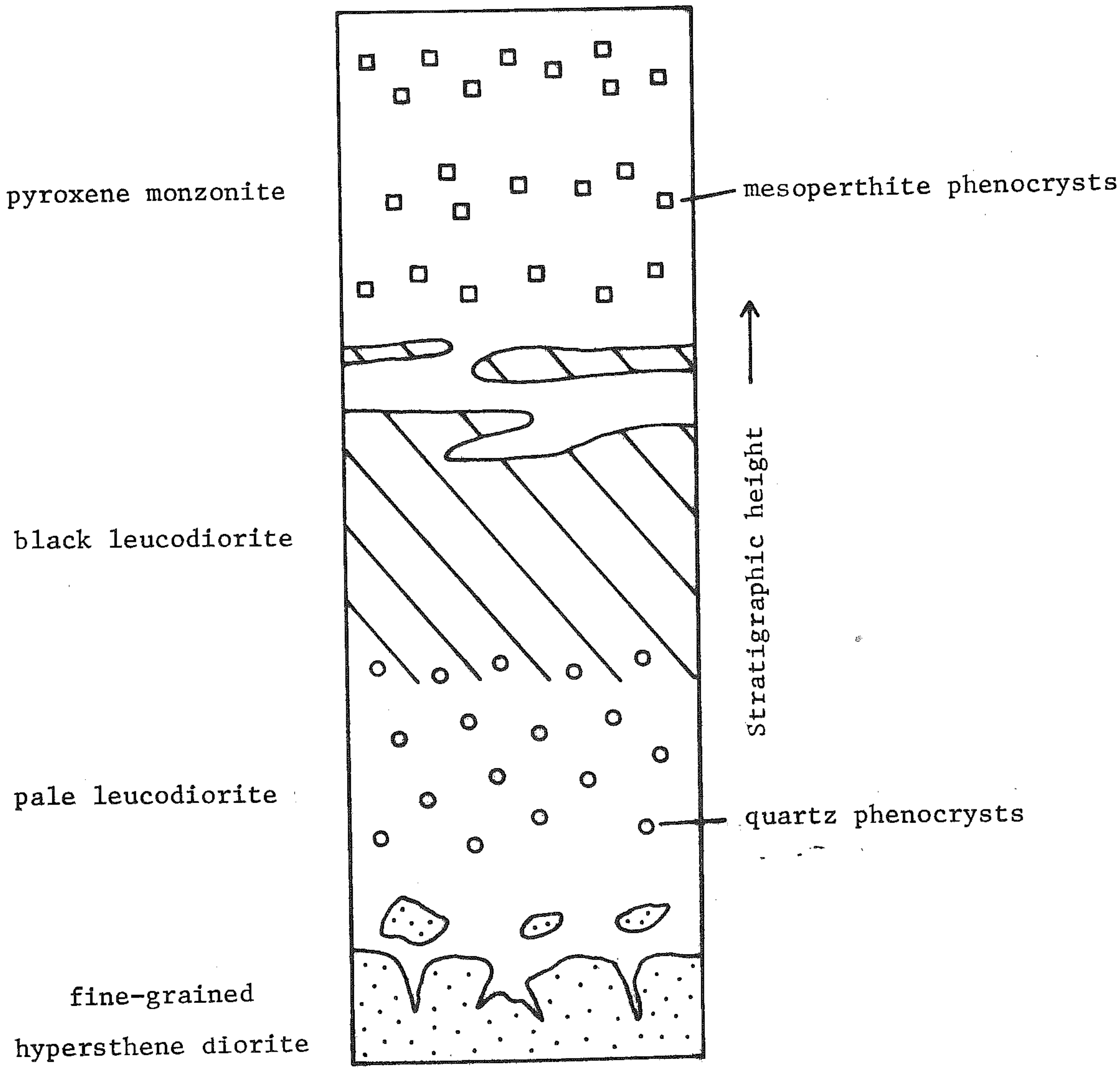


Fig. 25. Stratigraphic column for the intermediate intrusion showing a fully cognate interpretation.

intrusive rocks. The occurrence of hypersthene diorite and pale leucodiorite in a dike cutting troctolite also supports the idea that the fine grained intermediate rock is younger than the troctolite.

Another hypothesis, however, must reflect the possibility that the fine grained hypersthene diorite is a chill of the Wyatt Harbour intrusion and grades into olivine gabbros and troctolite. However, it is unlikely that a magma of hypersthene diorite composition would produce a troctolite - olivine gabbro body.

Wyatt Harbour Intrusion

The Wyatt Harbour intrusion has the shape of a narrow synform defined by layering dipping inward on either side. This is particularly shown in the central part of the island south of the northern terminus of the Wyatt Harbour intrusion. At its northern terminus, the intrusion is a narrow 50 meter dike which strikes NNW and dips SE. This dike perhaps represents the feeder of the body. The layering to the west of Wyatt Harbour is nearly horizontal with strikes of varying orientation.

The predominant rock type of the Wyatt Harbour intrusion is a medium grained troctolite. Layering is sporadic and indistinct except locally. The following primary features were noted in the intrusion: crossbedding, channel scour, isomodal layering,[2] size-graded layering, and swirled and planar laminations.

Medium-grained olivine gabbros and gabbro pegmatites occur in the northern part of the intrusion east of Pamialuk. Olivine gabbros are exposed along the eastern contact. To the west these gabbros are intruded by gabbro pegmatites containing minor olivine. Along the western contact the gabbro pegmatites become the dominant rock type and intrude blocks of medium grained olivine gabbro and troctolite.

A similar 4-6 cm olivine gabbro pegmatite is abundant in the southern peninsula west of Wyatt Harbour. Here the pegmatite intrudes medium

[2]A layer characterized by a uniform proportion of one or more cumulus minerals (Jackson, 1970, p. 392).

grained troctolite. The olivine in the pegmatite is subophitic and rimmed by pyroxene or oxides. Near Harbour Point, 5 cm pegmatite is interlayered with troctolite. One pegmatite unit is several meters thick and makes up most of the point. Here the pegmatite is associated with coarse 3 cm. troctolite with subophitic olivine. A plagioclase crystal from the Harbour Point pegmatite is $An_{55.6 \pm 2.6}$ and plagioclase from the host troctolite is $An_{52.5 \pm 1.3}$. This suggests that the pegmatite may actually be an early raft rather than a product of residual liquid.

Several rock types occur near the eastern margin of the Wyatt Harbour intrusion. In contact with anorthosite in the north is a fine grained olivine norite. A medium grained norite with subophitic textures occurs sporadically near the contact of troctolite with fine grained hypersthene diorite. Fine to medium grained gabbros are also exposed along the eastern margin of the Wyatt Harbour intrusion. The relationship of these rocks to the rest of the intrusion is ambiguous. As yet no attempt has been made to map separate units within the intrusion, and stratigraphic relations remain unclear.

Several large, mappable leucocratic inclusions have been found in the troctolite near its margins. One is a leucogabbro with plagioclase An_{75} and another is an olivine-hypersthene leucogabbro with plagioclase An_{80}. These rocks are interpreted as inclusions from the nearby anorthosite mass.

Granite, Diabase, Shear Zones and Faults

Granite dikes cut all major rock types on Nukasorsuktokh I. They show no preferred orientation. In contrast diabase dikes are commonly oriented E-W. They also cut all rock types.

East-west shear zones are also common. One E-W shear zone is approximately 2 km long and 75 m wide, extending from the Wyatt Harbour intrusion, across Wyatt Harbour, and into The Tickle. It therefore cuts all major rock types on the island. No displacement was detected. Several NW-striking faults displace basement and anorthositic rocks along the eastern shore of Nukasorsuktokh I. A left lateral displacement of approximately 0.3 km was noted for the northernmost fault (Fig. 22).

Conclusions

The following tentative sequence of events is proposed. The Archean Ford Harbour Formation is the oldest unit exposed. Into this unit was intruded a large magma body which differentiated to form marginal olivine gabbros and olivine leuconorites, eventually producing leuconorites. At some earlier stage, calcic anorthosite was formed which is now found as blocks in leuconorite. Intermediate rocks obscure age relations between the eastern anorthositic intrusion and the Wyatt Harbour intrusion or western leuconorite.

Field relations of troctolite and western leuconorite are unclear. Leuconorite at the northern end of the Wyatt Harbour intrusion shows evidence of flowage and perhaps remobilization by the troctolite. Anorthosite blocks interpreted as belonging to leuconorite occur in the troctolite. However, blocks of troctolite occur in what appears to be leuconorite. Contradictory relations are probably related to the difficulty in distinguishing in the field between gabbro pegmatites of the Wyatt Harbour intrusion and anorthositic rocks in contact with the Wyatt Harbour intrusion. The dike-like nature of the intrusion at its northern terminus is strong evidence that the troctolite intrusion cuts anorthositic rocks and is therefore younger. Other contradictory relations may be explained by partial mobilization of anorthosite during intrusion of troctolite.

Both pale leucodiorite and black leucodiorite cut troctolite. Pyroxene monzonites near The Tickle cut foliation in the basement and the contact between anorthositic rocks and basement rocks. The intermediate rocks are therefore the youngest major rock group on the island, excluding granite and diabase which both cut intermediate rocks.

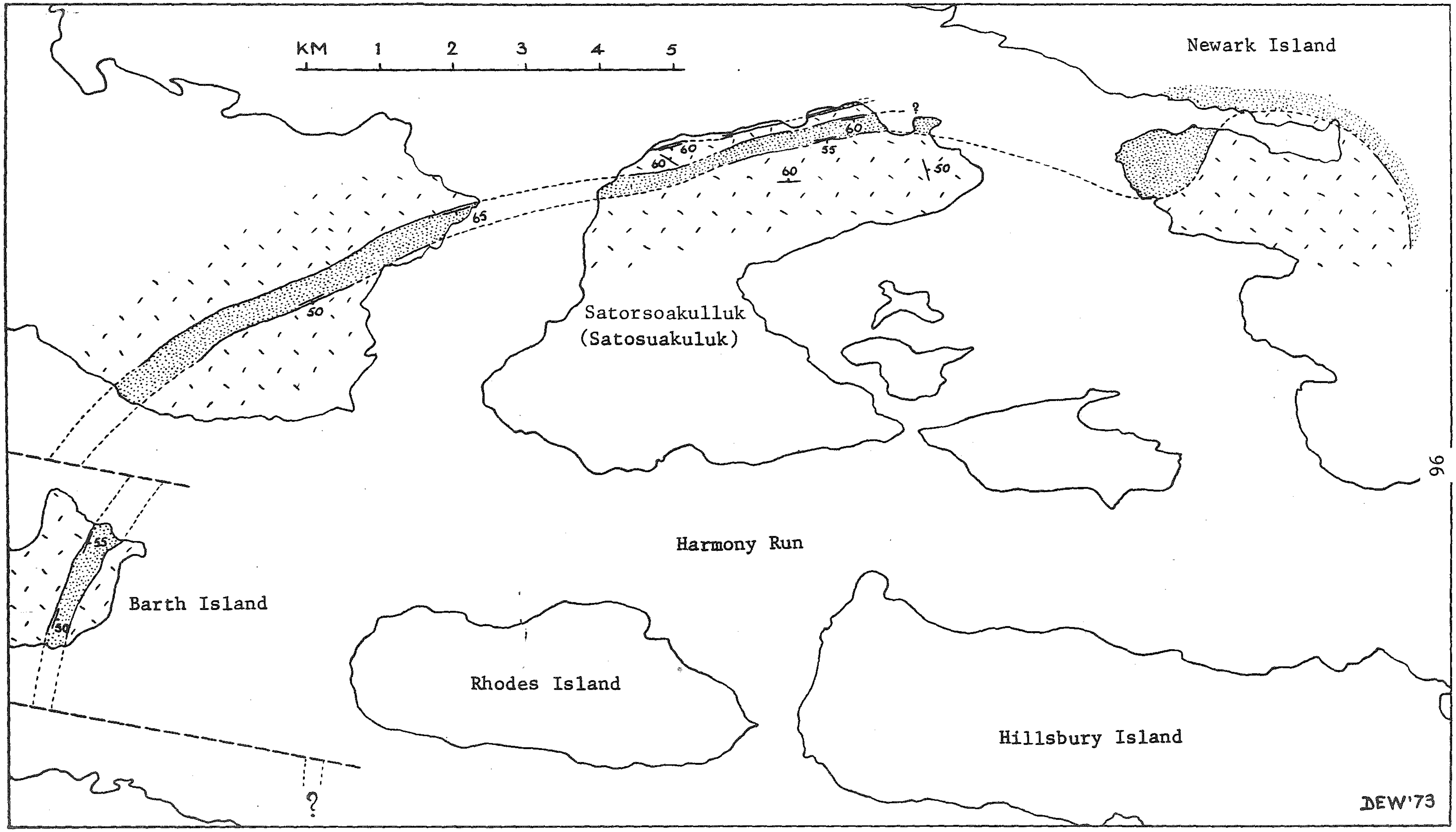


Fig. 26. Map showing gabbroic-granodioritic dike in anorthosite of the region north and northeast of Nain. The dike is offset by east-west trending left-lateral faults north and south of Barth Island. Strikes and dips are shown of contacts, and of layering in anorthosite on Satorsoakulluk I.

NAIN COMPLEX: INTERNAL RELATIONS

GABBROIC-GRANODIORITIC DIKE IN THE NAIN ANORTHOSITE MASSIF, LABRADOR

Dirk de Waard and Susan Hancock

Syracuse University and Mount Holyoke College [1]

Introduction

North of Nain a curved dike, about 20 km long and 300 m wide, occurs in anorthosite of the Nain massif. The dike was first outlined by Wheeler (1968), who designated it on manuscript maps as having a dioritic to tonalitic composition. According to Wheeler (pers. comm., 1973) no other dikes of this composition are known to occur in the Nain anorthosite complex. This uniqueness prompted a more detailed study of the dike in order to determine its structural and petrologic significance in the evolution of the anorthosite massif. Figure 26 shows the outcrop pattern.

Petrology

The dike rock is generally a fine to medium grained, dark rock which primarily consists of plagioclase and pyroxene, with variable amounts of quartz and K feldspar. Locally, large poikilitic hornblende up to 3 cm may occur. In several places phenocrysts or clusters of grains of feldspar are found.

Under the microscope the rock has a hypidiomorphic texture, with plagioclase, pyroxenes, apatite and magnetite as early phases, and interstitial K feldspar, quartz, hornblende and biotite. The plagioclase is sodic andesine, antiperthitic and weakly zoned. There is generally more clinopyroxene than orthopyroxene. The K feldspar, and especially the quartz, tend to be interstitially poikilitic.

There is little variation in grain size of the dike rock, though a somewhat finer grain was noted in some places at the contact with anorthosite. The rock generally has a homogeneous appearance. Locally there are heterogeneities in the rock, such as: 1. density-graded bedding, and, more commonly, a streaky or whispy layering due to a higher percentage of ferromagnesian minerals; 2. the presence in the rock of poikilitic hornblende; and 3. the presence of phenocrysts or clusters of grains of

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

feldspar, which are either spottily distributed, or occur concentrated in veins or schlieren in the dike rock.

Structure

The dike cuts the anorthosite along sharply defined contacts, with angular blocks of anorthosite in the dike locally abundant. Where the anorthosite is found to have a layered appearance the dike cuts across these structures. There are also smaller, parallel dikes and offshoots from the main dike in several places.

The total length of the dike, as far as observed, is about 20 km. The east end appears to merge with the gabbroic unit of the layered igneous complex of Newark Island (Woodward, FR 1972, p. 44). The southwest extension beyond Barth Island is as yet unknown. Considering a left-lateral displacement of about 3.5 to 4 km along an east-west strike-slip fault south of Barth Island (de Waard and Mulhern, FR 1972, p. 72), a continuation of the dike might be expected in the area around Nain.

The width of the dike varies between 400 and 200 m. The narrowing toward the east end is accompanied by the presence of parallel dikes which increase in thickness eastward. The southwest end of the dike has the considerable width of about 250 m, which may be indicative of extensive continuation southward.

The dike dips consistently south and southeast, between 50° and 65°. The dike as a whole thus resembles a cone sheet, somewhat elliptical in shape with a diameter of about 15 or 20 km. In order to accommodate a 300 m wide dike the cone of country rock would have to rise 400 to 500 m, or, alternatively, the country rock outside the cone sheet would have to subside that much.

Conclusions

The sharply defined contacts of the dike, intersecting plagioclase crystals, demonstrate that the anorthosite was in a solid condition at the time of intrusion of dike material. The fine grain size of the dike rock may indicate a relatively cool environment in which the rock solidified. However, the anorthosite was not cool enough to cause chilled margins, such as are typically found in the numerous diabase dikes of younger Precambrian age which intersect the Nain anorthosite complex.

The connection of the dike with similar rocks of the Newark Island layered intrusion demonstrates that the formation of the dike is to be considered part of the petrological and structural evolution of the anorthosite massif. At one stage in the evolution the anorthosite was underlain by magma from which the dike rock crystallized. The formation of the dike could be interpreted as the result of forceful uplift of a central area of brittle anorthosite; on the other hand, assuming an underlying magma (de Waard and Mulhern, FR 1972, p. 78) it could have been formed by collapse of roof rock north and west of the dike, and subsidence of the anorthosite into underlying magma. In either case σ_1 is vertical and σ_2 equals σ_3 , which results in a conical surface of greatest shear stress dipping 50° to 60°, and less at deeper levels.

Acknowledgement

Field and laboratory work are financially supported by National Science Foundation Research Grant GA-31873.

Appendix: Modal composition of dike rocks

Table 5.

	NA-170	BB-17
quartz	0.2	2.7
K feldspar	2.4	6.2
plagioclase	60.3	50.5
biotite	0.1	0.4
hornblende	-	4.4
clinopyroxene	15.8	12.1
orthopyroxene	13.6	14.1
apatite	1.5	3.7
zircon	0.1	0.2
opaque minerals	6.0	5.7
mafic %	37.1	40.6
An %	39.0±1.0	34.0±1.0
En % op	33.5±0.5	33.0±0.5
En % cp	41.5±1.0	40.0±0.5

Table showing modal and mineral compositions of two specimens of rocks collected in 1971 from the dike on the north shore of Barth Island. The rocks have a subophitic, predominantly fine-grained texture with larger euhedral plagioclase crystals, and large subpoikilitic to interstitially poikilitic orthopyroxene and (NA-170) poikilitic hornblende. K feldspar occurs in interstitial patches and as blocky exsolution in plagioclase.

ANORTHOSITE COMPOSITIONS IN THE CONTACT ZONE ON PAUL ISLAND, LABRADOR

Dirk de Waard

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Introduction

During the investigation of the contact zone between anorthosite and country rock in the eastern part of Paul Island in 1971 (de Waard, FR 1971, p. 14-26) specimens were collected of anorthositic rocks for the determination of mineral compositions. The rocks were collected in a grid of sample locations about 2.5 km apart. The sampling was done to explore the feasibility of obtaining information on possible systematic variations, such as cryptic layering, in the extensive anorthositic areas of the Nain massif by means of a grid system of this size.

Petrography

The initial grid consists of 12 sample locations (Fig. 27). In each locality a representative sample was taken of the rock type in that area. In addition, wherever possible, a specimen was collected of anorthosite occurring as inclusions in the anorthositic host rock, as well as a sample of pegmatoid leuconorite, which commonly occurs in patches in the host rock.

The anorthositic host rock varies in grain size between 1 and 5 cm, and has a texture that is equigranular, but more commonly seriate. The composition is generally leuconoritic with a mafic mineral content between 10 and 20%. The rock in four of the localities is almost black (dark facies anorthosite of Wheeler), and in the others it is gray or bluish gray in color (pale facies anorthosite of Wheeler).

The anorthositic rocks of the sampled inclusions are finer grained and more leucocratic than the host rocks. Layering, which is common in these rocks, is due to the presence of thin layers rich in mafic minerals alternating with layers of almost pure plagioclase. The inclusions are angular, and they are sharply bordered against the anorthositic host rocks.

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

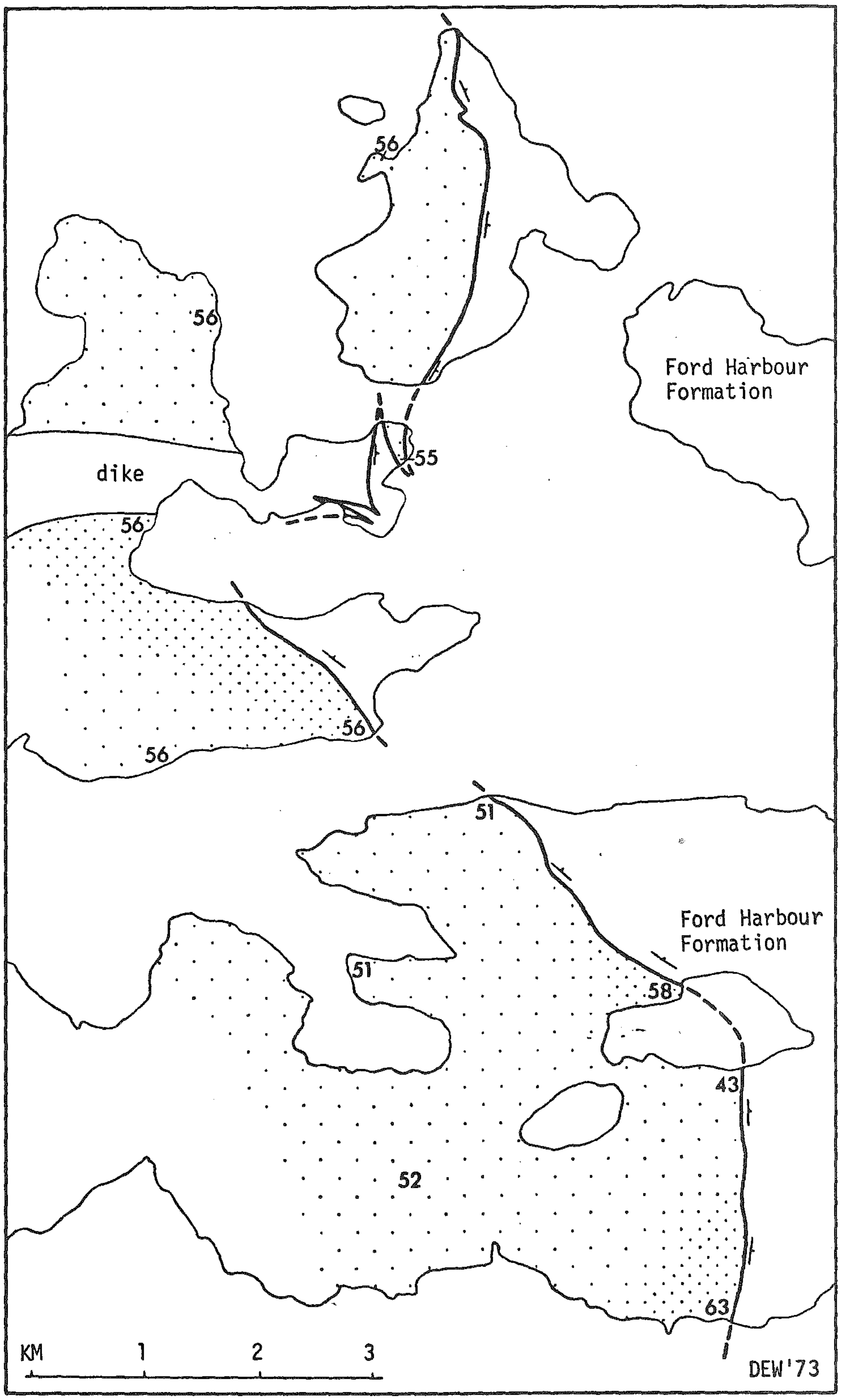

Fig. 27. Contact zone of anorthosite with country rock of Ford Harbour Formation in the eastern part of Paul Island. Numbers indicate mean plagioclase composition of anorthositic host rock in the 12 locations of the initial grid system. Close stippling represents distribution of dark facies anorthosite, wide stippling that of pale facies anorthosite. The contact dips east between 45° and 80°.

The pegmatoid leuconorite occurs in irregular, ill-defined patches and schlieren. At the margins the grain size decreases, and the pegmatoid rock grades into the host rock. These patches, or "sweat dikes" (Wheeler, FR 1972, p. 97-102), are common throughout the Nain anorthosite massif. On Paul Island several patches were found to contain granophyre in their center.

The map, Fig. 27, shows the grid of sample locations, the mean plagioclase composition of the host rock in each of the locations, and the distribution of dark and pale facies anorthosite. The compositions of plagioclase and orthopyroxene in all anorthositic rocks are given in the table. The determinations were done by research assistant Kate Mulhern, using the dispersion method after Morse. The relationship between the plagioclase compositions of host rocks and those of inclusions and pegmatoid patches are shown in Fig. 28. Fig. 29 demonstrates the relationship between the compositions of associated pairs of plagioclase and orthopyroxene in the investigated rocks.

Conclusions

Based on the limited number of sample locations, the following tentative conclusions may be drawn for the investigated portion of the Nain massif.

1. Anorthositic inclusions are generally more leucocratic and finer grained, and have a more calcic plagioclase than the anorthositic host rock. The pegmatoid patches have a less calcic plagioclase than the host rock.

2. Anorthosites determined in the field as being dark facies anorthosites have generally a more calcic plagioclase than those which were mapped as pale facies anorthosites, though the plagioclase compositions of the two groups appear to overlap.

3. Three out of the four dark facies anorthosites contain olivine, and two of those have a more calcic plagioclase than the one without. Two of the dark facies anorthosites are leucotroctolites; the other two are leuconorites. Six out of the eight pale facies anorthosites contain

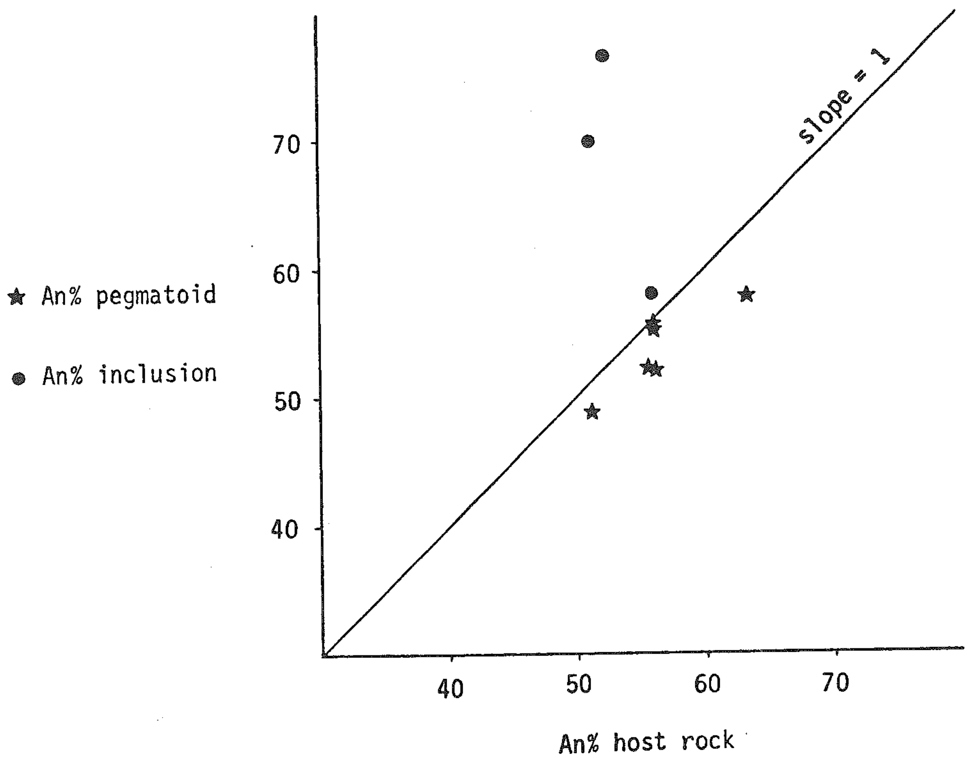

Fig. 28. Relationship between plagioclase compositions of anorthositic host rocks and those of associated anorthositic inclusions and pegmatoid leuconorite patches.

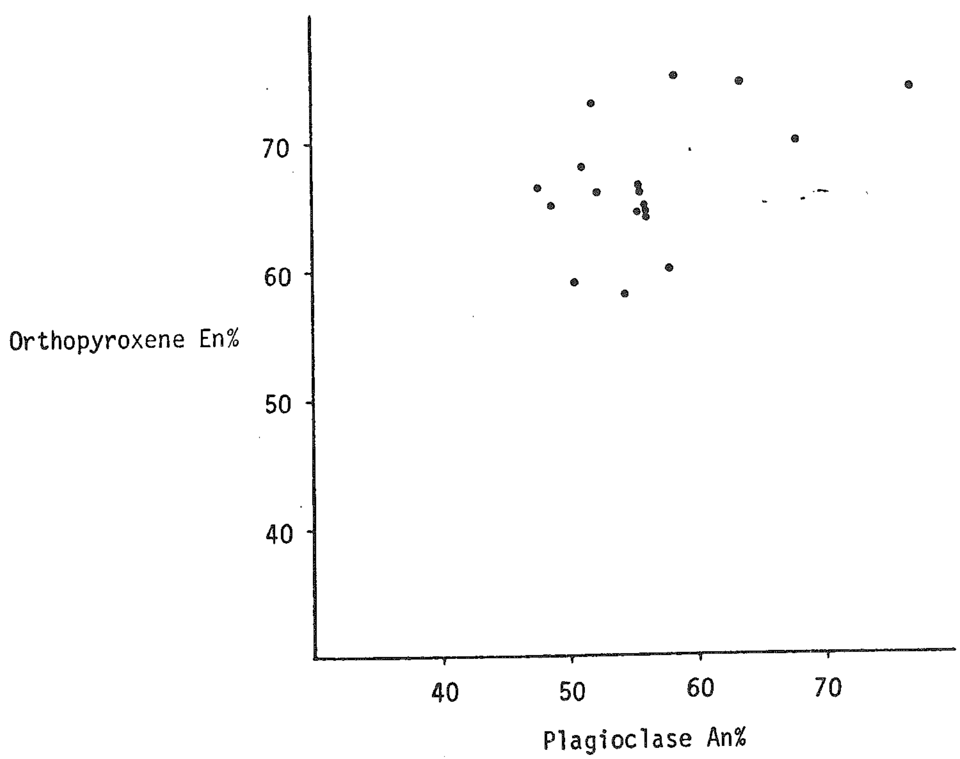

Fig. 29. Relationship between compositions of associated pairs of plagioclase and orthopyroxene in anorthositic rocks.

small amounts of interstitial quartz.

4. The present data indicate little about a systematic distribution of anorthosite types, or about a systematic variation of mineral compositions. All four locations of dark facies anorthosite are at the contact, but only about half of the anorthosite along the contact is of the dark facies type. There is a surprising homogeneity in plagioclase composition (An_{55-56}) in the northern part of the investigated area, though it includes rocks of different color and different texture. This contrasts with the southern part of the area where dark facies anorthosite (An_{58-63}) intermingles with pale facies anorthosite (An_{43-52}). Obviously, a larger area and locally a closer grid will be needed to detect and evaluate systematic variations in anorthositic rocks.

Table 6. Mineral compositions in associated anorthositic rocks.

	ANORTHOSITIC HOST ROCK			PEGMATOID LEUCONORITE		ANORTHOSITIC INCLUSION	
	rock type	An%	En%	An%	En%	An%	En%
NU-64	dark (olivine)	63.4±1.3	74.5±0.5	47.8±0.9	66.5±1	-	-
NU-68	pale (quartz)	43.1±2.2	altered	-	-	-	-
NU-73	pale (quartz)	50.5±0.9	59 ±1.5	-	-	-	-
NU-76	dark (olivine)	58.3±0.8	75 ±0.5	-	-	-	-
NU-77	pale	52.4±1.2	66 ±1	-	-	76.7±1.0	74 ±1
NU-78	pale (quartz)	51.2±2.5	68 ±2	48.8±0.8	65 ±1	67.9±0.6	70 ±2
NU-79	dark (olivine)	55.5±0.9	66.5±1	52.2±3.0	absent	-	-
NU-82	pale	56.2±0.9	altered	52.1±2.8	73 ±1	-	-
NU-83	dark	56.0±1.0	65 ±1	55.6±0.9	66 ±0.5	-	-
NU-87	pale (quartz)	54.6±1.9	58 ±1	-	-	-	-
NU-89	pale (quartz)	56.0±1.5	64.5±2.5	55.4±0.9	64.5±1.5	58.0±0.8	60 ±1
NU-94	pale (quartz)	56.1±0.8	64 ±1	-	-	-	-

FURTHER STUDY OF THE HETTASCH INTRUSION AND ASSOCIATED ROCKS

J. H. Berg

University of Massachusetts[1]

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Massive Leucogabbronorite
Hettasch Intrusion
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  Discussion
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Introduction

Field work during the summer of 1973 allowed completion of the mapping of the Hettasch intrusion and further elucidated the geology and petrology between Hettasch Lake and Port Manvers Run (Fig. 30). This report contains new data, current interpretations, and a brief discussion of the Hettasch intrusion. Certain rock units (e.g., North Ridge gabbro, Webb Valley metamorphic complex) were discussed in FR 1972, p. 49-64, and will not receive further treatment here. Following is a summary of the gross field relationships.

The Hettasch intrusion is part of the Nain anorthosite complex. The preserved parts of the intrusion consist mainly of leucotroctolite, anorthosite, and olivine leucogabbronorite; however, no roof rocks are recognized, and much of the original body may have been removed by erosion. The intrusion is synclinal in form and crops out over an area of

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

about 200 km^2. Its outer limb is in contact in turn with the North Ridge gabbro, the Webb Valley metamorphic complex and Foliated Anorthosite. The inner limb of the intrusion is in contact with the Massive Leucogabbronorite and Foliated Anorthosite. The northern extension of the intrusion may be cut off by the presumably younger Kiglapait layered intrusion, and the eastern terminus of the Hettasch intrusion is lost in a complex anorthosite block structure.

Foliated Anorthosite

A body of anorthosite lies in contact with both the outer and inner limbs of the Hettasch intrusion between Ado's Brook and Port Manvers Run (see Fig. 30). This unit is leucocratic, having an average color index between five and ten. Feldspar lamination is extremely rare, but typically there is a foliation defined by the varying abundance of mafic minerals (normally orthopyroxene, rarely olivine or clinopyroxene (?)). The rock commonly has a granulated texture, and the mafic layers locally appear to be stretched or smeared remnants of what once may have been a subophitic texture. In other places the rock is massive with good subophitic texture. The typical grain size is 1-2 cm, and locally there are megacrysts ranging in size from 5 cm up to 30 cm. The feldspar of this body has a distinct pinkish cast, and locally it becomes red or mauve in color. Also, locally, the megacrysts display a golden iridescence.

The foliation in the anorthosite rather uniformly trends north or northwest and dips moderately to steeply west or southwest. This structure is intersected at a high angle by the contact of the Hettasch intrusion (Fig. 30); thus the Foliated Anorthosite is clearly older than the Hettasch intrusion.

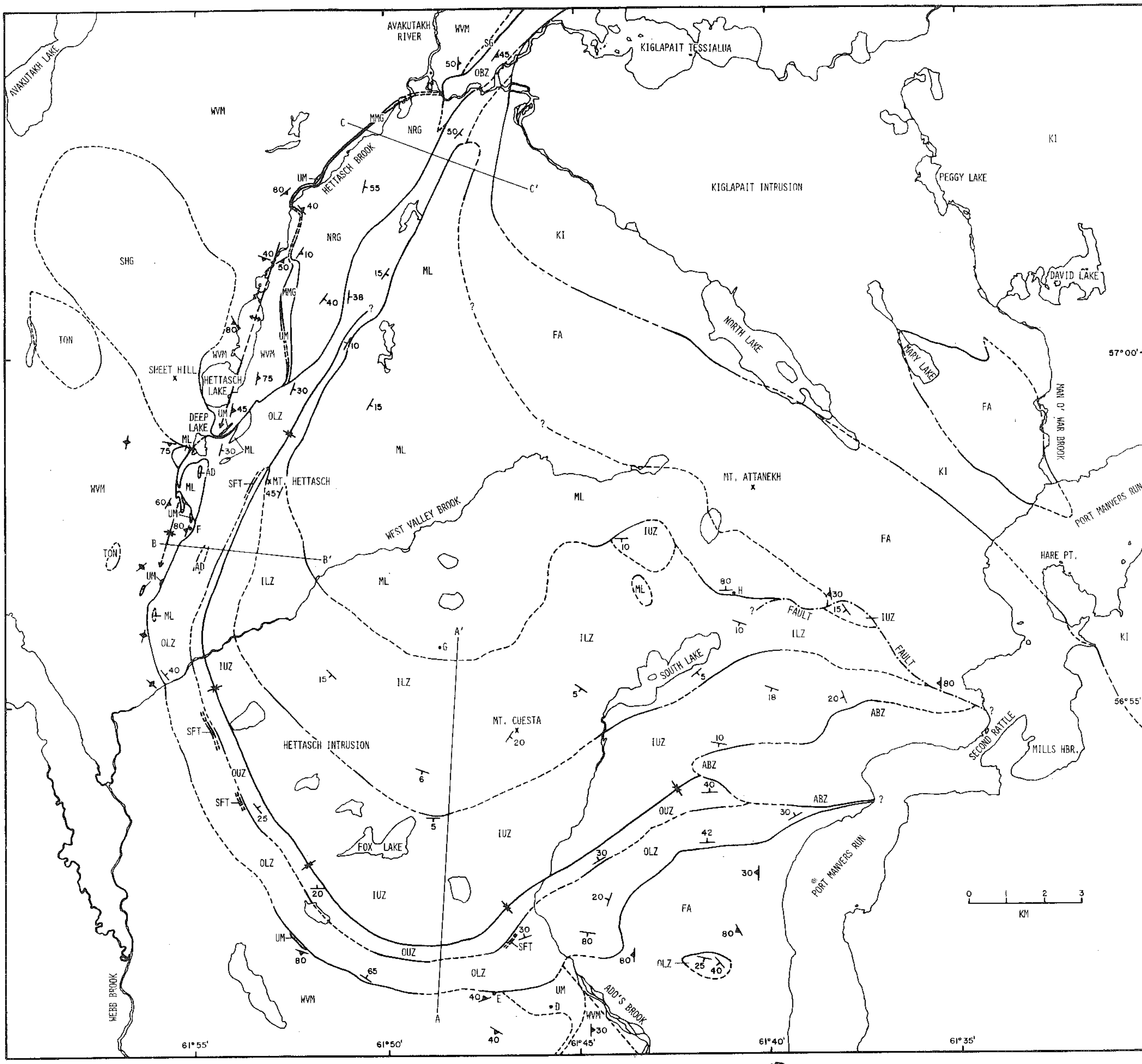
Massive Leucogabbronorite

This unit lies in contact with the inner limb of the Hettasch intrusion. In past reports (FR 1971, p. 45-46; FR 1972, p. 58) the unit was variously described as leuconorite and leucogabbro. New data confirm that hypersthene, not augite, is the dominant pyroxene. The term leucogabbronorite is used in accordance with the suggestions of the I.U.G.S. Subcommission on the Systematics of Igneous Rocks (Streckeisen, 1973).

This intrusion is very homogeneous, shows little granulation, and has a massive fabric. Layering and lamination are vanishingly rare. The grain size is 1-3 cm with 5-10 cm plagioclase megacrysts. The texture consists of unoriented, euhedral, and blocky plagioclase tablets set in a matrix of patchy-poikilitic pyroxenes. Typically, the plagioclase is iridescent, and the pyroxene is optically continuous through a roughly spherical zone having a diameter of 10-15 cm. The mean color index is about 20, and the plagioclase composition fluctuates among the middle to low An_{50}'s.

A discussion of the age relationship between the Massive Leucogabbronorite and the Hettasch intrusion is contained in last year's field report (FR 1972, p. 58-59), where it was concluded that the Massive Leucogabbronorite was the older of the two. Several new lines of evidence have added compelling support for an alternative interpretation that the Hettasch intrusion is older. North of South Lake there is an area of Massive Leucogabbronorite surrounded by rocks of the Hettasch intrusion (Fig. 30). Within the leucogabbronorite itself is a zone of very-coarse-grained laminated leucotroctolite, which is indistinguishable from nearby Hettasch material. However, the lamination in the zone strikes N-S (normal to the strike of nearby Hettasch rocks) and dips vertically. The interpretation is that the leucogabbronorite magma intruded the Hettasch rocks and stoped a block of Hettasch leucotroctolite which in the process was rotated to its present N-S orientation. The small leucogabbronorite mass is therefore an apophysis under this interpretation.

In addition, a rectangular block of laminated leucotroctolite, strongly resembling the Hettasch inner limb rocks, was found in the Massive Leucogabbronorite very near their mutual contact (Fig. 30, location G). A similar feature was discovered at location H (Fig. 30), but the relationships are not as clear-cut. Therefore the conclusion



AD Adamellite intrusive
TON Tonalite intrusive
SHG Sheet Hill granite
KI Kiglapait layered intrusion
OBZ Outer Border Zone (Kiglapait)
ML Massive Leucogabbronorite
IUZ Inner Upper Zone
OUZ Outer Upper Zone
SFT Snowflake troctolite
ILZ Inner Lower Zone
OLZ Outer Lower Zone
(IUZ, OUZ, SFT, ILZ, OLZ: Hettasch intrusion)

FA Foliated Anorthosite
ABZ Anorthosite Block Zone
NRG North Ridge gabbro
MMG Marginal mafic granulite
SG Snyder Group
UM Ultramafic body (peridotite)
WVM Webb Valley metamorphic complex

Fig. 30. Geologic map of the Hettasch Lake-Port Manvers Run area.

here is that the Massive Leucogabbronorite is younger than the Hettasch intrusion.

Hettasch Intrusion

General description. FR 1972 (p. 59-64) contains a description of the Hettasch intrusion, based on the study of about one half of the intrusion. Field mapping and study were extended over the rest of the intrusion during the summer of 1973.

The Hettasch intrusion is a layered intrusion of leucotroctolitic character. The mean color index (C.I.) is estimated to be between 10 and 15, and the mean density, based on 65 measurements, is estimated to be around 2.80. The intrusion is synclinal, or trough-like, in form rather than having the typical bowl shape of many layered intrusions. Also unusual is the fact that this intrusion is asymmetrical both structurally and stratigraphically, i.e., one limb of the syncline is not the mirror image of the other. Hence the intrusion is discussed in terms of two distinct limbs: an outer limb adjacent to the North Ridge gabbro, Webb Valley metamorphic complex, and Foliated Anorthosite; and an inner limb adjacent to the Massive Leucogabbronorite and Foliated Anorthosite.

The intrusion is broadly divided into two stratigraphic zones (Fig. 31), Lower Zone (LZ) and Upper Zone (UZ). When making reference to rocks on a specific limb the terms Outer or Inner will be attached to the zonal name, i.e., Outer Lower Zone (OLZ), Inner Lower Zone (ILZ), Outer Upper Zone (OUZ), and Inner Upper Zone (IUZ).

The Lower Zone is dominated by olivine and plagioclase and has a typical grain size of 1-2 cm. In the Upper Zone orthopyroxene, clinopyroxene, apatite, and opaque oxides become more common, and the typical grain size changes to 5-15 cm. Across the two zones plagioclase composition varies from calcic to sodic labradorite. Locally, at the base of the OLZ, there is a very fine-grained chilled margin whose chemistry is that of high alumina olivine tholeiite (Berg, 1973). The chemical analysis of this rock is listed in Table 7.

Stratigraphy: Lower Zone. The chilled margin is best developed against the Webb Valley metamorphic complex where it is a very fine grained (0.2-3 mm) olivine gabbro (see FR 1972, p. 59-61, for detailed description). At contacts with intrusive rocks of the Nain complex, the chilled margin is less obvious or absent; where present it is marked by only a modest reduction in grain size (to 5-10 mm), the presence of pyroxenes, and the lack of layering or lamination.

Higher in the stratigraphy the marginal rocks grade into 1-2 cm leucotroctolites of the Lower Zone. In the OLZ, the lower part is dominated by layering (lamination may be developed locally) and the upper part is a massive, structureless rock. Plagioclase megacrysts occur in some OLZ rocks, but they are less common than in ILZ rocks. In some OLZ rocks the olivine is patchy-poikilitic (intercumulus), while in others it is both cumulus and patchy-poikilitic. In the mafic layers the olivine is always cumulus.

Locally near the top of the OLZ is a zone of snowflake troctolite, described in FR 1972 (p. 61-62) and Berg (1973). This zone, which consists of delicately layered fine-grained troctolite containing radial clusters of bluish-gray plagioclase megacrysts, was better exposed in 1973 due to lower snow levels. This allowed more extensive observations, and several new features were identified. Graded layering is common and individual graded layers as thin as 2 cm were found. An exciting find was the discovery of layers of "perpendicular feldspars" (see Wager and Brown, 1967, p. 110-122). These layers consist largely of plagioclase crystals with high aspect ratios (5 cm x 2 mm), the long axes of which tend to be perpendicular to the layering. Near the tops of these layers the plagioclase crystals become curved, or locally broken off. Typically these layers are succeeded upward by, and alternate with, the thin, graded layers. These features indicate alternating periods of quiescence (growth of feldspars perpendicular to layering) and relatively strong currents (broken-off crystals and graded layering).

In the ILZ the 1-2 cm leucotroctolite is strongly laminated and unlayered (FR 1972, p. 62-63). The olivine is patchy-poikilitic (intercumulus) and the diameter of a single, optically continuous olivine

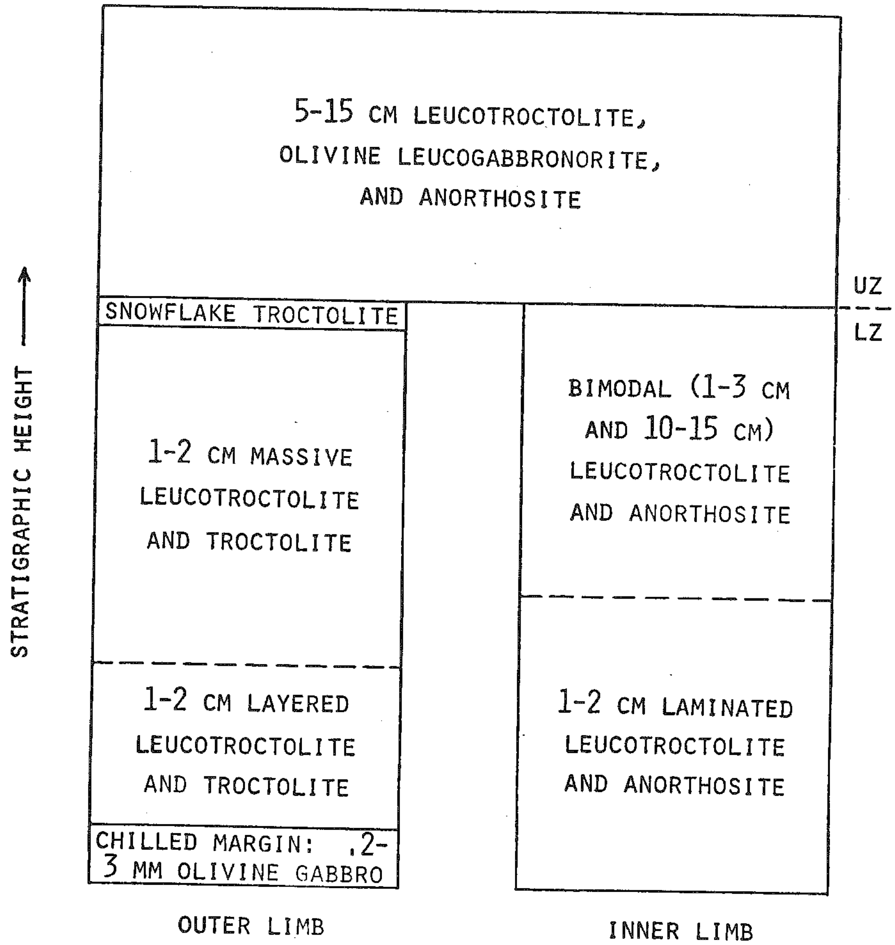


Fig. 31. Stratigraphy of the Hettasch intrusion.

Table 7. (HL 1009) Chemical analysis and CIPW norm of a sample of the chilled margin of the Hettasch intrusion. K. Aoki, analyst.

	Wt. %
SiO_2	47.50
Al_2O_3	18.87
Fe_2O_3	1.87
FeO	9.99
MgO	7.13
CaO	8.63
Na_2O	3.26
K_2O	0.38
MnO	0.15
TiO_2	1.27
P_2O_5	0.09
H_2O	0.61
	99.75

CIPW Norm	
or	2.25
ab	27.76
an	35.95
di	5.37
hy	3.15
ol	19.90
mt	2.73
il	2.43
ap	0.21

crystal typically exceeds 5 cm. Very rarely cumulus olivine is present. The ILZ rocks are more leucocratic than those of the OLZ, commonly having a CI less than 10, and plagioclase megacrysts become more abundant up stratigraphy. At the top of the ILZ and locally at the top of the OLZ, layers of very coarse leucotroctolite (UZ lithology) alternate with layers of 1-2 cm LZ leucotroctolite.

Stratigraphy: Upper Zone. The Upper Zone (UZ) is essentially the same for both limbs of the intrusion, except that the stratigraphic thickness of the OUZ is considerably less than that of the IUZ (a similar relationship holds for the LZ, too). The UZ is composed of very coarse-grained (5 - 15 cm) leucotroctolite, olivine leucogabbronorite and anorthosite (CI = 5-20). Olivine, orthopyroxene, augite, opaque oxides, and apatite are present in most of the rocks, in addition to plagioclase. Laminated rocks are somewhat more abundant than massive rocks.

Locally the IUZ is in direct contact with the Massive Leucogabbronorite. This could be the result of a transgression by the Massive Leucogabbronorite body, a transection of the contact (by the topography) at a higher stratigraphic level, or displacement along a fault.

Anorthosite Block Zone

Intimately involved with the Hettasch intrusion, although not actually part of the Hettasch stratigraphy, is the Anorthosite Block Zone (see Fig. 30). This occurs in an area where there ~~is~~ a complete gradation from Hettasch (i.e., leucotroctolitic) rocks to rocks which have a few pure anorthosite xenoliths in a leucotroctolitic matrix, to rocks which consist mainly of anorthosite blocks with just a few patches or dikes of leucotroctolitic matrix, and finally to rocks which consist solely of anorthosite. The contact on the geologic map (Fig. 30) is drawn where the anorthosite becomes dominant over the leucotroctolitic matrix.

The xenoliths, or blocks, of anorthosite are extremely angular and have sharp contacts with the matrix leucotroctolite. The angularity of the blocks and the intricate network of leucotroctolitic (and troctolitic) dikes indicate that the anorthosite was very brittle and was fractured, stoped, and injected with Hettasch liquid along a network of fractures. What was apparently one of the arteries of this network was discovered this summer. This artery, or sluiceway, consists of a nearly horizontal three-meter-thick dike which cuts sharply through the anorthosite. Distinct and very regular 1 cm scale layering is common in the troctolitic dike. The rock is fine to medium-grained, although there are layers which are rich in 1-2 cm plagioclase megacrysts. Spectacular en echelon channel scours, or trough bands, are common, and locally the plagioclase megacrysts occur in clusters forming "snowflakes". All of the prominent sedimentary features in this passageway point to the presence of a pulsating and meandering current persisting over a period of time.

The Hettasch intrusion does not appear to close around the eastern part of the Anorthosite Block Zone. Therefore the core of the zone may have been an attached protrusion into the Hettasch magma chamber, or perhaps this zone is an allochthonous mass which was first fractured and intruded, and which then became detached and slid into its present position. Some of the anorthosite blocks in Hettasch matrix may then be analogous to Wildflysch.

The anorthosite in the block zone is pale, and on freshly broken surfaces the plagioclase is typically gray. Much of the anorthosite is nearly pure plagioclase, but locally it contains minor amounts of pyroxene (and olivine?). The rock is massive and has a granulated texture. Although the feldspar is not as pink nor the CI as high as in much of the Foliated Anorthosite unit, the anorthosite of the Anorthosite Block Zone is tentatively correlated with this unit.

<u>Structure</u>. The structure of the Hettasch intrusion is that of an asymmetrical syncline, or trough (also described in FR 1972, p. 50-51, 59). The outer limb is quite steeply dipping (30° - 70°) and the inner limb has very shallow dips (0° - 20°). The axis of the intrusion is curved through nearly 160°. North of Mt. Hettasch the intrusion narrows and may become homoclinal, dipping to the southeast.

Between Mt. Hettasch and Fox Lake it is clear that the structure plunges to the south or southeast, because the syncline opens in that direction. Therefore, starting from the center of the intrusion and

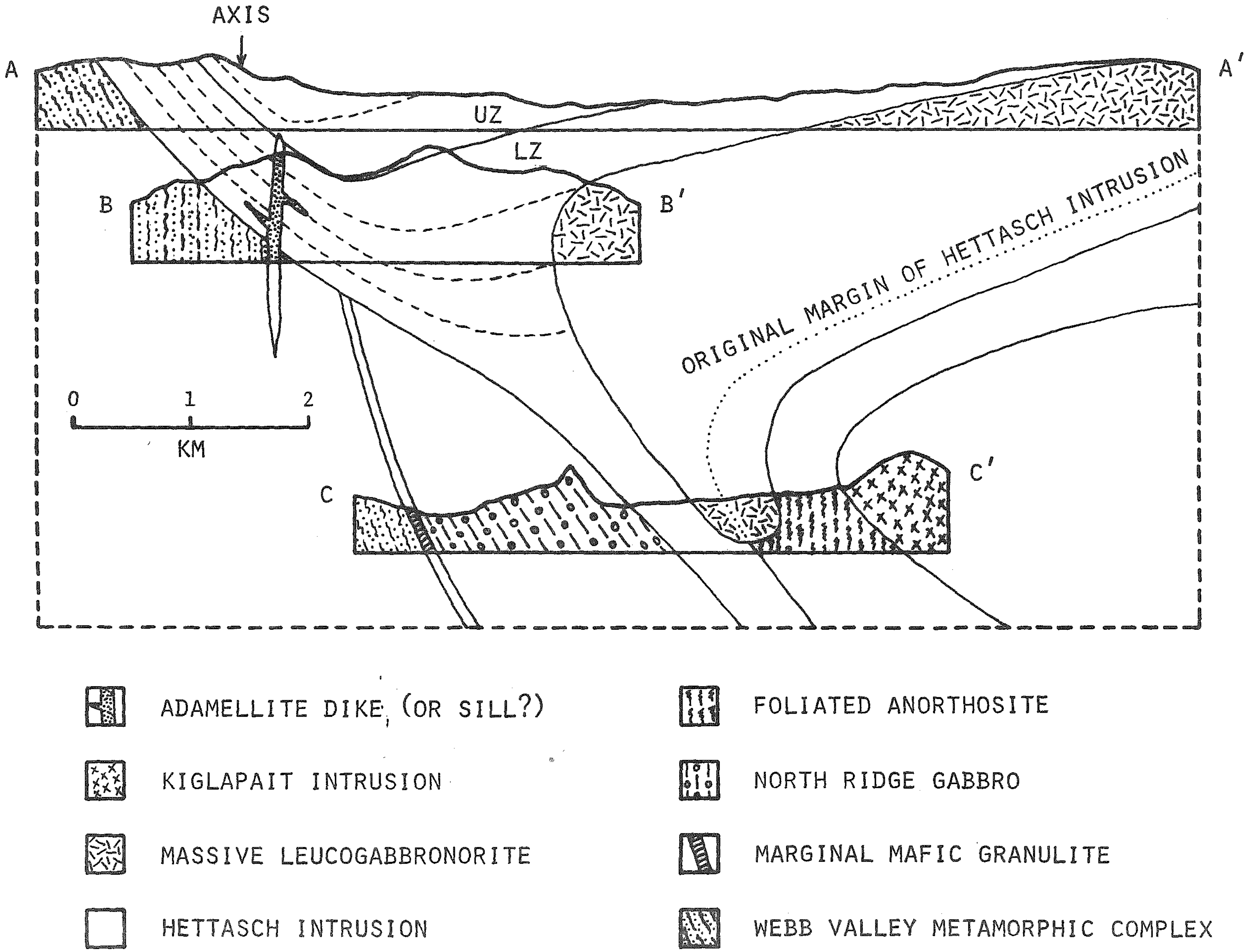


Fig. 32. Composite cross-section of the Hettasch intrusion and associated rocks. Lines of section are shown in Fig. 30.

moving along the axis toward the north should mean that one is passing into deeper levels of the structure. The interpretational cross-section (Fig. 32) is analogous to an axial projection, and consists of the stacking up of three cross-sections based on their order of depth in the structure. The resultant trough and feeder dike interpretation is similar to the structural interpretation of the Muskox intrusion (Smith, et. al., 1966).

Discussion. Field studies this year have indicated that in the main part of the Hettasch intrusion the outer limb has a lesser stratigraphic thickness and a higher color index than the inner limb. This, in addition to the fact that the outer limb is quite steeply dipping and layered or massive whereas the inner limb is shallow dipping and laminated, suggests that the two limbs had different depositional environments. It may be that the inner limb consists of true floor cumulates and the outer limb consists of wall "congelation cumulates" (Wager and Brown, 1967). Hence, there may be a facies change, a stratigraphic thickening or thinning, and a change in depositional style, all due to a change in depositional environment. The facies change (more mafic vs. less mafic) could result from a greater degree of supercooling in outer limb congelation cumulates; this would work especially well if olivine was not a cumulus phase in the inner limb floor cumulates (see below). The congelation cumulates would be thinner because of lying on a steep slope and retaining fewer primocrysts. As for depositional style, the congelation cumulates would form mainly by congelation of magma interrupted by intermittent density currents, whereas the floor cumulates would form by crystal settling from a steady-state convection current.

Bearing on anorthosite problems. Several aspects of the Hettasch intrusion bear on the problem of the origin of anorthosite. First, the mafics (including olivine) throughout most of the LZ, especially ILZ, are patchy-poikilitic, the principal exception being the olivine which occurs in the mafic layers of the lowermost OLZ. The lack of cumulus olivine, or other mafics, leaves plagioclase as the only cumulus phase during the LZ crystallization history. This implies crystallization in the plagioclase + liquid field, and subsequent crystallization of the intercumulus liquid on the plagioclase + olivine cotectic. The alternative is that crystallization occurred on the plagioclase + olivine cotectic, and the olivine was efficiently swept away to an unseen repository.

The first hypothesis, crystallization in the plagioclase + liquid field, does not require an anorthositic liquid. Emslie (1971) has shown that for a simple system, Di-En-Plagioclase (Ab_{40} An_{60}), the primary phase field of plagioclase at 15 kbar (dry) expands toward enstatite with decreasing pressure. Between seven and five kbar the enstatite field is replaced by forsterite; with a further decrease in pressure the plagioclase field continues to expand, now at the expense of olivine. At high pressures a liquid of high alumina basaltic bulk composition might have begun crystallization on the plagioclase + orthopyroxene (or olivine) cotectic or in the primary phase field of orthopyroxene (or olivine). As the magma ascended, the plagioclase field could have expanded until it encompassed the bulk composition. Thus, when the magma was finally emplaced at low pressures, crystallization in the plagioclase field in conjunction with crystal settling could have produced a plagioclase cumulate. Supercooling (supersaturation) at the margins of the intrusion could explain the local presence of cumulus olivine.

Crystallization of plagioclase-rich rocks will necessarily cause a magma to become enriched in mafic constituents with time. Although it was previously thought that the Hettasch intrusion became more leucocratic with increasing stratigraphic height (Berg, 1973), data now indicate that the UZ is more mafic than the ILZ. The UZ does not appear to be more mafic than the OLZ, but that may be due to supersaturated crystallization in the congelation cumulates postulated above.

A discussion of mechanisms deals only part of the anorthosite problem. Equally important is the question of what kinds of liquids were involved in the production of anorthosite. The textures and field relationships of the chilled margin (FR 1972, p. 59-61) indicate that these are strongly chilled rocks. Whether or not they represent a homogeneous, undifferentiated sample of the Hettasch magma is unresolved at this time (compare Leeman, et. al., 1973). The one available analysis* (Berg, 1973 and

*This composition is similar to the one computed by Morse (personal communication, 1973) for the Kiglapait layered intrusion.

Table 7), if representative of the original magma, suggests that the liquid which produced this anorthosite had a chemistry similar to high-alumina olivine tholeiite (subalkaline basalt). If so, a material balance is lacking, i.e., the exposed rocks of the intrusion sum to a composition too plagioclase-rich relative to the chilled margin composition, and either rocks higher in the stratigraphy have somehow been removed, or the liquid, after depositing the exposed rocks, became separated from them.

Even if the chilled margin is a true indication of the composition of the magma which produced the Hettasch intrusion, the Nain anorthosite complex consists of many distinct and separate intrusions, and there was undoubtedly a spectrum of magma compositions. What is ultimately important is a definition of this spectrum.

Acknowledgments

This work has been supported by a Grant-in-Aid of Research from the Society of the Sigma Xi and by two Penrose Bequest Research Grants from the Geological Society of America.

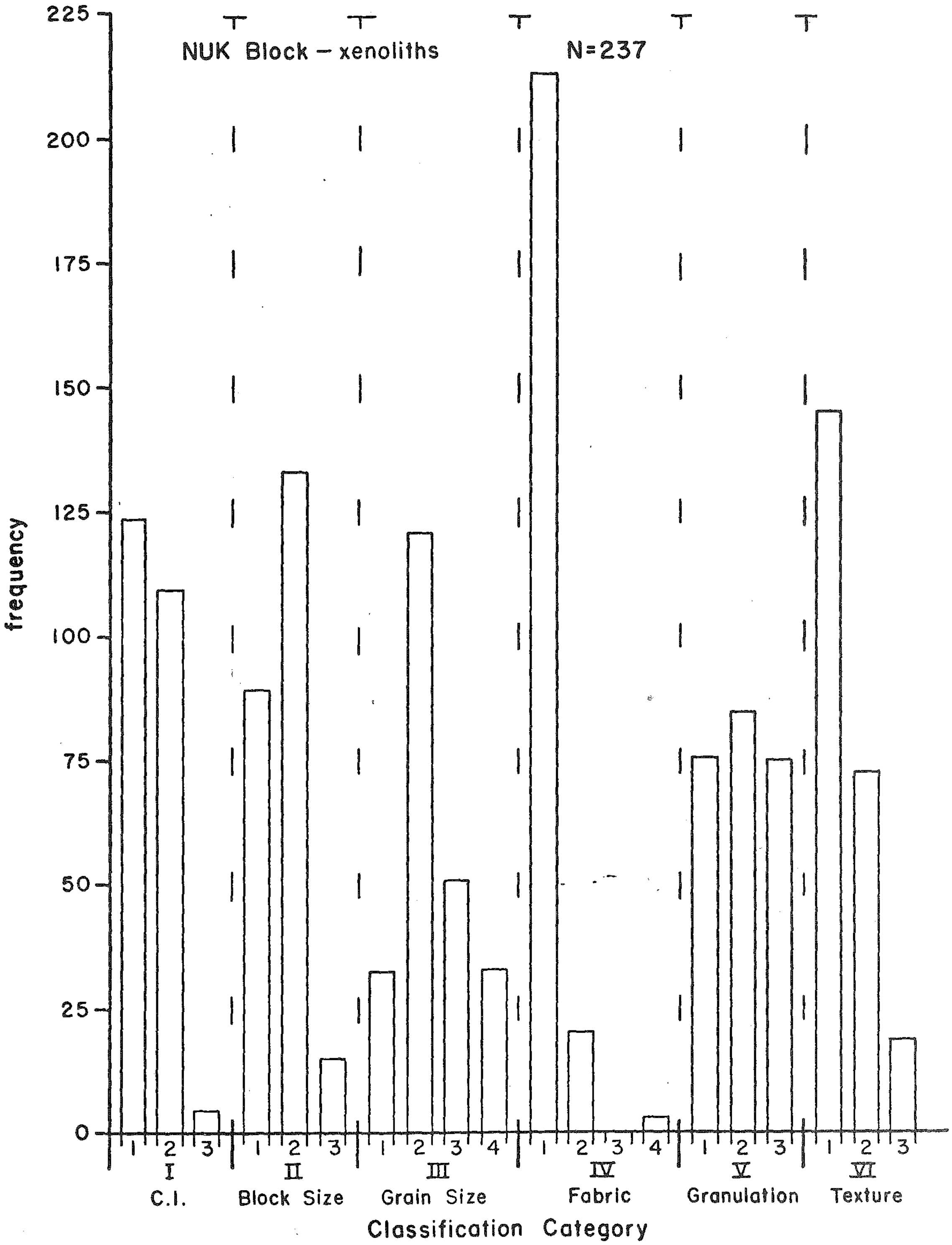


Fig. 33. Block type histograms for the block structure at North Bay, Nukasorsuktokh I.

NUKASORSUKTOKH BLOCK STRUCTURE

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Mount Holyoke College [1]

A characteristic occurrence near contacts of anorthosite massifs is that of "block structure": anorthositic xenoliths in an anorthositic matrix. In the Nain area, this structure is particularly well displayed along the coastline of North Bay, Nukasorsuktokh Island, and is briefly described by Morse (FR 1972, p. 106). Further mapping, by Davies, is reported elsewhere in this volume. The blocks are variable and can be classified according to the system in Table 8. They are autoliths within a relatively homogeneous leuconorite matrix. Most blocks are accompanied by a mafic rind which belongs to the matrix rock and which appears to have resulted from a chilling of the matrix magma against the block.

Block structure has commonly been referred to simply as a structural phenomenon (the result of autobrecciation or stoping), rather than as a petrologic problem. Preliminary investigations and sampling were done in 1972 as preparation for a more detailed study which was carried out in 1973. Petrologic work based on samples taken in 1972 indicates that the blocks may be dominated by adcumulus growth of plagioclase, the resultant crystals being little zoned. The matrix rocks, on the other hand, seem to display orthocumulus growth, with more zoned crystals and a wider range of plagioclase composition within samples (Morse, FR 1972, p. 110). Adcumulate origin of the blocks indicates isothermal growth at constant compositions at the time of crystallization due to the free migration of ions between the intercumulus liquid and the magma. Orthocumulus growth of the matrix rock means that the intercumulus liquid was restricted and therefore fractionation took place over a range in temperature, resulting in zoned crystals and subophitic texture. Additionally, the orthocumulate would have remained mobile for a longer period of time and to lower temperatures than the adcumulate. Thus, the mobile orthocumulate matrix mush would tend to stope the already crystallized areas of adcumulate growth at the contacts of the massif, forming the distinctive block structure. This

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

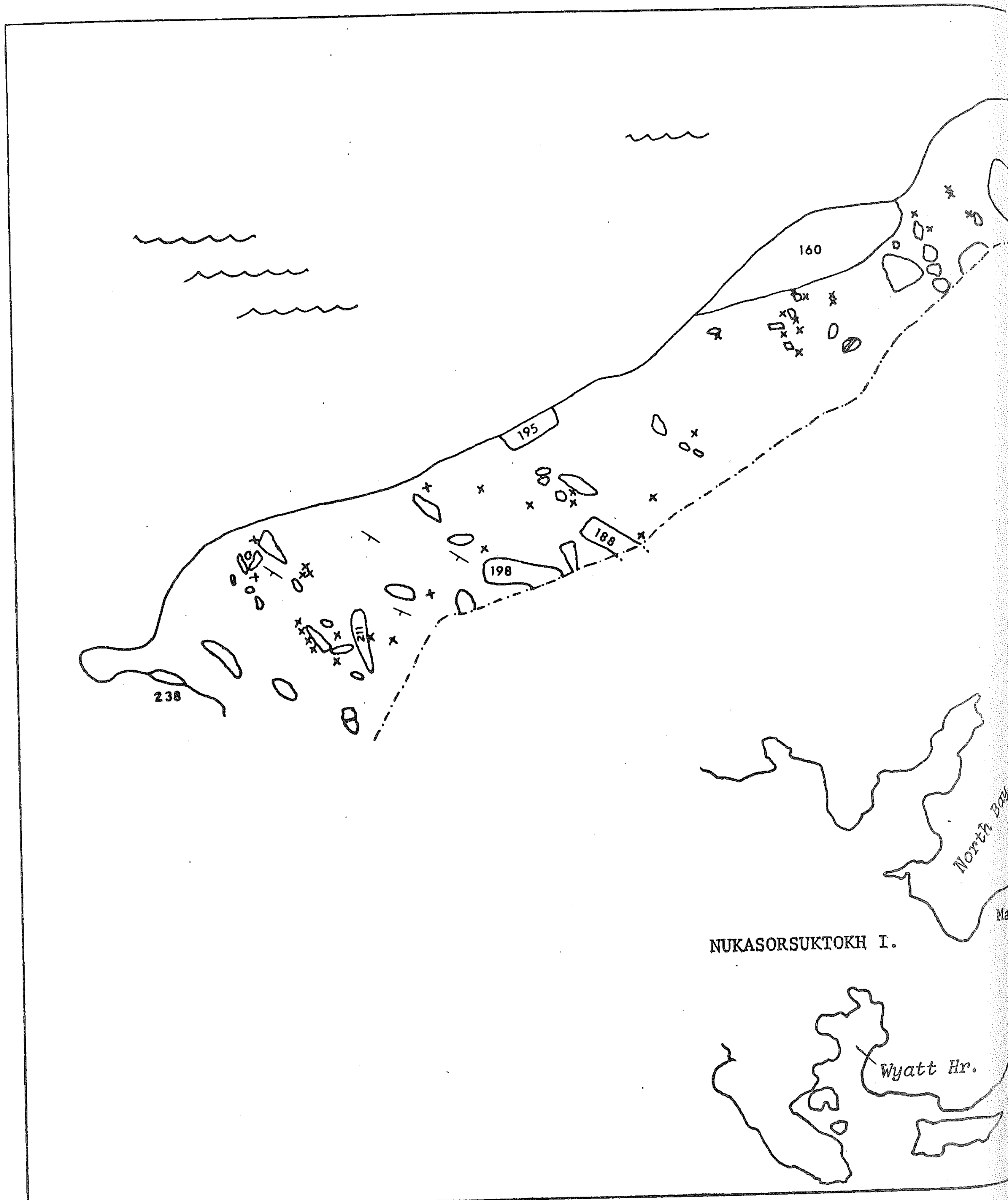

Fig. 34. Map of the North Bay block structure, Nukasorsuktokh I. The figure is continued on the next two pages, which contain scale and key.

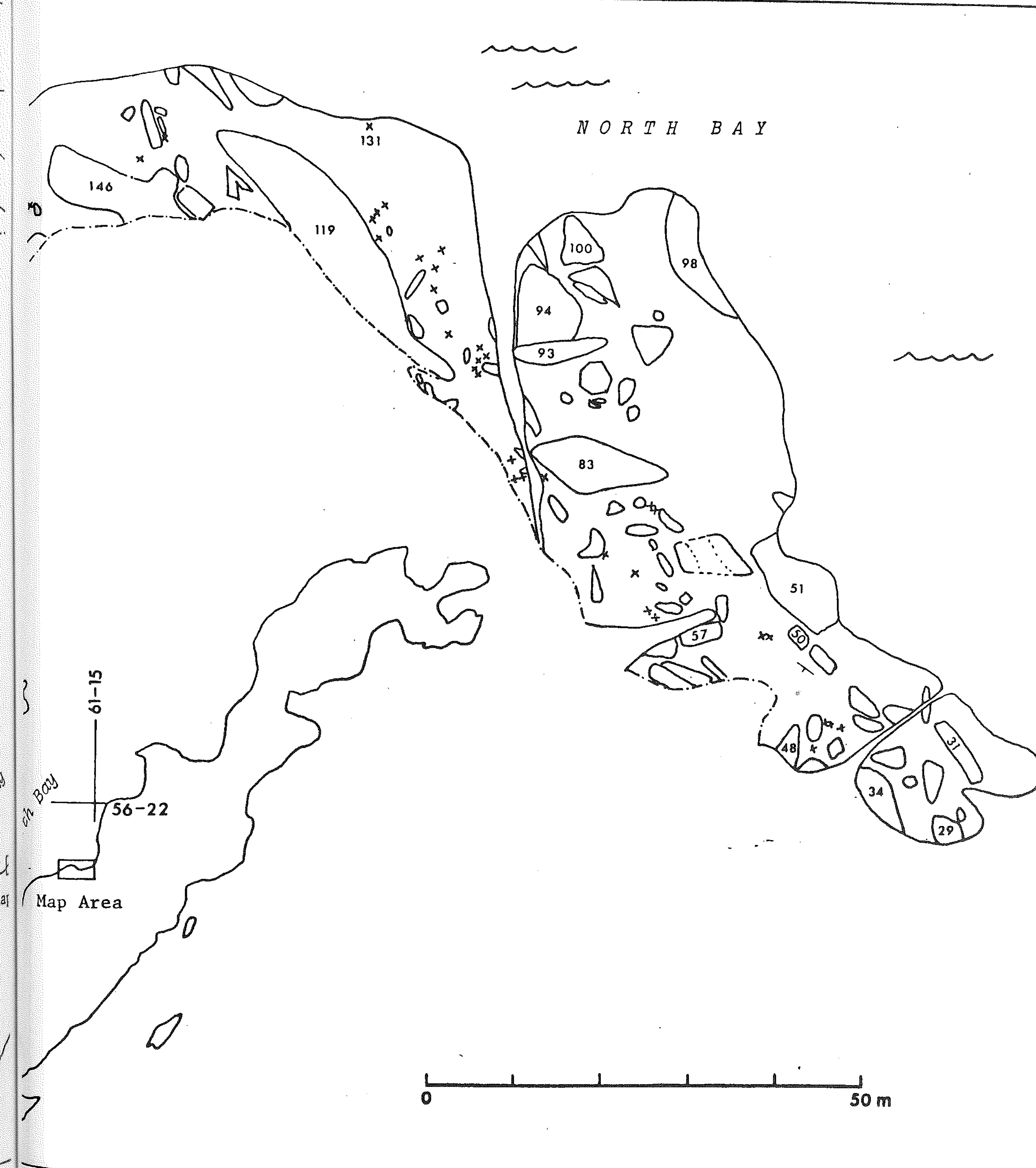

Fig. 34, continued. . . .

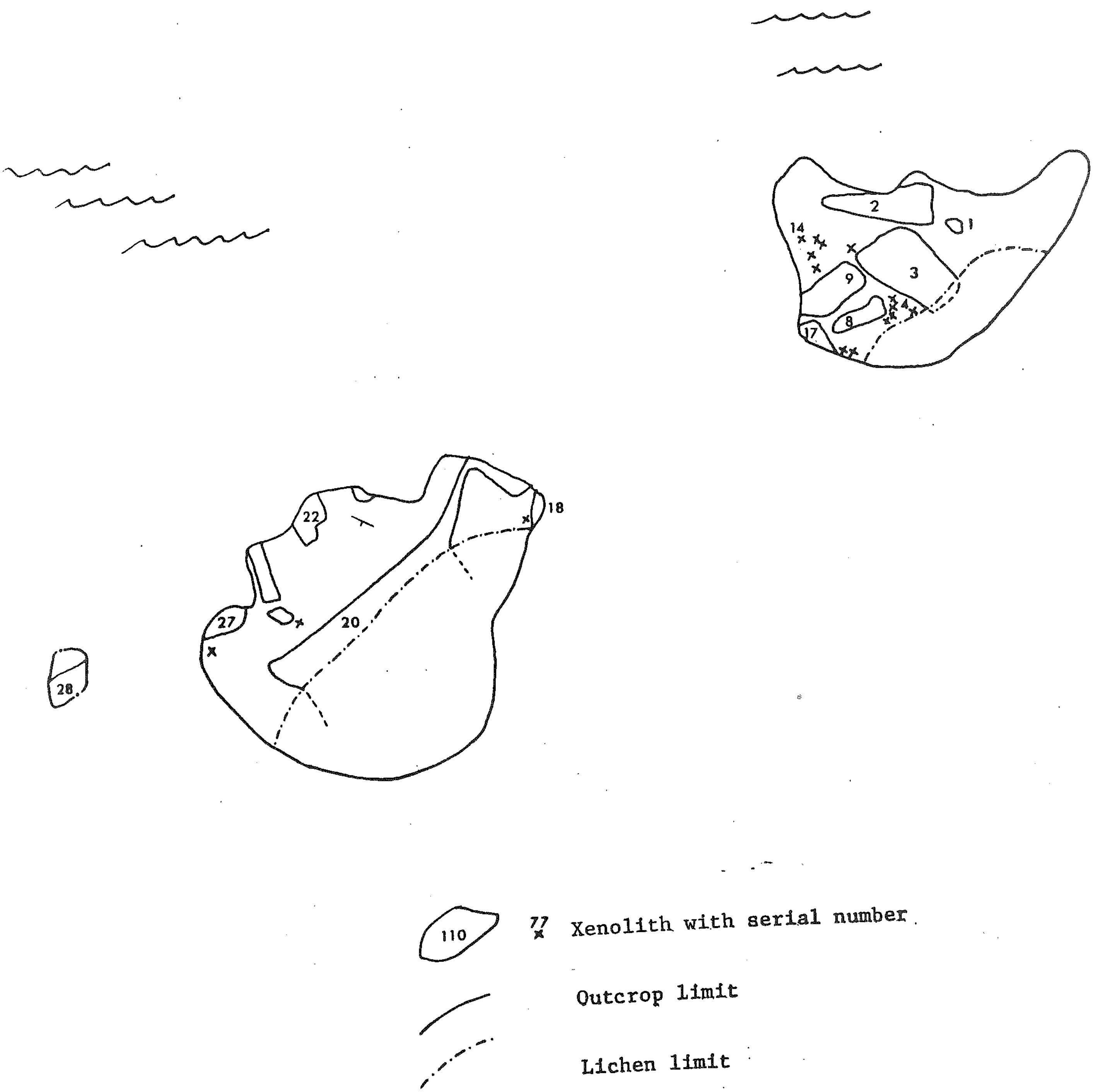

Fig. 34, concluded.

is the hypothesis which remains to be evaluated through detailed studies.

Field work in 1973 consisted of mapping and sampling a section of the coastline 0.5 km by 30 m in North Bay, where block structure is exceptionally well exposed. Two hundred and forty-one blocks were mapped using plane table and alidade (Fig. 34). Representative samples of the various block types, rims, and of the matrix rock were taken and their locations plotted on the map.

A tally of the frequency of the block characteristics has been made (Table 9) and compared in six histograms (Fig. 33) on the basis of the categories presented in Table 8. The histograms can be summarized in the following general description: Blocks in the North Bay block structure tend to be anorthositic or leuconoritic in composition; they are most commonly 1-10 m in size; they are dominantly of 1 cm grain size; very few have a planar fabric; their grain-margin granulation ranges uniformly from nil to severe; and most have a granular as opposed to subophitic texture. The classification system was on the whole satisfactory, but a few blocks with major deviations which made them difficult to classify in a straightforward manner have been deleted from the tally. Variations within the limits of the classification system include wide range in grain size within a block, and the inclusion of patches of apparent composition very different from the host block. Another interesting feature of some blocks is the presence of a bleached rind. This is probably due to the baking out of tiny inclusions of oxides that ordinarily darken the plagioclase. The color change is independent of color index. The small number of blocks with a wide range of internal variation were classified by noting all the characteristics which applied.

Most blocks are made obvious by rims of high mafic content that are often of pegmatitic coarseness. The pyroxene grains in such rims range in size from less than 1 cm to 15 cm and in many cases opaque oxides such as magnetite are also present. The rims are more clearly developed to the west of each block. There are many different rim types; some are well defined, others gradational, some simple and some layered.

The blocks occur within a matrix of subophitic leuconorite (70% plagioclase) with an average grain size of 1 to 3 centimeters. There are occasional 5- to 10-, and sometimes 20-centimeter plagioclase megacrysts, some of which display iridescence. The matrix rock shows subtle differences in color index, as layers trending 110°-140° true, with nearly vertical dips. The layering can be found throughout the mapped area if one looks hard enough, but is more distinct in the southwestern portion. Isolated seams of norite are present in the matrix rock, but are probably related to the rims.

Continued study of the samples taken will indicate the range and variation of plagioclase composition, and provide further data from which to interpret the origin of block structure and its bearing on the origin of the Nain anorthosite massif.

Table 8: Block Classification System, after Morse and Dymek.

I. Color Index
   1. anorthosite >90% plagioclase
   2. leuconorite >65% plagioclase (<90%)
   3. norite <65% plagioclase

II. Block size
   1. <1 meter
   2. 1-10 meters
   3. >10 meters

III. Grain size
   1. <1 centimeter
   2. average 1 centimeter
   3. average 5 centimeters
   4. average 15 centimeters

IV. Fabric
   1. massive
   2. foliated
   3. laminated
   4. layered

V. Granulation
   1. none
   2. minor
   3. all margins of plagioclase

VI. Texture
   1. granular
   2. subophitic
   3. "intersertal"

Table 9: Tally of block types according to the classification scheme in Table 1.

	I	II	III	IV	V	VI
1	124	89	32	213	76	146
2	109	133	121	21	85	73
3	4	15	51	0	76	18
4	–	–	33	3	–	–
Total	237	237	237	237	237	237

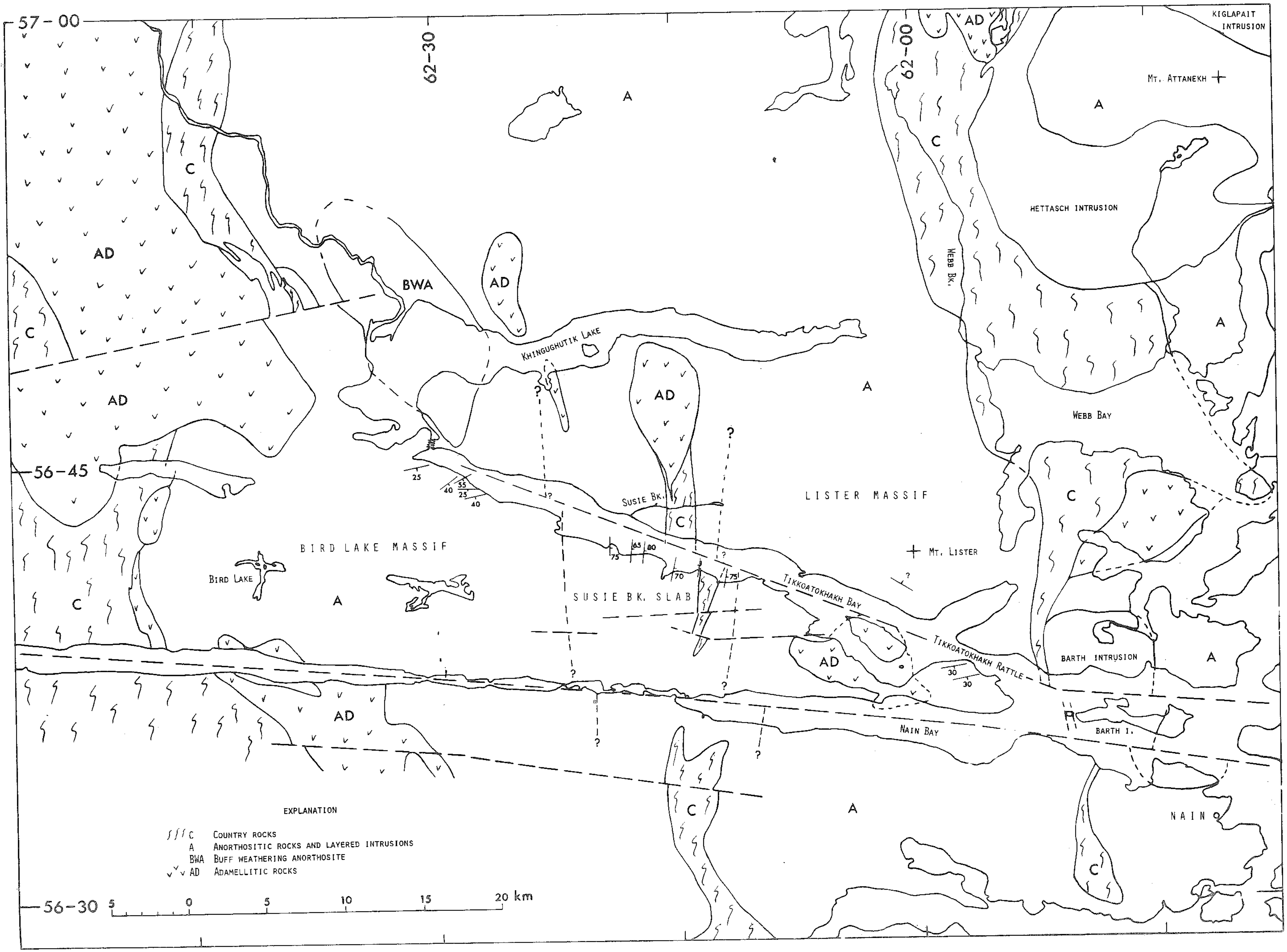

Fig. 35. Regional geology northwest of Nain, Labrador, after Wheeler (1968 and ms. maps).

LAYERED ANORTHOSITE MASSIFS ALONG TIKKOATOKHAKH BAY

S. A. Morse, University of Massachusetts, and
E. P. Wheeler 2nd, Cornell University[1]

In FR 1971 we reported (p. 65) an occurrence of layered anorthosite at Tikkoatokhakh Rattle, at the entrance to the long bay of the same name. At that time, the limits of this zone of southeast dipping layering were unknown, but were suspected to be large. Opportunities to examine this region from low-flying aircraft have since arisen, and with the aid of several days' ship-based shoreline study in 1973, have permitted the following generalizations on layered anorthosite in this area.

There appear to be at least two very large, untilted massifs of layered pale anorthosite flanking Tikkoatokhakh Bay (Fig. 35). We will call these the Lister massif, after the conspicuous 850 m mountain which dominates the entrance to the bay, and the Bird Lake massif, lying to the south of the western end of the bay. These are separated by a monoclinal slab, some 10 km thick and dipping about 75° E, of N-S foliated, weakly layered leuconorite to anorthosite. The latter unit contains giant orthopyroxenes with regular lamellae of plagioclase, and in addition, apparently cumulus ilmenite. We will call this unit the Susie Brook slab.

Lister Massif

Aerial observations indicate well developed large-scale layering on the south side of Mt. Lister. This has the same appearance from the air as that at Tikkoatokhakh Rattle, where the rocks are coarse to very coarse pale labradorite anorthosite to leuconorite. The strike of the layering is sub-parallel to the bay shore (ESE), but dips are not known. From lithologic mapping by Wheeler (manuscript), it is inferred that the massif, which may be layered throughout, has an area of some 400 km^2,

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

with unknown northward extent, as suggested on Fig. 35 . The gravity field over this massif and its surroundings is bland and unremarkable (D. Halliday, personal communication, 1973). The excellent exposures on the slopes of Mt. Lister, the relief, and the accessibility of the area by aircraft and canoe, make this massif a natural choice for a detailed study of the internal properties and compositional variation of a major anorthosite mass whose layering should provide good stratigraphic control. No ground observations were made in 1973.

Bird Lake Massif

Aerial observations revealed an abundance of southerly-dipping layering with moderate dips along the south shore of the western part of Tikkoatokhakh Bay. The mass may extend southward at least as far as the Nain Bay linear system, Fig. 35, based on earlier mapping (Wheeler, m.s.). An area in excess of 300 km^2 is implied.

Ground examination in 1973 yielded the attitudes of layering shown in Fig. 35 along the bay shore. The layering, easily visible in cliff faces from a distance, becomes elusive on close inspection. The rocks are coarse to very coarse grained, with an average color index (C.I.) near 10. Some 20-cm layers are megacrystic, and others are more mafic than average (C.I. = 25) with hypersthene and ilmenite as cumulus mafic minerals. Lamination of 5-cm plagioclase tablets is locally seen, and probably common. Subophitic texture is well developed. In many outcrops, 1-5 cm anorthosite contains irregular zones or patches of 15 cm leuconorite, with giant pyroxenes and plagioclase locally reaching a size of 1/2 m. Iridescence in greens and blue-greens is common in plagioclase. There are local zones of norite, C.I. up to 40.

Giant pyroxenes in many of the rocks examined consist of a spongy to granular intergrowth of pyroxene and minor plagioclase. The granules are millimeter-sized. If one believed that orthopyroxene could contain plagioclase in solid solution, one would be tempted to ascribe the spongy and granular intergrowths to a recrystallization reaction from initially homogeneous pyroxene. On the other hand, relationships on a coarser scale locally show that plagioclase has crystallized in "reverse ophitic" texture around fragments (or crystals?) of pyroxene, implying nearly contemporaneous growth from the melt of plagioclase and hypersthene in intimate relation. Further mention of plagioclase-pyroxene intergrowths is made below.

Distinct layering was not seen in the eastern part of the Bird Lake massif, and the structural relationship of this massif to the Susie Brook Slab is essentially unknown.

Susie Brook Slab

This unit of leuconorite is distinguished by discontinuous "stretched" layering which dips uniformly 75 ± 10° E. Mafic layers are enriched in cumulus pyroxene, commonly of 15 cm scale, and lesser amounts of ilmenite commonly concentrated near the base of the layer and therefore of apparently cumulus origin. Primary sedimentary and erosional features are lacking or obscured by an apparently penecontemporaneous deformation, which amounted to a subhorizontal extension in the plane of the original layering. Large pyroxenes or clusters of mafic minerals are rotated to mutual parallelism of outline or internal fabric, and thin, tapering lenses occur along the trace of layering, which may once have been continuous. The late magmatic timing of this deformation is suggested by the following facts: 1.) planar features are almost perfectly parallel to layering, 2.) the subophitic texture of giant pyroxenes is deformed but not obliterated, 3.) deformation does not penetrate individual giant pyroxenes, and 4.) there occur undeformed dikes of leuconorite, apparently cognate and at least very similar in appearance to the host rock.

As in the Bird Lake massif, large crystals of pyroxene commonly consist of a granular sponge, possibly consisting of plagioclase and hypersthene in a matrix of augite. In addition, there occur abundant coarse hypersthene crystals with uniformly distributed tabular lamellae of plagioclase parallel to c of the hypersthene host. These lamellae are under one millimeter thick, and constitute less than 10%, perhaps less than 5%, of the total crystal volume. Examination in oil immersion shows that the plagioclase lamellae are of labradorite to andesine composition, and very strongly zoned, perhaps suggesting either a eutectoid intergrowth or exsolution strongly controlled by epitaxy.

The Susie Brook slab, near its eastern border, merges with a conformable zone of more mafic rock of varied mineralogy, containing garnet toward its center. This zone seems to have lithologies ranging from those of country rock to those of the noritic rocks, and may be a foundered fragment of the roof.

Summary

Both the Bird Lake massif and the Susie Brook Slab are distinctive in having cumulus ilmenite, and pyroxenes with spongy intergrowths of plagioclase. These distinctive features suggest a genetic relationship which is, however, at least partially obscured by the strikingly different fabric of the two bodies. In any event, the granular or spongy pyroxene texture is not obviously a product of deformation, since it occurs in the unstretched Bird Lake massif. The occurrence of primary ilmenite makes both these bodies attractive for comparison with the well-known ilmenite ore deposits associated with some Grenville anorthosites, and offers some encouragement for further mineral exploration in this part of the Nain anorthosite. Similar mineralogical features may occur in the Lister massif, which has as yet been examined but briefly on the ground.

Together, the two massifs and the slab constitute a very large areal extent (on the order of 10^3 km^2) of layered noritic anorthosite and related rocks. It will be of importance to determine, in detailed field studies, the up-stratigraphic mineral variation of these bodies, their mutual contact relations, the reasons for their curious pyroxene intergrowth with plagioclase, and the extent, if any, of their gradation toward buff-weathering anorthosite or more acid rocks. Already, it can be said that these bodies demonstrate large-scale crystallization of anorthositic rocks from magma saturated with hypersthene and ilmenite.

BASIC DIKES

BASIC DIKES IN THE NAIN - KIGLAPAIT REGION

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University of Edinburgh[1]

The following are some observations regarding the basic dikes sampled in the Nain area between August 26 and September 3, 1971. I found these rocks more interesting than I had expected and a thorough petrochemical study of the diabases in this region would, I am sure, be most rewarding.

Only seven dikes were examined in this very inadequate piece of sampling. Chemical analyses and dike descriptions are given below in Tables 10 and 11. The dikes subdivide readily into two groups. One has tholeiitic character and includes two dikes (ESE dike on Nain Hill, Ld 20, 21, 22 and the E-W dike on Paul Island, Ld 4, 5). The other group (samples Ld 1, 3, 9, 17, 23) is clearly alkalic. These strike between N-S and NE-SW while the two tholeiitic dikes trend ESE-WNW to E-W, and (on the basis of one intersection) may be younger. Some, at least, of the alkalic dikes are younger than the Kiglapait-Nain troctolites and anorthosites.

Both the tholeiitic dikes are markedly feldspar-phyric. The large Nain Hill dike is strongly silica oversaturated and the zonation evident in the field, with phenocrysts being increasingly important from chill to center is shown up clearly in the three analyses across this dike. The other tholeiitic dike is less siliceous, is olivine normative and does not carry two separate pyroxenes as does the Nain Hill dike.

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

Table 10. Chemical analyses of basic dikes in the Nain region. Descriptions are given in Table 11, at the end of this article.

	1	2	3	4	5	6	7	8	9	10
SiO_2	44.8	45.5	48.2	49.0	46.9	44.6	53.9	52.3	52.8	44.3
TiO_2	2.4	3.2	1.9	1.8	3.4	3.3	1.8	1.8	1.3	3.3
Al_2O_3	16.2	14.1	16.6	16.7	14.1	15.2	13.7	15.4	19.1	15.3
Fe_2O_3	2.41	3.06	3.12	4.71	3.05	2.62	1.80	2.38	2.89	2.51
FeO	12.14	11.30	8.55	6.99	11.54	13.10	8.92	9.21	5.99	13.47
MnO	0.21	0.19	0.22	0.18	0.20	0.21	0.16	0.17	0.13	0.21
MgO	6.47	4.48	4.83	4.97	4.55	5.88	3.86	4.46	3.26	5.88
CaO	8.75	7.13	8.37	8.31	7.10	8.28	6.46	8.02	9.04	8.18
Na_2O	3.38	3.81	3.50	3.62	3.83	3.47	4.40	3.43	3.77	3.50
K_2O	0.83	1.88	0.93	0.94	1.92	1.42	1.64	1.16	1.02	1.42
P_2O_5	0.66	1.50	0.48	0.43	1.50	1.20	0.70	0.54	0.39	1.35
H_2O^+	1.63	1.09	3.14	2.45	1.34	0.77	1.52	1.27	1.48	0.69
CO_2	$<$0.10	0.15	0.14	0.08	$<$0.10	$<$0.10	$<$0.10	$<$0.10	$<$0.10	$<$0.10
	99.98	97.39	99.98	100.18	99.53	100.15	98.96	100.24	101.27	100.21
	C.I.P.W. norms									
q	-	-	-	0.15	-	-	2.21	2.99	3.11	-
or	4.99	11.53	5.67	5.68	11.55	8.44	9.94	6.92	6.04	8.43
ab	24.63	33.45	30.57	31.33	32.98	24.83	38.19	29.32	31.96	24.63
an	27.01	16.41	27.70	27.15	15.88	21.83	13.12	23.43	32.24	21.93
ne	2.40	-	-	-	-	2.55	-	-	-	2.76
di	10.01	7.61	9.07	9.42	7.78	9.12	12.03	10.43	7.82	7.77
hy	-	0.36	12.68	14.55	4.32	-	16.39	18.45	11.01	-
ol	20.95	15.69	4.40	-	12.57	20.04	-	-	-	21.09
mt	3.55	4.60	4.67	6.99	4.50	3.82	2.68	3.49	4.20	3.65
il	4.63	6.31	3.73	3.50	6.57	6.30	3.51	3.45	2.47	6.29
ap	1.59	3.69	1.17	1.04	3.62	2.86	1.70	1.29	0.93	3.21
cc	0.23	0.35	0.33	0.19	0.23	0.23	0.23	0.23	0.23	0.23
D.I.	32.2	44.98	36.25	37.17	44.52	35.81	50.34	39.23	41.11	35.82
Normative An% of feldspar	47.70	26.74	43.32	42.31	26.30	39.62	21.42	39.27	45.90	39.88

Table 10., continued.

Trace-elements ppm

	1	2	3	4	5	6	7	8	9	10
Ba	440	1190	1030	700	1190	730	880	880	790	720
Zr	205	290	200	180	275	350	270	165	140	340
Y	42	52	37	37	52	52	40	35	27	55
Sr	300	265	425	460	285	270	340	465	595	265
Rb	15	40	12	10	40	32	22	15	12	30
Zn	120	140	145	110	120	125	145	115	95	130
Cr	90	90	150	110	110	100	120	150	150	90
V	180	140	170	180	120	170	230	200	150	170
Ni	280	300	510	330	380	390	410	530	630	390
Cu	50	30	55	45	40	35	30	40	25	35

Partial analyses by D.F. Strong. Analyses for FeO, CO_2, H_2O^+ by M. Saunders. Trace-element analyses by G.R. Angell.

1 Ld 1
2 Ld 3
3 Ld 4
4 Ld 5
5 Ld 9
6 Ld 17
7 Ld 20
8 Ld 21
9 Ld 22
10 Ld 23

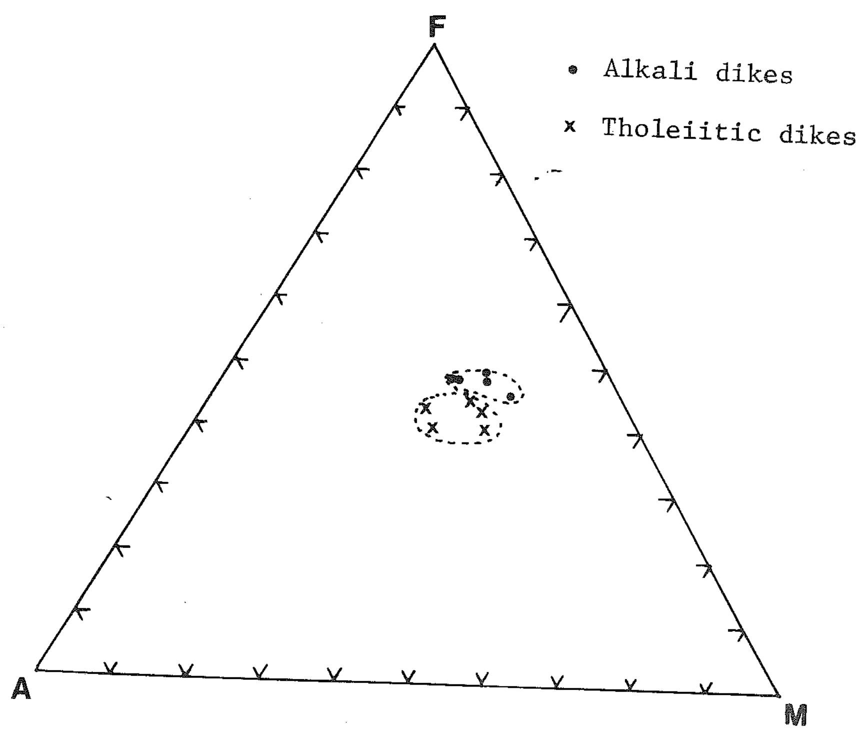

Fig. 36. FMA plot of Nain region basic dikes.

Three of the alkalic group possess normative nepheline (without any adjustment of the Fe"/Fe"' ratio). These are the most magnesian dikes sampled and have the lowest silica contents. Each has about 20% normative olivine and has a differentiation index in the range 32-36. Alkali contents, (especially potassium) are high for such magnesia values and the rocks cannot really, in view of their low SiO_2 and relatively high MgO, be called hawaiites and are perhaps better designated as potassic alkali basalts, or trachybasalts since they have normative andesine.

Two of these three alkalic dikes (Ld 17 from Partridge Point, Kiglapait area, and Ld 23 from Nain Hill) are chemically and petrographically indistinguishable and have such a distinctive composition that it is likely they are contemporaneous intrusives. The other two alkalic dikes, Ld 3 and Ld 9, are also chemically very similar. They are slightly more siliceous than the ne-normative dikes, while being more alkalic and less magnesian. They display the highest incompatible element values (K_2O ∿ 1.9%, Ba ∿ 1200ppm, Rb ∿ 40 ppm, P_2O_5 ∿ 1.5%) and have 11.5% normative orthoclase. They could well be regarded as being part of the more highly differentiated residua. Interestingly they show no normative nepheline and are nearly critically undersaturated, suggesting the possibility that we have here (another) alkalic basalt series in which silica undersaturation is lost with increasing differentiation. The 'series' cannot appropriately be described as alkali basalt → hawaiite (→ mugearite) but edges closer to the absarokite → shoshonite type of suite.

Despite the very small sample size, all ten analyzed specimens from the seven dikes indicate that we probably have a basaltic province in the Nain district characterised by very high K, Ba and Zr and Ni. This generalization holds for both the tholeiitic dikes and for the alkalic ones. Secondly, and again despite the small sample, it is clear that we most definitely do not simply have a number of uniform tholeiitic diabases in the area, and that genuinely undersaturated alkali dolerites play a significant role.

Iron-enrichment is moderate but not exceptional in these dikes, nor are they especially aluminous.

The high incompatible element contents, the fact that no diabases with over 6.5% MgO were collected, and the petrographic indications that these basaltic magmas were precipitating plagioclase at higher temperatures than the commencement of pyroxene crystalization, are all features in common with the Gardar dikes of S.W. Greenland. The trend of the five alkaline dikes in the Nain region is also not inconsistent with the dominantly NE to ENE trend of the Gardar alkaline dolerites.

Much broader sampling--and good age determinations--of the Labrador dikes are clearly desirable!

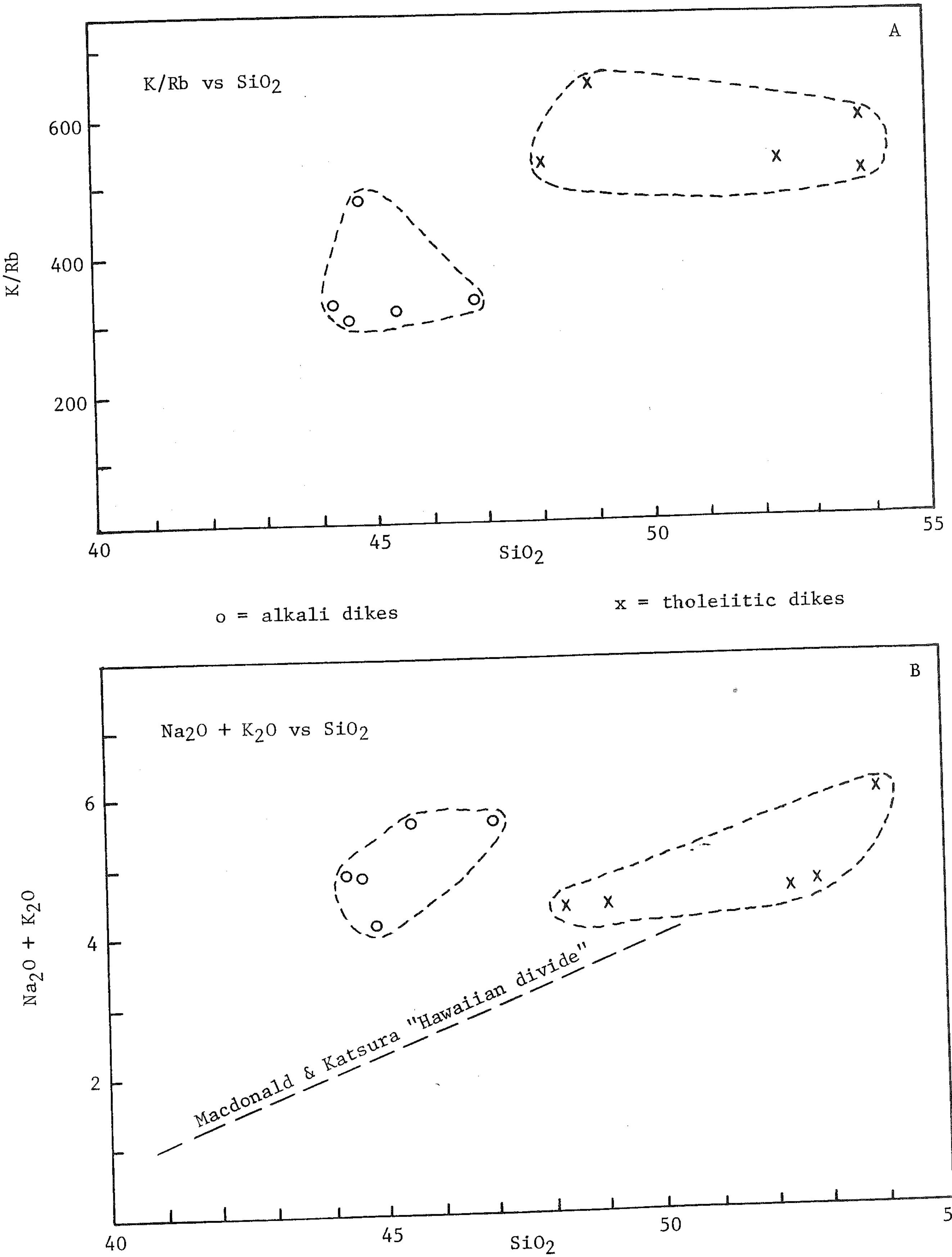

Fig. 37. Alkalies vs silica plots of basic dikes from the Nain region.

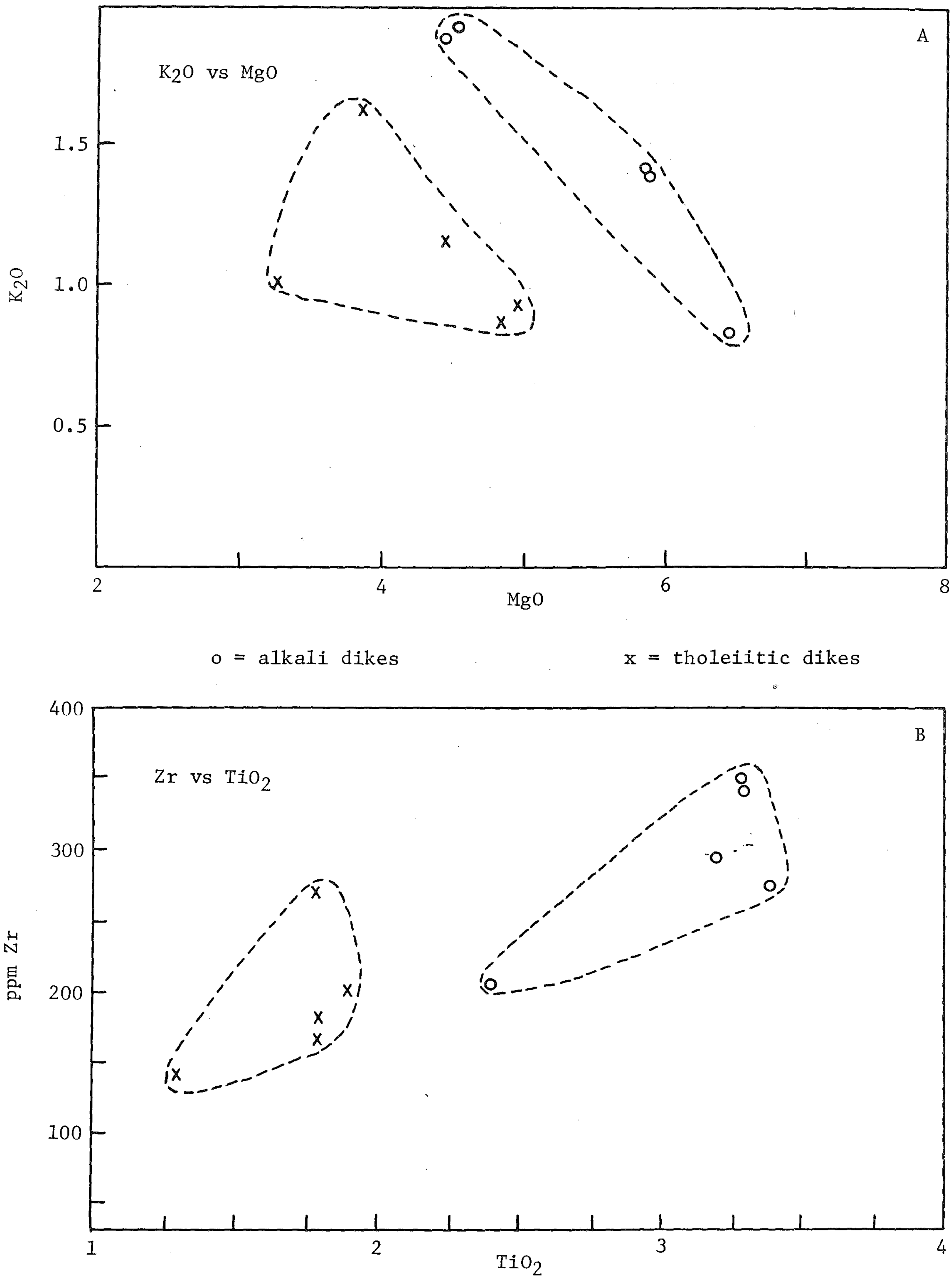

Fig. 38. Selected chemical parameters of basic dikes from the Nain region: A, K_2O vs MgO; B, ppm Zr vs % TiO_2.

Table 11. Descriptions of dikes.

Ld 1 20 m dike traversing S. side of Nain Harbour, vertical. Strike 077 i.e. ∿ENE-WSW. Cuts anorthosite. "Clean" aphyric chilled margin. No rheomorphism.

Is a coarsely ophitic dolerite. Ophitic pink Ti-augite. Plagioclase somewhat sericitized. Turbid interstitial alkali feldspar. Some biotite, partly chloritized.

Petrographically clearly an alkali dolerite. Confirmed by analysis indicating it to be slightly ne-normative, with 45% SiO_2 and 0.83% K_2O. Is the most basic dike collected with 6.47% MgO (all others < 6%!) and D.I. of 32.2.

Ld 2 1 m vertical dike on the S. side of Ford Harbour, extreme SE of Paul Island. Strike 096 i.e. ∿ E-W. Aphyric. Sample from dike center.

Chloritic pseudomorphs after olivine. Subophitic matrix of plagioclase, chlorite (? after pyroxene), opaques and some calcite. Not analyzed.

Ld 3 2 m vertical dike very close to Ld 2. Strike N-S. Fresh diabase with small plagioclase phenocrysts. Cuts quartzo-feldspathic gneiss.

Subophitic dolerite. Phenocrysts not noted in thin section. Mafics much oxidized. Former olivine probable. Colorless augite. Plagioclase distinctly clouded. Biotite is prominent and abundant acicular apatite is associated with turbid interstitial alkali feldspar. Probably a mildly alkalic olivine dolerite.

Analysis however shows it to have < 4% hy, with ∿ 45% SiO_2, 4.5% MgO and 1.9% K_2O, i.e. it is very distinctly potassic and lies virtually on the critical plane of undersaturation.

D.I. = 45, i.e. is a trachybasaltic rock with normative feldspar An_{27}. Has distinctly high Ba and Rb. High P. Almost identical to Ld 9 (analysis 5), q. v.

Ld 4 2.5 m E-W dike from Higher Bight, Outer Cove, Paul Island. Cuts pyroxene granulites. Is rich in large plagioclase phenocrysts, Ld 4 is from chilled facies.

Plagioclase phenocrysts within matrix of plagioclase and interstitial chlorite and opaques. Am of opinion that the interstitial material replaces original glass. Has nearly 13% hy, 48% SiO_2, 4.8% MgO and 0.9% K_2O. D.I. 36. Is petrographically (and chemically) acceptable as having been a tholeiite.

Ld 5 Central facies of the Ld 4 dike. Coarse ophitic dolerite with plagioclase phenocrysts up to 1 cm. Matrix of plagioclase, serpentinized olivine, pinkish augite. No alkali feldspar recorded. Chemically, no change from Ld 4.

Ld 9 10 m diabase dike. Strike 014, i.e. ∿ NNE-SSW. Cuts adamellite or granodiorite at September Harbour on Dog Island. Sparse plagioclase phenocrysts.

Ophitic rock with conspicuous ilmenite plates. Plagioclase and interstitial areas of (turbid) alkali feldspar and apatite. Colorless augite and olivine oxidized to magnetite. Major element chemistry very similar to Ld 3. Has 4% hy. D.I. 44. Like Ld 3 it is unusually rich in Ba and Rb and has very high K, P and Ti.

Ld 17 Chilled contact of feldsparphyric diabase dike. NE-SW. Cuts Kiglapait gabbros and reaches coast at Partridge Point. Width uncertain because of poor outcrop.

Is an ophitic olivine dolerite. Ti-augite distinctly rosy. Fresh, moderately Fe-rich, olivine. Interstitial turbid alkali feldspar. Clearly an alkali olivine dolerite.

Low silica (44.6%), 5.9% MgO, 1.4% K_2O. D.I. - 36. 2.6% ne. High Zr, 350 ppm.

Ld 20 Chilled-contact of 30 m dike cutting anorthosite, N. side of Nain Hill. WNW-ESE. Slightly porphyritic chills (becoming increasingly feldsparphyric inwards!).

Few small sericitized plagioclase phenocrysts noted in thin section. Matrix of turbid plagioclase, chloritized ferro-magnesian minerals, opaques. Relatively abundant (? 5%) quartz and apatite needles. A good quartz-dolerite.

Almost 54% SiO_2, 3.9% MgO, 1.6% K_2O and over 6% total alkalis ! D.I. is 50, and normative feldspar is An_{21}. Really a tholeiitic andesite chill. 2.2% normative q.

Ld 21 Dolerite from 1 m 'in' from contact. Some dike as Ld 20. Pseudomorphed (serpentinized) olivine. Matrix of plagioclase, altered olivine, and clinopyroxene prisms. Suspect some of the latter have pigeonite cores. Interstitial quartz and quartz/alkali feldspar micrographic intergrowths.

3% normative q. Has more Ca and Al than Ld 20, reflected in more abundant normative plagioclase and more basic normative plagioclase than Ld 20 (An_{39}). Also, less Zr, Y, Rb, Zn, V but more Sr.

Ld 22 Dolerite from center of the Ld 20/21 dike. Coarse dolerite with large plagioclase phenocrysts. Matrix of plagioclase, pale pink augite prisms, some with colorless pigeonite cores. Quartz or quartz/feldspar micrographic intergrowths and apatite, interstitially. Shows a continuation of the trend shown from Ld 20 → 21 with rising Al, Ca, Sr and declining K, Ba, Zr, Y, Rb, Zn, V. Normative feldspar still more calcic as well as being more abundant than in Ld 20/21.

Ld 23 5 m dolerite dike, approximately N-S, believed to be cut by the Ld 20/21/22 dike. Is aphyric and consists of plagioclase, roseate Ti-augite, magnetite and fresh olivine. Interstitial turbid alkali feldspar. Petrographic similarities to Ld 17 and near chemical identity to Ld 17. Has 2.7% ne and D.I. of 36. With 6% MgO and 1.4% K could be regarded as an unusually potassic basalt. Shares high Zr with Ld 17.

HYDROGRAPHIC REPORT

S. A. Morse

University of Massachusetts [1]

INTRODUCTION

The work of the Nain Anorthosite Project continues to take R/V *Pitsiulak* into uncharted waters, and the practice of running sounding lines in such waters was continued in 1973 whenever conditions were favorable. This was particularly appropriate in northern waters, where, except around Saglek* and Hebron, existing charts show little more than the early sounding tracks of Macmillan, Forbes, and Nutt. Local people in Labrador occasionally refer to their land as the last place on earth, and indeed one sometimes understands this feeling when, with a sense of *dêja vu*, one is plotting on sheets whose most recent soundings are those he helped to make more than twenty years before. However, this paucity of modern information is not surprising; few but scientists and adventurers have had much need of charts in this part of the world, although modern expansion of coastal fisheries may make them desirable in the future.

It is perhaps more surprising that our Track 47 was discontinued southward for lack of a plotting sheet. Not even the preliminary 1:50,000 sheets were available in 1973 for this area, despite the fact that it lies on the heavily travelled inside track from Davis Inlet to Nain. There is no large scale hydrographic chart in this area. This calls to mind an anecdote related by Wheeler (personal communication, 1973), who was a guest aboard HMS *Challenger* when Cdr. A.G.N. Wyatt received instructions to sound a track from Nain to Davis Inlet as he terminated his work

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*Eskimo spellings in this part of the report are those of published charts. They differ from the uniform orthography of Wheeler (1953) which is preferred.

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

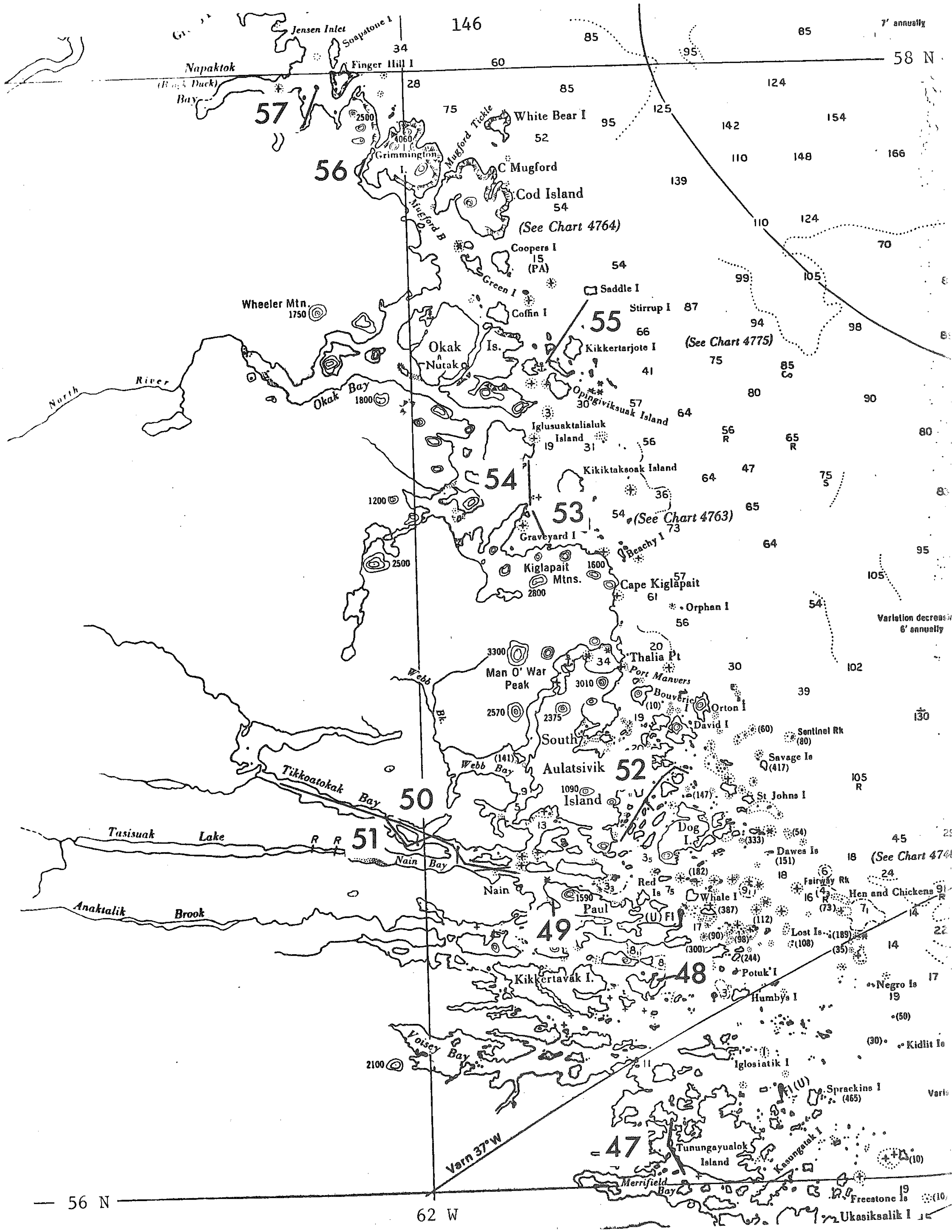


Fig. 39. Locations of southern 1973 sounding tracks on Chart 4700; tracks 47 to

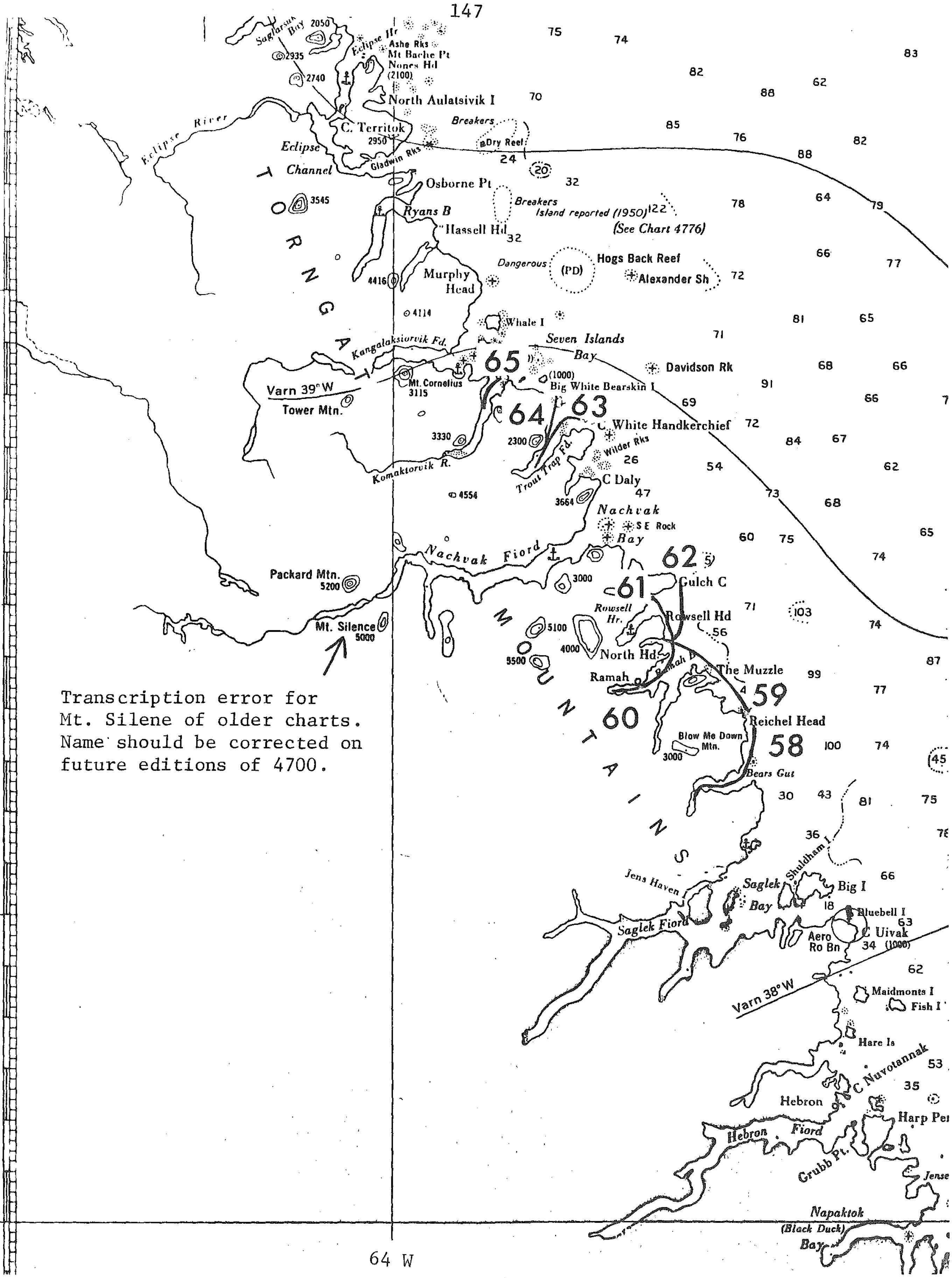


Fig. 40. Locations of northern 1973 sounding tracks on Chart 4700; tracks 58 to 65.

around Nain. "Plotted on what, for God's sake?" he roared. The situation remains unchanged after 40 years.

A total track length of 159.4 nautical miles was sounded in 1973, in contrast to the 250 miles sounded in 1972. The decrease reflects repeated travel over old routes in the Nain area, and most of the new mileage refers to the area north of Nain. Fathometer records and edited field sheets are being submitted with this report to the Canadian Hydrographic Service. Table 12 is a list of the tracks sounded in 1973, with serial numbers continuing from previous years. Position control was as described in FR 1972, p. 126. There follows a summary of dangers, followed by track notes for the season's work. For track locations see Figs. 39 and 40.

DANGERS TO NAVIGATION

Refer to Table 12 and track notes for other details.

Tom Gear's Run, track 47. A 3-fm shoal lies in the sounded track off the SW corner of Tunungayualuk I. This is apparently not the same as the shoal reported by Forbes (Am. Geogr. Soc. Sp. Pub. 22, Nav. Notes, p. 12-13) in 1938.

Nukasusutok I., track 48. A 2-fm shoal lies approximately on the 20-fm contour of Chart 4748 in the northeast bay of the island. This shoal was examined visually and located by ranges.

Two Mile Bay, track 49. The entrance is shoal (2 fm) and sinuous, but feasible for small craft.

Barth I., west end, track 50. A large shoal (to 1 fm) extends almost a mile west of the islet off the west end of Barth I., in the Nain Bay area.

Tikkoatokak Rattle approaches, tracks 50 and 51. An extensive shoal (to 2 fm or less) makes out about 8 cables in an ENE direction from the SW shore approaching the rattle entrance. This part of a bar which deepens to 4 fm on track 51. On this bar occur standing waves and overfalls during the ebb tide with easterly wind; the bar is dangerous for small craft at such times.

Sapogatsiak Bay, tracks 63 and 64. There appears to be a 4-fm bar extending at least one mile northward from land in the eastern entrance

NAIN ANORTHOSITE PROJECT - R/V *PITSIULAK*

Table 12. 1973 Sounding tracks, listed from south to north.

Note: Spellings are those of published hydrographic charts. Sheets designated 14 -- are Canada Topographic Series 1:50,000. LAB refers to an air-photo. All others are Canadian hydrographic charts. For track numbers 1-46, see 1972 report.

	Date 1973	Plotted on	Fathometer Roll	Mileage
I. Area south of Nain				
47. Tuktuinak I., Tom Gear's Run	26 Aug	14 C/3	6	6.2
48. Nukasusutok I., NE bay	16 July	14 E/6	(overlay)	3.9
			flat	
49. Two Mile Bay, survey	15 July	LAB-44-166	flat	5.
II. Area north of Nain				
50. Akpiksai Pt. to Tikkoatokak B.	19 Aug	14 C/12, D/9	6	26.
51. Tikkoatokak B. to Nain B.	21-22 Aug	14 D/9, C/12	6	14.
52. Kikkitauyarsuk to Carey I.	17 July	14 C/11	1	13.
53. Snyder Bay	30 July	14 F/4	5	2.
54. Hodgdon Hr. to Tikkerarsuk Pen.	30 July	14 F/5, F/4	5	7.
55. Ametok I. to Saddle I.	30 July	4764	4	8.2
56. Lost Channel, western track	27 July	14 E/16	4	3.0
57. Drachart I. to Rifle B.	26 July	14 E/16	4	5.6
58. Reichel Head to Bears Gut	23 July	4769, 14L/14, 14 L/10, 14L/11	3	14.5
59. Reichel Head to Reddick Bight	20 July	14 L/14	2	14.
60. Reddick Bight to Ramah	22 July	14 L/14	3	9.
61. Delabarre B. to Reddick Bight	22 July	14 L/14, 4769	3	3.5
62. Reddick Bight to Gulch Cape	21 July	14 L/14, 14 M/3	2	6.5
63. Sapogatsiak Fiord mouth	22 July	4771	3	5.
64. Sapogatsiak Bay to Fiord bottom	21 July	4771	3	10.
65. Komaktorvik Fiord, outer	21 July	14 M/5	3	3.
TOTAL 1973				159.4
TOTAL 1971-1973				446.3

to the fjord. A 4-fm pinnacle occurs within the provisional 20-fm contour ESE'ly of Nautilus Rocks in the sounded tracks crossing the mouth of the Bay.

NOTES ON 1973 TRACKS

47. Tuktuinak I., Tom Gear's Run. Aside from the 3-fm shoal noted in "Dangers," above, the track appears deep and clear of dangers where soundings are plotted. Shoals occur two miles to the SE of the end of the track, but attempts to maintain position control in this area were unsuccessful, so plotting was discontinued. Track was run N to S.

48. Nukasusutok I., large northeast bay. A 2-fm shoal is located on the charted 20-fm contour, 1.3 cables off the most prominent point of land on the SE shore of the bay, at 50° - 22'.30 N, 61° - 14'.75 W relative to the grid of Chart 4748. This shoal was examined visually during a survey of part of the bay. It is part of a ridge sloping gently to 5 fm toward the SW, the ridge being about 1 cable long above 5 fm and dropping steeply off to 10 and 17 fm toward shore and 23, 25 fm away from shore. Ranges to the shoal: entrance islet aligned with hill behind Ford Hr., western tickle just closed (see Fig. 41). The shoal can be avoided by holding to the center of the bay, about 3 cables off the SE shore, in more than 20 fm. A grid of 10 closely spaced survey lines confirms the general validity of Chart 4748 in the mid-portion of the bay. A closed 30-fm contour can be drawn around a 33-fm basin just SW of the plotted shoal. Examination of the 2-fm shoal was completed at 1630 hr. ADT, about 2 hr. after low water.

49. Two Mile Bay. This bay, facing Nain on Paul I., has a shoal entrance between two piles of rocks, but is apparently clear of dangers inside (see Fig. 42). The entrance was negotiated a number of times, both before and after the survey of 15 July. The bay affords good shelter except in westerly winds, but is inferior to Kauk Hr. (5-1/2 miles south of Nain) as a refuge. Directions: to enter from Nain, steer about 126° T along the axis of the bay toward the knoll at the head of the bay, in line with the central entrance rocks. When on range between

SHOAL

Nukasusutok I., North bay

R/V *Pitsiulak*, Track 48

Surveyed and examined 16 July 1973. Base: Topo sheet 14 C/6. The area examined lies within soundings on Chart 4748.

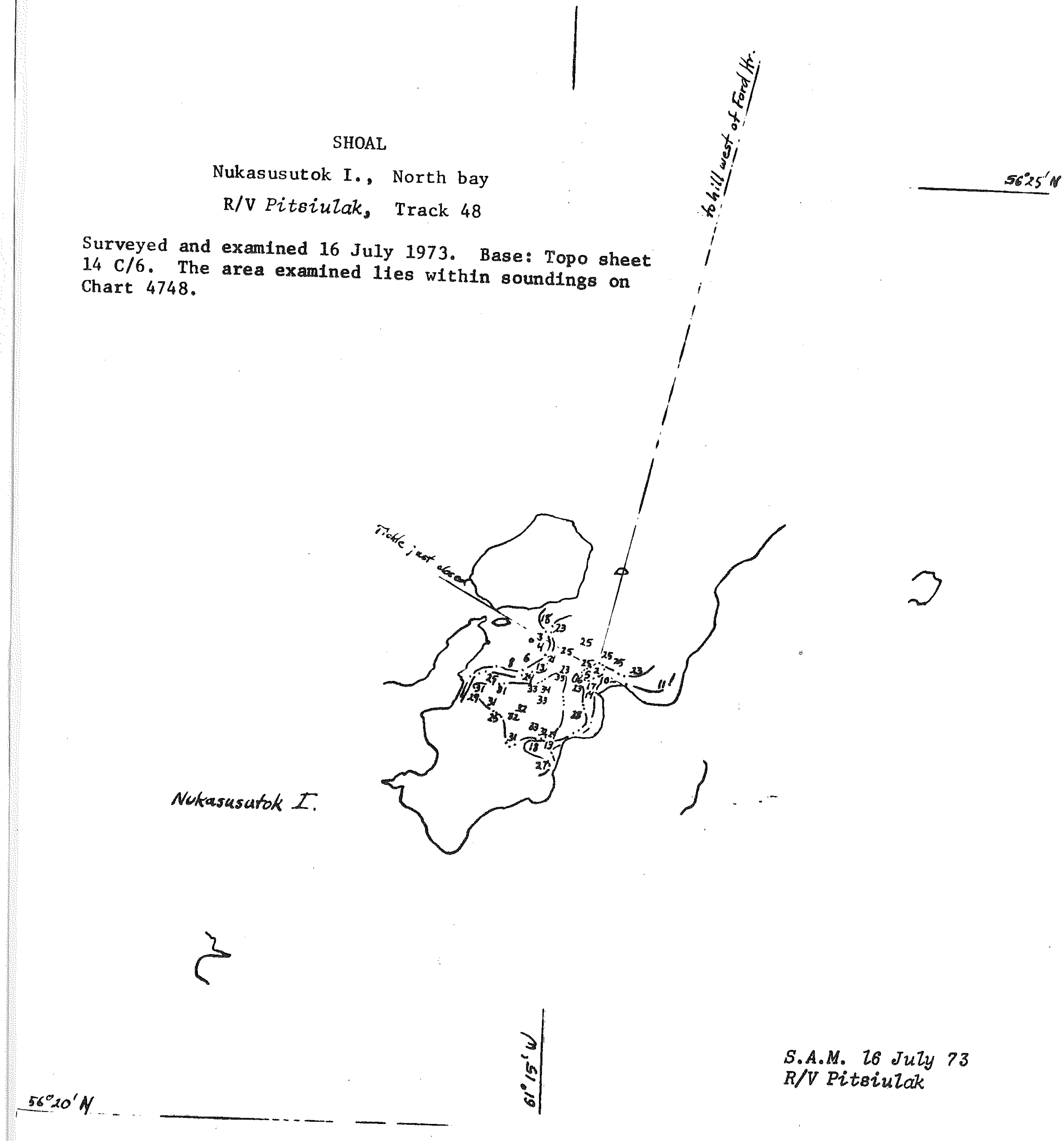
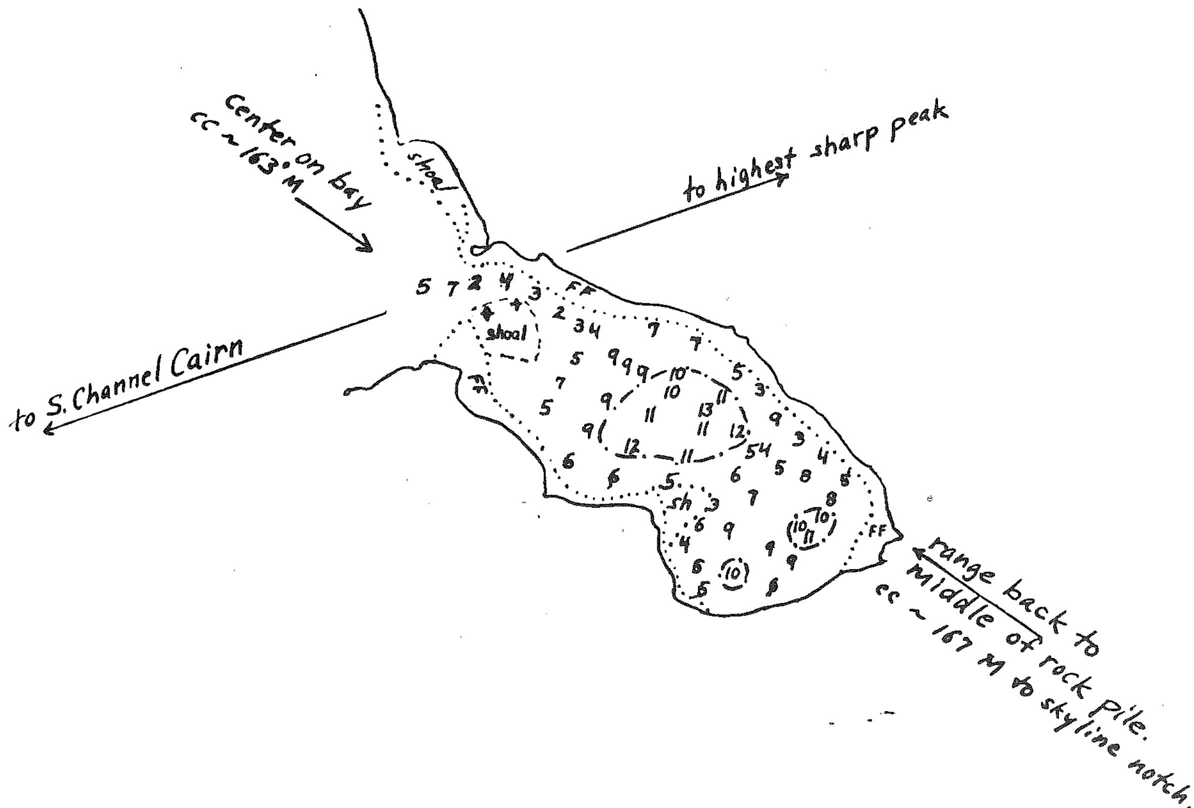


Fig. 41. Survey of shoal, Nukasusutok I. NE harbor. Track 48.

TWO MILE BAY, LABRADOR

R/V *Pitsiulak*, Track 49

Surveyed 15 July 1973, 1740 to 2035 hr ADT. HW ~1835 hr. Soundings reduced to LW. Base: airphoto LAB 44-166. 1100 rpm. Weather fair, wind W 5-10 kt.



S.A.M. 15 July 73
R/V Pitsiulak

Fig. 42. Harbor survey of Two Mile Bay, Track 49.

South Channel Cairn and the highest sharp peak to the ENE on Paul I., steer 086°T toward said sharp peak until the northern entrance rocks are close abeam to port. Thereafter steer about 130°T, keeping the middle of the rock pile astern and aiming for a skyline notch, until well clear of the shoal and rocks to starboard.

50 and 51. Akpiksai Pt. to Tikkoatokak B. The track along Nain Bay south of Barth I. is clear of dangers. To clear the large shoal off the west end of Barth I., a vessel should favor the mainland shore to south and west. Tikkoatokak Rattle is the narrow constriction at the outlet of the bay, at 56°-38' N, 61°-54' to 58' W. This narrows, about 3 cables wide, drains a watershed of more than 2000 square miles, and in consequence an impressive current occurs at ebb tide. A bar in the approaches to the rattle gave a least depth of 4 fm in 1973 along track 51, but is shallower to the west, and the northern shore of the rattle entrance should be favored. Standing waves and overfalls occur on this bar on the ebb tide with an easterly wind, making it a dangerous place for small craft at such times. A conspicuous boulder pile to the north and a conspicuous single boulder to the south mark a "gateway" at the narrowest part of the rattle. Good depths (least 5 fm) were recorded between the bar and this gateway, and for a distance of nearly one mile to the east of the gateway the fathometer trace shows large-scale ripples (or underwater dunes) on the bottom. The geometry and hydrology of this system suggest that underwater hazards to navigation are very unlikely to occur west of the bar. At the gateway sill, the bottom drops rapidly to more than 20 fm, and rather steadily thereafter to a maximum depth of 82 fm midway along Tikkoatokak Bay, west of which the bottom rises more or less steadily to the bay head, which is sandy. There are no superior anchorages in the bay, but good shelter can be found at several places on the south side, particularly at Khasighiatsite B. in 5 fm, a cove 62°-16' W in 6-8 fm, and probably at Ighloliote B., which was not thoroughly investigated but which is frequently used by local people.

Track 50 was run westward, and 51 eastward.

52. Kikkitauyarsuk to Carey I. This track is mainly within the area of Chart 4748, and entirely in the area of BA 265, to which reference is made for the names. The track between Central I. and the small islets to the west appears clear of dangers; it is used by local boats. Our track then winds around Misfit I., continues toward Carey, and after an interruption continues from Carey I. south to Misfit.

53. Snyder Bay. The track runs SE'ly across the bay to Kiglapait Hr. The rock SE of Tikkerarsuk Pena. was investigated at low water and located by a round of range lines. The location indicated on Chart 4763 was confirmed. Depths of 10 and 20 fm were found close by the rock.

54, 55, 56. No comment needed.

57. Drachart I. to Rifle B. The track is deep and clear of dangers. Good anchorage in 4 to 10 fm, mud, is available in the bottom of Rifle B.

58. Reichel Head to Bears Gut. A long track in deep water except at the entrance of the south arm of Bears Gut, where a depth of 11 fm is encountered. Bears Gut is a wind funnel, and affords poor anchorage (10 fm) for small vessels. Note absence of island shown on Chart 4769 at 58°-45' N.

59. Reichel Head to Reddick Bight. The track appears clear of dangers. A 20 fm area off North Head suggests the possibility of a shoal further to the north, but good depths were obtained nearer shore on track 60. The bottom of Reddick Bight affords a good anchorage in 4 to 6 fm. The so-called seaplane anchorage would appear to lie in rather deep water.

60. Reddick Bight to Ramah. The track appears clear of dangers, with depths approaching 100 fm in the outer part of Ramah Bay, as shown also on Chart 4769. Our track avoided the 15 fm spot east of Lookout Pt., but encountered a 14 fm spot in mid-bay west of Lookout Pt. Culture: Lookout Pt. name is misplaced on sheet 14 L/14, correct on Chart 4769. Houses should be deleted on Chart 4769.

61, 62. No comment needed.

63. Sapogatsiak Fiord mouth. Track run from fiord outward along north side of Cape White Handkerchief. A 4-fm bar appears to run northward

from the south shore to the rocks shown on Chart 4771, and possibly beyond, toward the 4-fm spot on track 64. The small islet near shore was circumnavigated, with 5 fm depth on the inshore side.

64. Sapogatsiak Bay to Fiord bottom. A 4-fm pinnacle constitutes a danger between the two sounded tracks on 4771, lying 1.15 mi Az 101°T from the SE extent of Nautilus Rocks. Another 4-fm shoal occurs 1.45 mi Az 129°T from the same reference point, along a generally shoal stretch (10-15 fm) in the mouth of the bay. Existing soundings suggest the presence of a submerged and dissected bay-mouth sill or bar. The rest of the track appears clear of dangers to the foreshore flats at the bottom of the fiord. Anchorage in 3 to 10 fm can be obtained south and west of the largest Waldron I., which provides good shelter for small vessels unless the wind blows out the fiord. The area toward shore north and west of the Waldron Is. is shoal, at least in part, and further reconnaissance was not attempted.

65. Komaktorvik Fiord, outer. A short track was run part way into the fiord. A rock which dries is located at UTM 594787 (Sheet 14 M/5), somewhat farther west than shown on Chart 4771. The whole of the sounded track is surprisingly shoal for a fiord mouth, suggesting the presence of an extensive sill.

ERRORS IN NAMES

Chart 4700: Lat. 59° For Mt. Silence read Mt. Silene, as for example correctly given on Chart 4769.

Sheet 14 L/14: Lookout Pt is misplaced: see Chart 4769, which is correct.

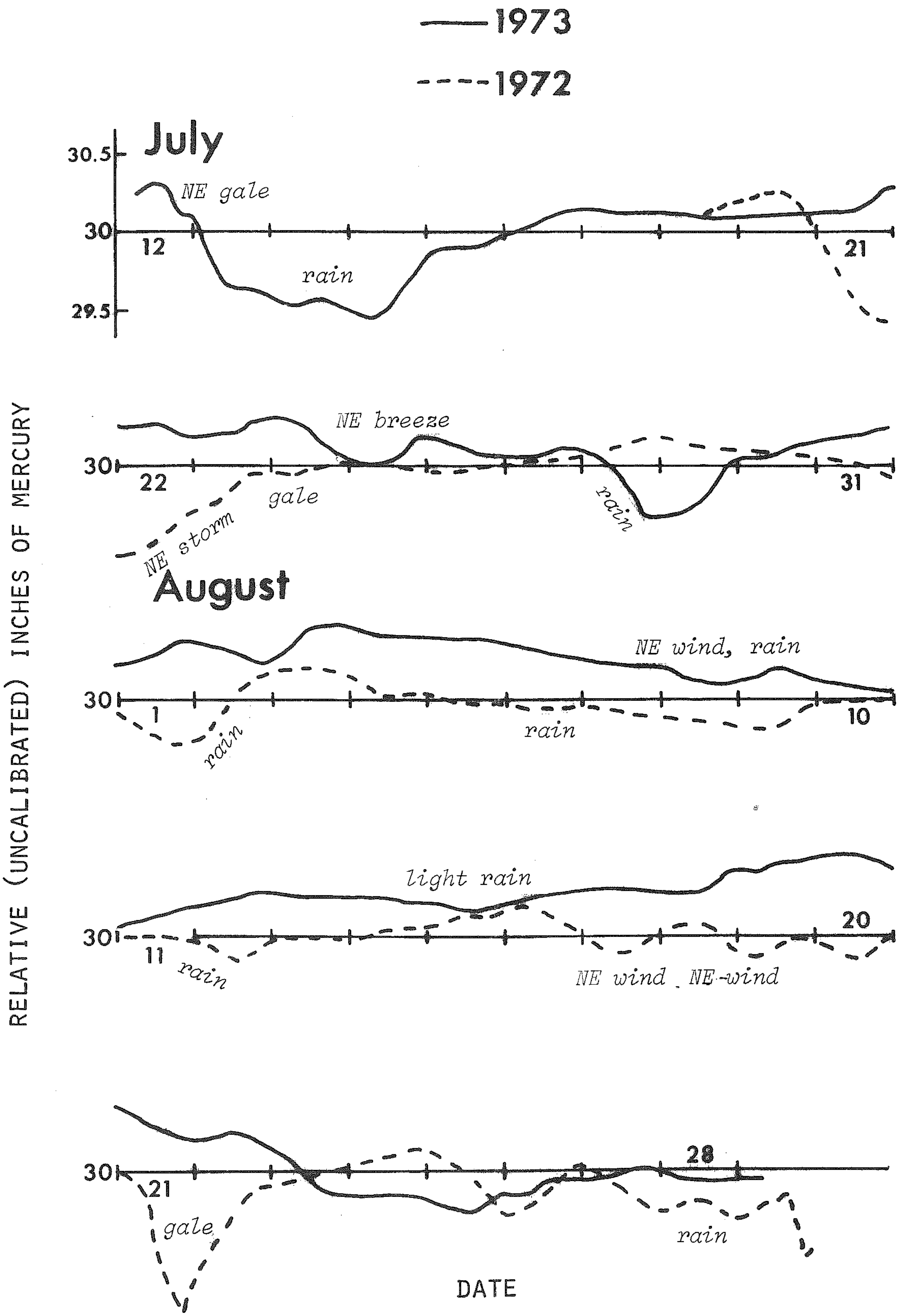


Fig. 43. Barometric pressure recorded aboard R/V *Pitsiulak*, 1972-1973 seasons.

OPERATIONS

S. A. Morse

NARRATIVE REPORT

Spring arrived very early in Nain, and the harbor ice became unserviceable for aircraft by 28 May. Flying with float-equipped aircraft was resumed by about 11 June. The operation of R/V *Pitsiulak* was much delayed by machinery problems of diverse origin. On 20 June, an early crew of three (master, research assistant, and cook) reached Nain and began putting the vessel back in commission. Their work was far from complete by 23 June, when the main research group arrived on schedule. The field personnel were taken by motorboat to Khaukh Hr., where they assembled and tested field gear and rations. Professor de Waard's party was able to go almost immediately to its field area at Barth Island via 20-ft. freight canoe, and indeed required no other transporation aid until the end of the season, moving by easy stages with canoe from Barth I. to Base I., Newark I., and Dog I. when weather was suitable. This is an apt illustration of the seaworthiness and comfort of these large freight canoes, which can carry a load of 3000 lb.

On 26 June the main research group was moved by motorboat to Nukasorsuktokh I., where they held field seminars at Wyatt Hr. and in the northeast bay of the island until 8 July, their stay being extended somewhat excessively by delays in vessel readiness. By 9 July, however, all field parties were in place, the Brand party having joined the group at Nukasorsuktokh I. for a few days before flying in to a small lake west of Khingughutik Lake.

R/V *Pitsiulak* was launched on 30 June, and towed to a mooring, where machinery repairs were continued. By 7 July she was able to undertake a shakedown cruise to Khaukh Hr., and on 8 July she proceeded to Nukasorsuktokh I. to begin operations on a limited basis. For the next 10 days, geologic and hydrographic work alternated with mechanical repairs in the vessel's operations. On 18 July, Wheeler established an inland camp by airlift, to continue geologic mapping left off in 1972. By 19 July, with geochronologists aboard, it appeared feasible to begin the annual northern trip to study and sample the Archaean and younger Precambrian rocks north of the Nain area. The major mechanical defect by this time was a bad starter on the main engine; this was cleaned for the second time, and could be coaxed to function. As it turned out, the starter improved with every day's run thereafter. Taking the precaution to arrange radio schedules and meeting places with the trout collecting vessels also travelling north, we left Nain as scheduled on 19 July, stopping at Cutthroat that night and at Reddick Bight on 20 July.

With the help of excellent weather, *Pitsiulak* continued along the spectacular mountainous coast of northern Labrador to Kangalasiorvik Fjord on 21 July. This farthest north for the vessel permitted sampling in the supposedly younger rocks beyond the northern limit of Archaean rocks. During the next 10 days, nearly ideal working conditions made possible the comprehensive sampling reported by Barton and Hurst in earlier pages of this report, as well as numerous sounding tracks in uncharted bays and fiords. This success was a welcome change from the frustrations of 1972, when pack ice blocked all travel north of Mugford Tickle. The northern trip ended with two days' work with Berg in the Kiglapait area, and the vessel reached Nain again on 2 August with more than a ton of samples stowed in the lazarette, not to mention several hundred pounds of scrap steel ballast liberated from the dump at Säglekh.

Helicopter support from the Canadian Earth Physics Branch permitted a two-day visit to inland parts of Berg's Hettasch layered intrusion, 4-5 August, and then an extra trip to Wheeler's area for sampling on 9 August, following his return to the vessel.

An interesting Archaean anorthosite having been discovered by Hurst at Okhakh Hr., it was decided to send a team of geologic "trouble shooters" there to explore the extent of this rock type. A party composed of Dunlavey, Runkle, and Saunders was accordingly taken to Okhakh on 6-7 August, and left to work until they were retrieved by the trout collecting boat *Silver Star* a week later.

By mid-August, several field parties prepared to leave to resume academic duties. It was possible to hold an abbreviated field conference 16-17 August led by de Waard at Dog I., and by Davies at Nukasorsuktokh I. Two parties had left the field by 18 August, and R/V *Pitsiulak* then undertook a geological and bathymetric reconnaissance of Tikkoatokhakh Bay, 19-22 August. By this time, problems of shaft, engine, and bearing alignment had become serious, necessitating adjustment every few hours of running time. These problems reinforced an earlier decision to take the vessel to the nearest shipyard for overhaul.

On 24 August, all field operations were terminated, and all research personnel left the field on 25 August except those manning the vessel on her trip south. The vessel, with a full crew of seven, left Khauk Hr. that evening for St. Anthony, Nfld., stopping for the night at Perrett's Tickle, then at Burnt I. in the Adlavik area, before reaching St. Anthony at midnight on 28 August. A delay of several hours was encountered at Webeck Hr. on the 27th, where a shaft bearing became seriously overheated and had to be rebedded. Another brief stop was made at Holton I. to repair the last fragments of the main exhaust system, which had corroded almost beyond repair. The elapsed time from Khaukh Hr. to St. Anthony was 55 hr., much of the run being made in heavy seas.

At St. Anthony, the vessel was put in charge of the International Grenfell Association Dock Division for repairs. A visit was made in late September during the refitting, and it was seen that the high talents of the shipyard were able to bring the vessel back to a condition of excellence. A safety inspection was also carried out during the visit.

The vessel was returned to Nain by Mr. Max Tiller and a crew of two during the period 13-20 October, encountering gales of wind and very heavy seas, as expected at this time of year. The lateness of this transit for a small vessel was noted with approval in the coastal newspaper "Kinatuinamot Illengajuk", and Mr. Tiller reports, "The vessel behaved well under adverse conditions, and she could go around the world." *Pitsiulak* was moored at Khaukh Hr. until late November, when she was hauled out on her cradle at Nain, and laid up for the winter.

This narrative would be sadly incomplete without a statement of appreciation to those people in Nain who did so much to help us get going through the spring and summer. Particular thanks are due Mr. Tiller and Mr. William Metcalfe, who shared their considerable expertise despite the lateness of the hour on the aggravations of their own mechanical problems ashore. Mr. Tiller is also to be congratulated for his seamanship and his zest in taking a holiday to return the vessel to Nain. Much credit is also due Mr. H. Haynes and Mr. H. Webb for their organizational efforts and long hours of help. The willing efforts of such people have been essential to operational success, and have helped to build a base of experience from which future operations should go forward more smoothly.

TOPICAL SUMMARIES

Ice

The contrast between 1972 and 1973 in regard to ice conditions was extreme. In 1972, breakup occurred in Nain 2-3 July, and pack ice occurred around Nain until 10 August. In 1973, breakup occurred before 11 June, and after the bay ice disappeared in the next few days no more ice was encountered for the rest of the summer. The northern pack ice never came in to shore at all in the Nain area. Instead, the pack ice and large icebergs were encountered early in shipping lanes to the south, and reached far south of Newfoundland, where they caused far more difficulties than normal and reached the attention of the public in the northeastern U.S.

Pack ice can be helpful (as in 1972) to vessel operations in the outer islands because it eliminates big seas which can prevent or hinder landing on exposed shores. This aid to geological work was absent in 1973, and work in the outer islands would not have been convenient even if the vessel had been operational during the early season. On the other hand, we encountered no obstruction to navigation this season in operations north of Port Manvers, which was a welcome contrast to the frustrations of 1972.

Weather

1973 was an exceptional year also in regard to weather. Spring arrived early in Nain, and from May till late August there was an almost unbroken succession of warm, comfortable weather. Only one major tent-splitting gale occurred, on the 12-13th of July. This was followed on 14-15 July by a wet northeaster, and half-day northeasters occurred on 25 and 28 July and 16 and 23 August. Other periods of inclement weather consisted mainly of afternoon showers, generally without bad winds. Stretches of fair weather as long as seven and 10 days were encountered. The weather was so consistently good that field parties were forced to use fair days for office work at camp, a luxury rarely encountered in Labrador.

Barometer records further illustrate the contrast between 1972 and 1973 (see Fig. 43). Of the 41 calendar days when overlapping records were kept aboard R/V *Pitsiulak*, the barometer was higher in 1973 on all but seven days.

No fresh snow was encountered in the 1973 season, and there were very few mornings with ice in the water bucket. This was a truly exceptional year for early breakup and fine weather, and one not likely to be equalled often.

Vessel Maintenance

A variety of circumstances conspired to make 1973 a nadir in the operational effectiveness of R/V *Pitsiulak*. During the autumn of 1972, the vessel was partly flooded through the failure of a corroded salt-water pipe. Although the resulting damage was relatively minor, not all of it was promptly treated, with the result that a whole series of peripheral mechanical problems needed correction in the spring of 1973. These included repeated failure of the starter and electrical generating system, and gumming of the main engine, which had to be partially disassembled for inspection and freeing-up. To compound our difficulties, one of the vessel's large batteries was inadvertantly thrown out from its winter storage site by a Canadian utility company, and much delay was incurred before a replacement was eventually furnished by the company. In addition, difficulty was encountered in launching the vessel from the short slipway.

As a result of these difficulties, the period from 20 June to 7 July was spent by vessel personnel in vessel repairs. The vessel became adequate for sustained operations only on 16 July, and was plagued thereafter by a deteriorated starter, an inoperative battery charger (which was replaced by an inferior standby charger), a disintegrating exhaust system, and a worsening shaft alignment. Accordingly, the decision was made to move up the date of shipyard overhaul from 1974 to 1973, and at season's end, the vessel was taken to St. Anthony, Newfoundland, for repairs.

The auxiliary generator which showed serious deterioration in 1972 was replaced in 1973 with a new 6 kw alternator, which was mounted on the existing Lister engine. This performed satisfactorily, but was used infrequently while the main battery charger was away for repairs. The capacity of the vessel's battery system has been greatly increased during the overhaul, to permit full utilization of the upgraded generator and charger.

The vessel's hull remains in excellent condition, an annoying sternpost leak now having been repaired. New shaft bearings were installed during overhaul, and no further bearing troubles were experienced during the return trip to Nain.

The vessel's main engine and navigational equipment have continued to function perfectly, thus permitting safe operations once the peripheral mechanical problems could be corrected.

Despite the loss of much of the vessel's working time to mechanical problems, the shore-based field parties were able to work at nearly peak efficiency, partly through intermittent use of a locally chartered boat. The major loss to shore-based field work was in the ship's laboratory service operations, which could not be maintained at peak levels because of the mechanical troubles cited above.

During the refitting of the vessel, her mechanical reliability has been increased by providing redundant components for the most vulnerable parts of her equipment.

Communication

Field and ship radios continued to work satisfactorily with minor exceptions. No long auroral blackouts occurred, and the network of shore stations was sufficiently well spread out to provide contact via relays on all but a very few of the diurnal radio schedules. A routine monthly recharging schedule has been initiated for winter upkeep of the portable radio batteries.

Radiotelephone communication from Nain to points south has been somewhat improved by installation of a new antenna and transmitter, but traffic has also increased, so that satisfactory telephone communications to outside points are difficult to achieve.

Flying

Charter aircraft continued to provide major logistic support for camp and personnel movements in areas away from salt water. The new twice-weekly scheduled flights to Nain have greatly facilitated movements of personnel into and out of the field area, and have been of some help in obtaining spare parts. A weekly summer mail flight to Nain was inaugurated in 1973.

In addition to the usual support of fixed-wing aircraft on charter, we derived great benefit in 1973 from the use of helicopters chartered by the Gravity Division of the Canadian Earth Physics Branch. In return, we shared current geological results and, as mentioned in FR 1972, our field workers are in the process of supplying rock densities to aid in the interpretation of regional gravity data. Helicopter airlifts proved invaluable in support of Wheeler's work inland, including the acquisition of a large sample of fresh rock thought to be parental to ovoidal rapakivi granite for geochemical study. Helicopter airlifts were also instrumental in permitting a field inspection of J. H. Berg's Hettasch intrusion, in an area otherwise very difficult of access.

Laboratory

As in past years, a primary mission was to provide microscopic mineral identifications, composition determinations, and modal analyses to shore-based field investigators. All parties made use of this service, and R. E. Hodgson was able to determine 96 mineral compositions and make 239 mineral identifications during the latter part of the summer when laboratory operations were feasible.

Subsistence

Staples were increasingly obtained at local stores, although some permanent stocks are maintained at Nain during the shipping season. Stocks of freeze-dried foods are accumulated a year in advance to minimize transport by air freight, which is still required, however, for early season supplies of fresh food.

The cod fishery continues to be dormant in northern Labrador, and for the second straight year no codfish were caught during our field season. Arctic char continue to be available despite heavy fishing in certain areas, and as usual, these excellent fish provided an important supplement to our diet.

Health

There were no injuries or debilitating illnesses among the Project personnel in 1973.

Wintering

After repairs were completed in St. Anthony, and the vessel returned to the Nain area, she was moved in Khaukh Hr. during October and November, and hauled out in her cradle on the government slip in Nain in late November. The cradle has been reinforced and provided with a bridle of 1" wire cable to aid in hauling. Continuing availability in Nain of a D4 crawler tractor has done much to ease the problems of hauling the vessel.

Cooperative Investigations

Among the numerous research programs in the Nain area, a number were of direct bearing on the anorthosite project. Excellent cooperation and communication were maintained among the various groups, which included parties of the Gravity Division of the Canadian Earth Physics

Branch (D. Halliday in charge), the Geology Department of the Memorial University of Newfoundland (MUN) under K. D. Collerson, and the Physics Department of MUN under G. S. Murthy. Of collateral interest, cooperation was also maintained with an archaeological research team from the U. S. National Museum under William Fitzhugh, and with a fisheries research team of the Canadian Department of the Environment under L. Coady. Co-operation with these and other groups is expected to continue in the future, to the mutual benefit of all.

SUMMARY OF OPERATIONS

The 1973 working season lasted 62 days, beginning 24 June after an early breakup, and with the aid of a local boat for placing field parties in their working areas. One party (de Waard) provided its own transportation by 20-ft. canoe until the end of the season. R/V *Pitsiulak* made her northern trip for geochronological sampling in the period 19 July to 2 August, reaching a farthest north at Kangalasiorvik Fjord on 21 July. No pack ice was encountered during the season. Beginning field seminars were conducted by Wheeler at Nukasorsuktokh I. for the benefit of new personnel. Field visits by thesis advisers were made in July at Plansky's field area on Paul I., and in August at Berg's area in the Hettasch intrusion. A field conference was held in August on Dog I. and on Nukasorsuktokh I. The shipboard laboratory furnished 96 mineral composition determinations and 239 identifications. Hydrographic surveys totalled 159 miles of reconnaissance track, and included harbor surveys at Two Mile Bay (Paul I.) and the north bay of Nukasorsaktokh I.; these are reported separately. The calendar of operatives below summarizes the main events.

Calendar

June 11	Approx. flying resumed at Nain on water
20	Early operations crew to Nain to work on vessel
23	Main research group to Nain
26-30	Field seminar at Wyatt Hr., Nukasorsaktokh I.
30	Vessel launched; second research group to Nain
30-July 8	Field seminar at north bay of Nukasorsuktokh I.

July	9	All field parties in place
	14-18	Geological work among islands near Nain
	18	Wheeler to Ikkinikulluit area
	19-31	Northern trip
August	1-2	Geology - Kiglapait area
	2	Return to Nain
	4-5	Visit to Hettasch intrusion
	7	Field camp established at Okhakh Hr.
	9	Wheeler back from field area; helicopter trip for sampling
	14	Brand party terminated season
	16-17	Field conference
	18	de Waard party terminated season
	19-22	Vessel in geological reconnaissance, Tikkoatokhakh B.
	24	Field operations terminated
	25	All research personnel out; Vessel to St. Anthony, Nfld.
	28	Vessel arrived St. Anthony; running time 55 hr.
October	13-20	Vessel to Nain, running time 65 hr.
	21	Vessel moored at Khaukh Hr.
November		Vessel hauled out on cradle, Nain.

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