THE NAIN ANORTHOSITE PROJECT, LABRADOR: FIELD REPORT 1974

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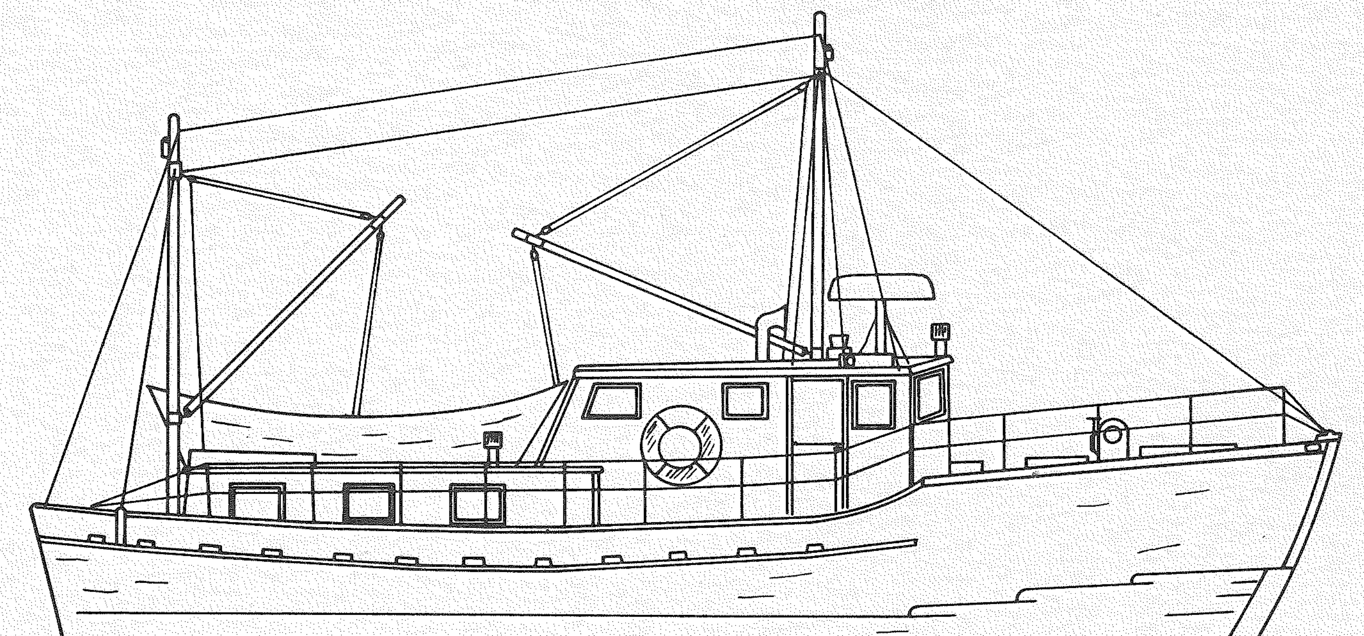

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THE NAIN ANORTHOSITE PROJECT, LABRADOR: FIELD REPORT 1974

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Interim Report under NSF Grant GA-41256X
"Evolution of anorthosite and related crustal rocks in coastal Labrador."

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January, 1975

E. P. Wheeler 2nd

1900 - 1974

(Wyatt Harbour, 1972)

Everett Pepperrell Wheeler 2nd

This quietly spectacular man died on 30 October 1974, at his home in Blue Mountain Lake, New York. Those who knew him will readily comprehend the enormous loss which his passing brings to the members of this Project, as well as the irony of his terminal illness; Stefansson's book "Cancer, Disease of Civilization" was glaringly prominent in the living-room bookshelf during his last days.

This is not the place for a biographical memorial, but it is fitting to record here some highlights of his contributions to Labrador geology. In his early travels he discovered a major river in central Ungava which now, along with a mountain, justly bears his name; his early topographic maps were invaluable to surveyors and visitors for several decades.

The scale of Pep Wheeler's life-work can only be described in heroic terms: the territory he mapped in 48 years covers something like 27,000 square kilometers. This is equivalent to 48 fifteen-minute quadrangles at the latitude of the Adirondacks. (He always said if he couldn't average a quadrangle a year he was falling behind. It is nice to know he came out even.) Until the post - WW II period brought aerial photography, his base maps were the product of his own surveying; even later, the restricted photo coverage of inland areas forced the continuation of his topographic mapping. After wartime service with the Corps of Engineers, he returned, now with his wife Eleanor, to a 3-year cycle of summer-winter-summer in the field, followed by laboratory work at home in Ithaca for winter-summer-winter. Winter work in the field was often concentrated in the uplands, where triangulation nets could be extended and wind-blown outcrops examined and sampled. "There is more outcrop exposed there in the winter than in the eastern U.S. south of the glaciated area at any time," he would say. The resulting geologic manuscript map covers a large wall at a scale of one mile to the inch. Small-scale versions were printed in 1960 and 1968, and a new version at 1:500,000 is available in ozalid. The detailed map appears to be the only one in the world covering a large anorthosite complex; it is unique also in containing much petrographic information (Johannsen families, An and En values).

Wheeler's typewritten field notes fill 14 large loose-leaf notebook binders, and thin section descriptions occupy an equal amount of shelf space. He worked more for posterity than for himself. Specimens and sections have already yielded several important papers by or with others, notably those of Smith (e.g. J. Petrology, 1974, p. 58) and a fascinating new contribution on osumilite by Berg and Wheeler (see abstract in this volume). Chemical analyses were accumulated slowly over the years, eventually giving rise to the first comprehensive statement, with de Waard, of the chemistry of what he finally came to call simply the Nain complex. His description of this complex (1942) was the first, and in comparing the page-sized map of 1942 with current versions, it is interesting to note how much of what we find important today is already there -- for example, the Snyder Group, the Barth Island complex, the Barth-Newark dike, the Kiglapait intrusion, and the two large western adamellite bodies are all discernible. This early report was followed in 1955 by a major paper on the adamellites, and then by a succinct review of the whole complex in 1960.

The messages in these and later papers were never strident, often hesitant, and on occasion occult, for he did not wish to overcall his hand or outrun his data. But his work was full of insights, many of which he recognized when they came back to him freshly perceived by one of us. Aided by his superbly organized notes, his recall of what he had seen was phenomenal, and his comprehension of its importance impressive. In the heady weekend-long winter gatherings of what he dubbed the Mountain and Muskeg Society in Canton, Ithaca, and Blue Mountain Lake, and later in the even more exhilarating days of discovery and argument aboard the vessel which he named *Pitsiulak*, many a wild idea was brought up short on the hard fact of his experience, and many a good idea was tested to the hilt against his comprehensive knowledge. His perceptions were never ruled by preconceptions. He was flexible and resilient, but dogged in pursuit of disturbing evidence of all sorts in the rocks.

No man who was not sensitive to his natural and human surroundings could have survived a half-century of productive research and travel in Labrador. Like Stefansson in his analytic observation, and in many ways like Rasmussen in his rapport with the Inuit, he was both an articulate "survivor" and the object of deep affection and respect among the people of Labrador. He could name the plants and animals -- all of them, it seemed -- and direct you to the mushrooms of the week. He was the sort of gourmet, both at home and abroad, who could concoct the "Nain Gourmet's Almanac" reproduced in FR 1971. He was a classicist, but more importantly a romantic. When visiting with him, especially at home with Eleanor, it was easy to forsake geology for the delights of literature, ballet, film, history, travel, and a remarkable wine cellar.

This Project literally owes its existence to Pep Wheeler and his work. He rejoiced in the chance for continued field work, and even more in the opportunity to help young people get started in it. For him it was by no means enough to survive in a rigorous environment; one should learn to live graciously. It was his pleasure to spend a few weeks with the early crews each season, helping them by example to become comfortable, and helping them with relish to become ensnared in the baffling but exquisitely displayed field relations of the rocks. It was then his custom to visit special problem areas with the vessel, and afterward to spend several weeks by himself in a remote, physically demanding, and appallingly difficult field area. It will be a long while before some of this ground is covered again; not all the powers of the space age can substitute for his kind of field work.

The members of the Project were always aware of their privilege in working and learning with this gentle man. He repaid their love many times over. And as Emerson once said of another, "How little this man suspects, with his sympathy for men and his respect for lettered and scientific people, that he is not likely, in any company, to find a man superior to himself. And I think this is a good country that can bear such a creature as he is."

-- S.A. Morse

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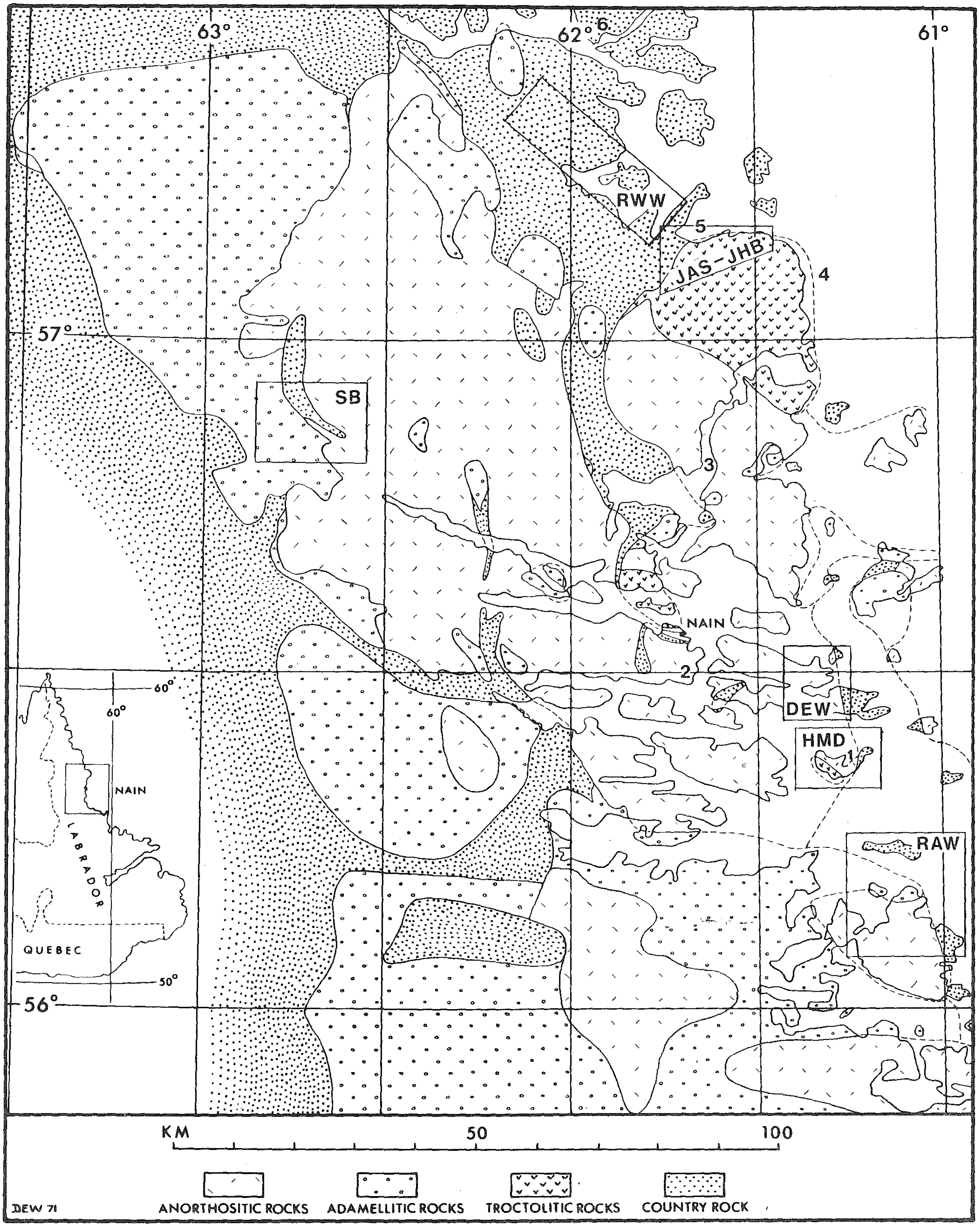

Fig. 1. Regional geology of the Nain area, after Wheeler (1968), showing locations of 1974 field areas. Identification of areas, north to south: RWW, Wiener (Tessiuyakh Bay); JAS-JHB, Speer and Berg (Kiglapait contact aureole); SB, Brand (Lower Khingughutik River); DEW, de Waard (Paul Island); HMD, Davies (Niatak - Nukasorsuktokh); RAW, Wiebe (Tunungayualok I.). Numbers refer to other localities cited in text: 1. North Bay, 2. Khaukh Hr., 3. Port Manvers Run, 4. Cape Kiglapait, 5. Snyder Bay, 6. Okhakh Island. For other names see Figs. 24 to 26.

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INTRODUCTION AND REVIEW

The *Tagesbuch* of the Moravian Mission station at Nain contains many entertaining or curious entries. Among them is that of a summer's day in 1926 reporting the arrival of the young American E.P. Wheeler, with the cryptic notation "He has come to study our rocks!" One of the beauties of language is that an exclamation point can say so many things. No doubt surprise and pleasure were included in the original emotion, but in retrospect it seems appropriate to infer an element of prophecy in that bit of punctuation. To Pep Wheeler, the rocks deserved the exclamation point. They kept him busy and happy. Once when thanked for a very fine field excursion, he said "I don't see why; you people did all the work, and nobody can blame me for the geology of Labrador". Readers of past reports in this series will have seen the signs of his continued blameless activity. A new discovery by J.H. Berg in 1974 makes it appropriate to cite an example of his valuable insight, and in so doing to comment on an intramural debate which has rarely been publicized because of a scarcity of definitive information.

The anorthosite problem has many bizarre or puzzling facets, several of which are discussed in this fourth field report of our series. One of these is the not uncommon occurrence of granular mafic or basic rocks near anorthosite in the contact zones. Such rocks are particularly well developed between the Kiglapait intrusion and the Snyder Group, where they have been called the Outer Border Zone (OBZ) of the Kiglapait intrusion (Morse, 1961, 1969).

The OBZ was originally classed by Wheeler (e.g. 1968) as "granulite of uncertain origin". This was an apt name. The uncertainty was more or less disavowed by Morse in 1961, and again, somewhat less strongly, in 1969. For fifteen years no other single topic occupied more of their discussions and correspondence. Morse found it a reasonable conclusion that this was a variety of chilled margin of the Kiglapait intrusion, contaminated by water from the adjacent Snyder Group to give brown hornblende in equilibrium with plagioclase, olivine, augite, titanomagnetite, and locally, hypersthene. This conclusion appeared to be strengthened by a systematic mineralogical study of his specimens performed by Berg (1971). Metasedimentary material, which bothered Wheeler, was ascribed by Morse to slivers of country rock in a *lit-par-lit* injection, or to xenoliths. Wheeler, inclined toward a metamorphic origin, was even more bothered by the granular texture and lineation. In a 1966 postcard, he reported that he had discovered a memorandum to himself which ran: "I am impressed by the shifts to which Morse must resort in explaining this rock..." Still further shifts are required. Berg has now had several opportunities to visit the OBZ for himself, and in this volume he reports that a large part of the original map unit consists of metasedimentary rocks belonging to an entirely new sequence overlying the Snyder Group. Among these are an oxide iron formation and a sequence of cordierite-bearing granulites. At the top of this sequence, he reports a thin olivine gabbro porphyry which he interprets as the true chilled margin of the Kiglapait intrusion. The metasedimentary units are interlayered with abundant, more resistant basic granulites; these are the lithologies originally mapped and sampled as OBZ. The basic granulites can no longer be imagined as a contaminated chilled margin of the intrusion unless it be supposed that the new metasedimentary sequence is largely xenolithic, and this seems unlikely because of its persistence along strike and because of the presence of a better, thinner candidate for a chilled margin. The basic granulites must therefore either be metabasalts belonging to the new stratigraphic sequence, or conceivably sills which preceded the emplacement of the main body of magma. This latter notion, which should by no means be identified with Mr. Berg, stems from the problems of mineralogy, texture, and mafic basaltic bulk composition which seem awkward to explain under a hypothesis involving metamorphosed extrusive or hypabyssal basalts. In short, while doubts remain, the entire problem takes on a decidedly different cast with the identification of the new stratigraphic sequence.

By such random walks do we proceed toward the truth.

Among other bizarre facets of the Nain complex is the discovery by Wiebe, reported herein, of adamellite containing diorite inclusions which show strong evidence of having been liquid at the time they were incorporated into adamellite. In fact they are chilled against adamellite, and they show convex protrusions typical of basic magma mixed with acid magma elsewhere in the world. The diorite inclusions plus adamellite matrix define a hybrid rock unit in which the ratio of the two members varies widely, but in which the adamellite is the carrier member. Visitors to the area were impressed with the strength of the evidence for mixing of magmas; this needs to be stressed, because Professor Wiebe is acutely embarrassed at having found such evidence, now for the third time, in every major field area he has investigated (California, Nova Scotia, and Labrador). If it is a pathological manifestation, it is a remarkably contagious one, as any visitor will discover for himself.

The ancient Archaean rocks which occur in the surroundings of the Nain complex have long been one of the targets of our research, because of a conviction that the origin of the complex must be judged in the context of the entire history of crustal evolution in this area. Last year we reported the discovery of Archaean anorthosite similar to that of certain noted Greenland occurrences. The occurrence at Okhakh Harbour offered little in the way of stratigraphic or structural information, but it seemed reasonable to infer from the presence of an altered ultramafic cumulate that the calcic anorthosite might be part of a differentiated basic sill. Wiener has now examined a far more extensive occurrence at Tessiuyakh Bay which has the distinctive signature of tiger-striped gneiss (foliated hornblende anorthosite) found at Okhakh Harbour. This turns out to be an undoubted example of a basic sill which varies repetitively from an ultramafic basal unit through hornblende melagabbro and gabbro to anorthosite. Rhythmic and graded layering, magmatic erosional features, and the vestiges of large plagioclase phenocrysts all testify to the origin of the unit, and allow the rudiments of a regional structural interpretation to be made. The structural integrity of the unit is preserved despite wholesale engulfment in granite, so that the remnants of the basic sill are entirely xenolithic. This is a feature held in common with Greenland examples. Genetically, such anorthosite-bearing sills may have more in common with the highlands of the Moon than with massif anorthosite, and yet it is tempting to ask whether they, too, represent an unusual and perhaps temporally restricted event in earth history. The problems of dating these rocks have been severe, and yet we can at least say that the major ones which are older than 2.6 Gyr and which appear to have much in common probably include Sittampundi, Limpopo, Fiskenaesset, Okhakh-Tessiuyakh, and the Stillwater complex of Montana. Possibly Bushveld should also be included. There is food for thought, and grist for the isotopic mill.

The P-T conditions in the contact aureole of the Nain complex have much to say about the emplacement depth and history of that complex. Last year, Berg was able to define closely, in terms of existing experimental data, the pressure of metamorphism in one part of the contact aureole. He has extended this work, chiefly by means of cordierite-garnet equilibria (and through the courtesy of several collaborators who provided specimens) to a far wider geographic distribution which sparsely encompasses the entire aureole of the complex. The data show a remarkable and so far systematic pattern of higher pressures (near 6 kbar) in the central latitudes of the aureole, decreasing to lower pressures (less than 4 kbar) toward the north and south. Other geobarometers agree remarkably well. Berg stresses the point that whereas the absolute calibration of the barometers may require revision, the relative differences must be meaningful, and this leads to interesting problems of interpretation. Again, the results clearly point to moderate rather than great depths of emplacement, and the profound depths once ascribed to all massif anorthosite can now be relegated to the status of myth.

These conclusions are supported in detail by the work of Speer, who discusses the metamorphism of the Snyder Group and other rocks in the contact aureole of the Kiglapait intrusion. He recognizes four mineral zones defined by the reactions leading to the appearance of cordierite and sillimanite, and to the disappearance of andalusite. The latter reaction overlaps to some extent the familiar second sillimanite reaction, which is not mapped as an isograd here because of the apparently variable behavior of water. The presence of iron formation and calc-silicate rocks afford still further possibilities for evaluating the roles of volatiles, temperature, and pressure in the Kiglapait contact aureole.

Speer defines a new lithologic unit, the Kiglapait Coast Migmatite, which shows evidence of partial melting due to the presence of the Kiglapait intrusion. The rheomorphic part of this unit was previously known as the granodioritic matrix of an agmatite in Wendy Bay; what Speer has done is to trace this melt fraction away from the Kiglapait contact through a transition zone and back to the primitive lithologies of the Tikkegharsuk migmatites.

The melt he describes is therefore a rejuvenated low-temperature fraction of these migmatites, occurring after a presumed interval of at least 1 Gyr. Recognition of this unit, and confirmation of an eastern segment of Snyder Group lithology near Perry's Gulch, should provide keys to a satisfactory characterization of the rocks in the contact aureole, which were only hastily mapped by previous workers.

Within the anorthosite complex, Davies has found a substantial area of calcic anorthosite brecciated by noritic material on Uighordlekh Island. This refractory material closely resembles the pure anorthosite which occurs as xenoliths in "block structure", and the large occurrence may in effect be the autochthonous source rock of such xenoliths. Using this relationship as a starting point, Davies has worked out the probable age relations of five rock types of the anorthosite kindred, based mainly on the lithology and abundance of their foreign inclusions. It is hoped that correlation by these methods may eventually be extended to contiguous or similar areas, which will be an important first step in understanding the wave after wave of successive intrusive events which appear to characterize the Nain complex.

Working on a nearby part of Paul Island, de Waard and Hancock report a different manifestation of the phenomenon of multiple anorthositic intrusion, in this case one which could easily have been overlooked and which may be much more common than hitherto recognized. This example consists of a large irregular dike of anorthosite emplaced in anorthosite. The separate identity of the two units is fortunately revealed by the presence of olivine in the younger one.

Brand has continued to unscramble a plethora of intrusive rock types in a small area of the western contact zone. Among these are three types of anorthositic rocks, three dioritic rocks, and a pyroxene granite. A dark monzodiorite is now found to be mappable, and a remarkably tabular xenolithic slab of leuconorite occurs well within its host granite body. Field relations in this complex area are now sufficiently well established for the laboratory study to be very rewarding.

The progress of laboratory research is now such that many interesting results of this Project are appearing in print or in theses. Abstracts of such papers appear in a separate section of this report, along with a bibliography. Of particular interest will be the substantial geochemical contributions of Barton on the Mugford Group, Snyder Group, and basic dikes of the Nain region. Two articles which spring from 1974 work and which would have received extended treatment in this report if not for their expected early appearance elsewhere are those of Berg and Wheeler on osumilite and of Morse on plagioclase lamellae in hypersthene. The former is the first report known to us of osumilite in a deep-seated environment, and it is especially important because it may help to explain why experimental studies to date have failed to show a stable field of existence for this mineral; at the same time it suggests important evidence for the scarcity of water in rocks of the Nain contact aureole. The latter article demonstrates that the plagioclase lamellae in hypersthene cited in last year's field report by Morse and Wheeler are in fact exsolution products from a former pyroxene with appreciable amounts of jadeite and Ca-Tschermak's molecule. The article draws almost solely on work performed aboard R/V *Pitsiulak*, and is buttressed and extended by a valuable paper in preparation by R.F. Emslie of the Geological Survey of Canada, who cites similar occurrences elsewhere in North America and in Norway. The origin of such lamellar intergrowths is presumed to be related to decompression, although from what depths and by what means remains unclear.

-- S.A. Morse

REGIONAL GEOLOGY

An Archaean Gabbro - Anorthosite Complex, Tessiuyakh Bay

Richard W. Wiener

University of Massachusetts[1]

Introduction

Archaean anorthosite and associated hornblende gabbros (e.g. "tiger-striped gneiss") were collected from the east shore of Okhakh Harbour, Labrador, in 1972 and mapped in more detail in 1973 (Hurst et al., FR 1973, p.9). The Okhakh locality was revisited in 1974, and then on the basis of Wheeler's "tiger-striped gneiss" localities (Fig. 4, p. 14, FR 1973), the Tessiuyakh Bay region was examined with the hope of finding more Archaean anorthosite and discerning its field relations. This report outlines the discovery of a layered, metamorphosed and deformed sill composed of anorthositic to hornblende ultramafic rocks hereafter named the Tessiuyakh Gabbro Complex. The complex occurs among migmatitic country rocks and is everywhere cut by abundant granite. It bears a strong resemblance to Greenland occurrences of Archaean hornblende gabbro-anorthosite described by Windley (1969).

Rock Units and Petrography

Country Rocks. The country rock into which the Tessiuyakh Gabbro was emplaced is a migmatitic gneiss. It crops out extensively (see Fig. 2) on Tikkegharsuk Peninsula, inland around Nakharvik Brook and at places within the Tessiuyakh Gabbro Complex. It is a pink to green weathering, white to gray, medium-grained, quartzo-feldspathic gneiss. The leucocratic layers contain quartz, plagioclase (An_{20-40}), microcline, olive-brown to green hornblende and red-brown biotite, with lesser amounts of epidote, magnetite and apatite. The melanocratic layers contain quartz, plagioclase (An_{30-40}), green hornblende and brown biotite, with lesser amounts of epidote, magnetite and pyrite.

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

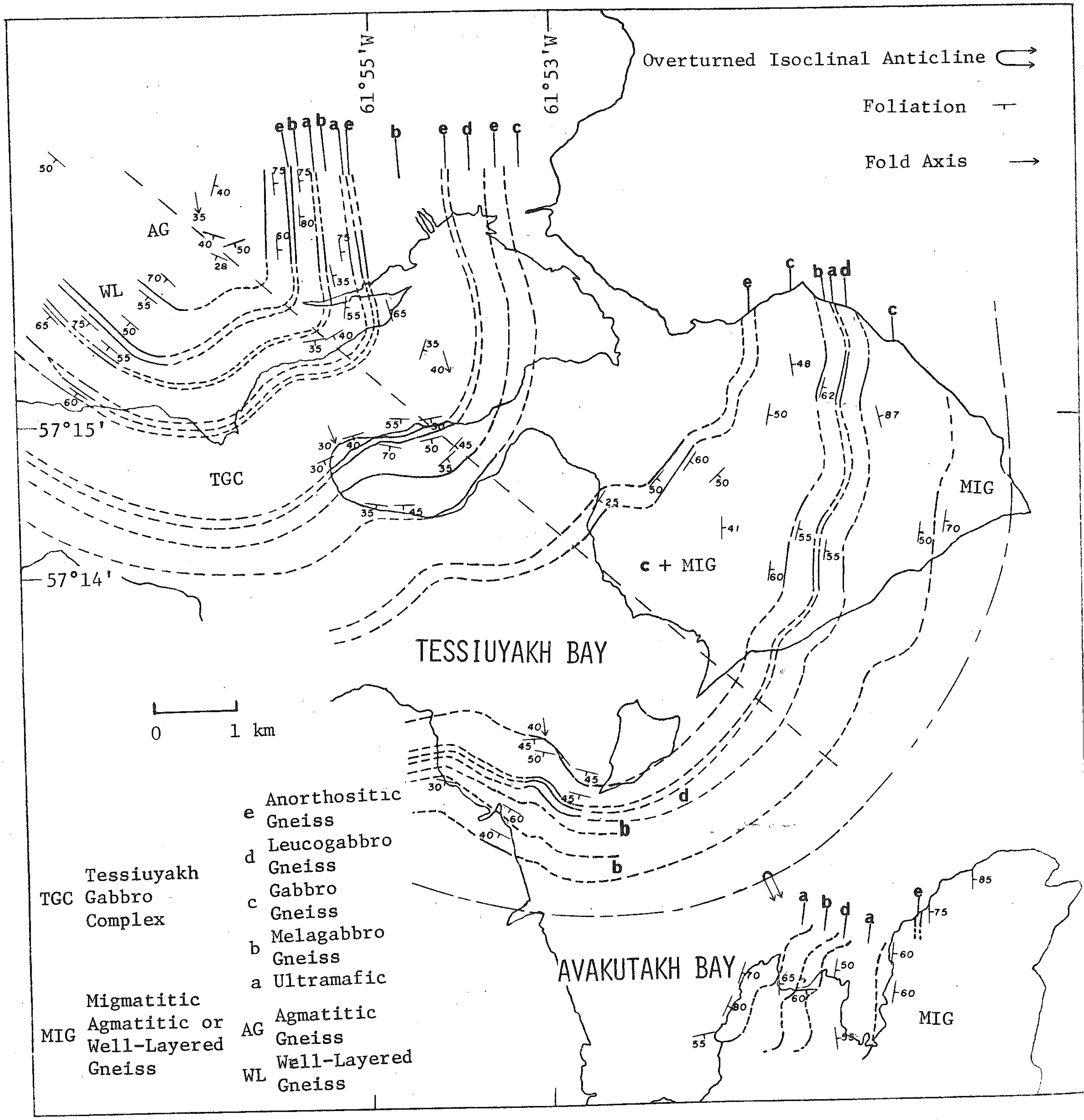

Fig. 2 . Geologic sketch map of the outer Tessiuyakh Bay area.

Granite. Leucocratic medium- to coarse-grained granitic rocks intrude the Tessiuyakh Gabbro and the migmatite everywhere. Their composition ranges from leucotonalite to kaligranite with plagioclase $\sim An_{25-30}$. A medium-grained variety is gray and either massive or mildly foliated. The foliated variety shows flowage around agmatitic blocks. The coarse-grained granite is pink to white and pegmatitic with large crystals of feldspar and chlorite (after biotite?). These three varieties are for the most part undeformed.

Another medium-grained, tectonically foliated granite is interlayered with migmatite and locally gabbro. Since these granites are deformed, they are probably older. In numerous locations, leucocratic layers in migmatite can be traced into coarse granitic dikes. These granites may have been generated as the partial melt of the migmatites. Alternatively, their source is elsewhere and the gneisses are merely injected by granite sills and dikes.

Tessiuyakh Gabbro Complex. The Tessiuyakh Gabbro Complex is a folded, metamorphosed and disrupted stratiform igneous complex. Parts of the intrusion are presently known to occur over an area measuring about 13 km along the axial trace SE-NW and 4-7.5 km across the axial trace (Fig. 2). The true thickness of the repeated sequence of gabbro and migmatite is $\sim$ 11.3 km, assuming an average dip of 60° and no isoclinal folding. The rock units are hornblende anorthositic gneisses (color index ≤ 10), hornblende leucogabbro gneisses (CI 10-30), hornblende gabbro gneisses (CI 30-65), hornblende melagabbro (CI 65-90), and hornblendites (CI 90-100). Everywhere these rocks occur as xenoliths in granite.

The cummulate igneous origin of the complex is clear-cut. Elongate, anhedral plagioclase phenocrysts are ubiquitous (Fig. 3), especially in the more mafic members. Graded rhythmic layering also is present, mainly in the more mafic members (see Fig. 4). A detailed description of one such occurrence accompanies Fig. 4. Primary lateral facies changes on a map scale were observed on the NW peninsula of Tikkigatsighak Island (gabbro to anorthosite) and on an island south of Sutton Island in Tessiuyakh Bay. On outcrop scale all forms of gradation among the rocks of the complex may occur. (By contrast, in Okhakh Harbour, two generations of anorthosite were observed: a massive coarse-grained blue-gray anorthosite is cut by tiger-striped anorthosite. Multiple intrusive relations are seen on the west shore of Okhakh Harbour where tiger-striped anorthosite foliation is cut sharply by hornblendite, and tiger-striped anorthosite in turn invades the ultramafic rocks with apophyses of plagioclase-rich material.) At Tessiuyakh, the relationship between hornblendite and anorthosite is commonly transitional through gabbros on outcrop scale (graded layering). This relationship is locally in the nature of a pencil-thin contact. The anorthositic to hornblende leucogabbroic gneisses are poorly to well-layered, medium- to coarse-grained plagioclase-hornblende-epidote gneisses, with accessory biotite and chlorite. The gneisses are characterized by folia or double-tapering streaks of coarse green hornblende (with minor epidote) and grey to white medium-grained granular plagioclase, which give the gneisses the (Siberian) tiger-striped effect noted first by Wheeler.

The hornblende gabbro gneisses and granulites contain minor orthopyroxene and pyrite in addition to the anorthositic mineralogy. These rocks are the most common bearers of plagioclase phenocrysts.

The hornblende melagabbro gneisses and hornblendites are greenish-black, massive, medium- to coarse-grained rocks. Hornblendites and hornblende melagabbros are associated together as are the anorthosites and leucogabbros. Gradations into gabbro (rarely anorthosite) are present. One petrographic analysis shows a predominance of green to brown-green hornblende with zoned plagioclase (average An_{41}) and minor orthopyroxene, biotite and magnetite. Minor bodies of gray-green serpentinized olivine(?)-pyroxene granulite and green actinolite-chlorite rocks are associated with some of the hornblendites. The actinolite and chlorite zones appear as cores in hornblendite blocks in the migmatite.

Diabase. Post-metamorphic diabase occurs in dikes crosscutting all earlier rock structures. In many places the diabase (as in the Koghukulluk Bay region) occupies faults and shear zones which clearly show on airphotos

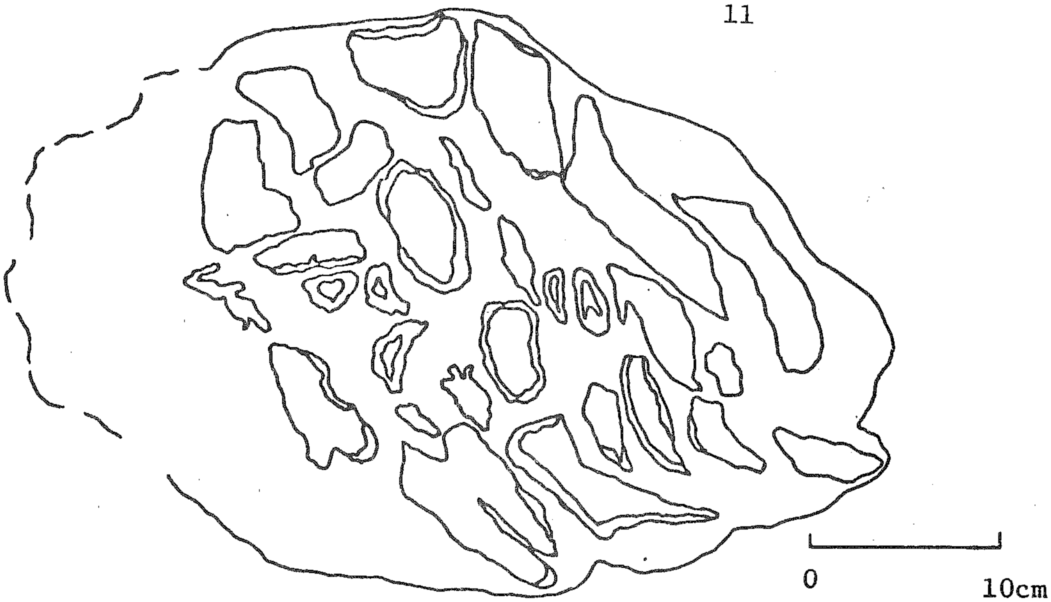

Fig. 3.

Zoned plagioclase phenocrysts in a hornblende-rich matrix

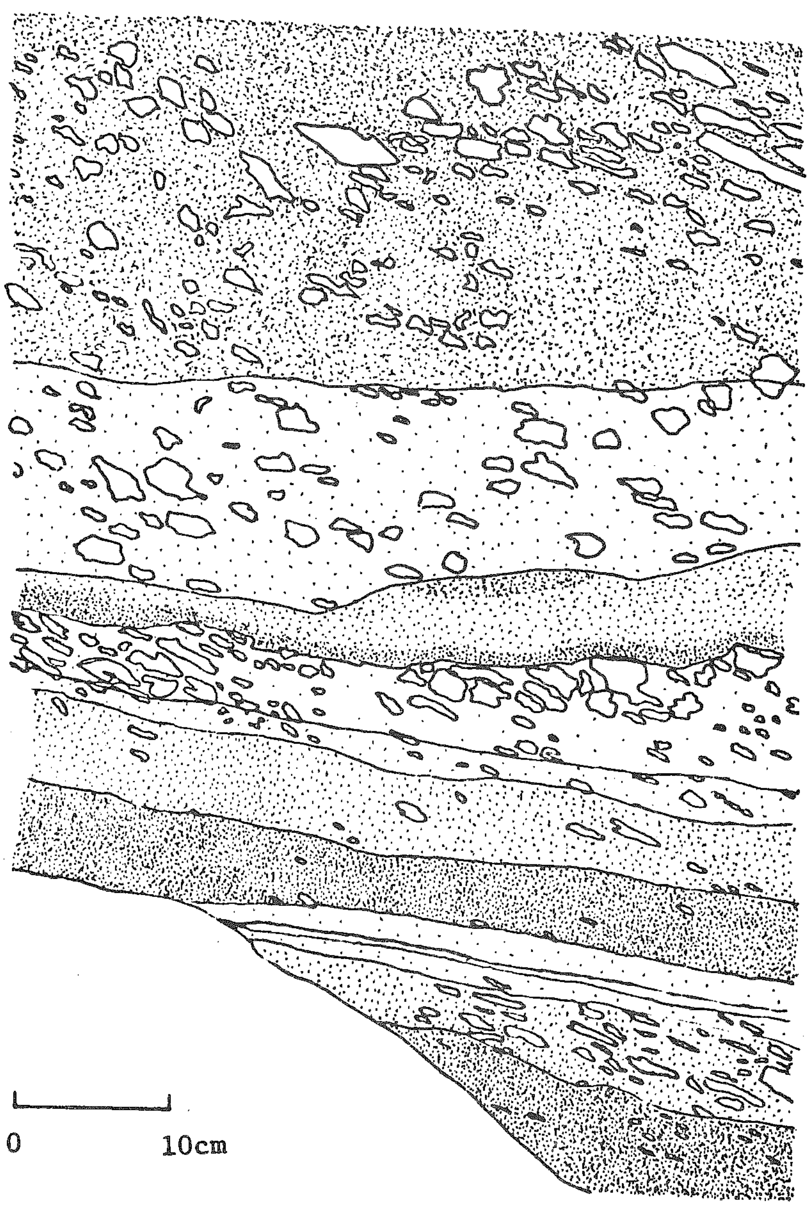

Fig. 4.

Graded layering in gabbro with imbricate plagioclase phenocrysts and the ground as pronounced linears. The diabase is often sheared against the walls of the dike. The country rock shows quartz and chlorite mineralization, slickensides, and granulation along the shear walls.

Structural Relations

The structure of the Tessiuyakh Gabbro is an antiform plunging 160-165° at 35° (see Fig. 2); this, with one exception, is the general trend and plunge of minor fold axes. The axial plane strikes approximately 312° and dips SW at about 50°. The axial trace is indicated on Fig. 2.

The contacts are alternately sharp and gradational; this is true on outcrop scale as well as map scale. At the mouth of Nakharvik Brook, two distinct anorthosite layers are traceable around parts of the fold; they are exposed on both limbs and the NW unit is well foliated in contrast with the SE unit. On the east shore of Avakutakh Bay the stratigraphic succession indicates igneous tops to the east (right side up). To the northwest, the sequence is upside down (tops to N in southerly dipping units). If this method of topping is reliable here, the presence of an earlier isoclinal structure is a strong possibility; an earlier axial trace would be crossed from SE to NW passing from the upper limb to the lower inverted limb of the earlier structure (see Fig. 2). Minor fold evidence (refolded folds) support this possibility. The hinge of the early fold would lie to the W or N along strike. No obvious repetition of the stratigraphy across the possible axial trace has yet been deciphered.

The contacts with the migmatite are conformable, or possibly they are fault contacts. The Tessiuyakh Gabbro may have been intruded as a Stillwater-type sill. The contact is also transitional in that fragments of the Tessiuyakh Gabbro are found in migmatite terrain either as sills of snipped-off ultramafic boudins (locally folded) or as angular fragments in the partial melt of the migmatite. The migmatite is also present as layers within the Tessiuyakh Gabbro. This probably reflects either multiple injection of sills or piecemeal fragmentation of the Tessiuyakh Gabbro by the partial melt of the migmatite.

The Tessiuyakh Gabbro has been strongly deformed so that a gneissic foliation of alternating hornblende and plagioclase-rich layers developed parallel to primary layering. The foliation is accentuated where granite has been injected, recrystallized and flattened parallel to the gabbro gneiss foliation. Where granite is undeformed, local rotations of the Tessiuyakh Gabbro have occurred. This feature is also prevalent at Okhakh Harbour and at Wheeler's occurrence #3 (FR 1973, p. 14). In places the gabbro (especially the melagabbro) is massive; there are gradations from well-layered to massive gabbro. Plagioclase phenocrysts have been stretched and flattened. In places the phenocrysts define a prominent second foliation at an oblique angle to the layering; this structure must be either a record of magmatic currents or a secondary deformational feature (see Fig. 4). Individual grains are for the most part granular. Some of the gabbros are cataclasites.

The ultramafic rocks rarely show the sheared or flattened textures of the more leucocratic (anorthositic) members of the Tessiuyakh Gabbro. The high mafic content evidently accounts for the different fabric development during deformation. Sheared anorthosite is commonly formed in close proximity to massive melagabbro. The ultramafics also behaved competently with respect to the migmatites and granites; squared-off boudins of hornblendite indicate a very high ductility contrast.

The internal structure of the migmatite varies from agmatitic gneisses with angular mafic inclusions (often the Tessiuyakh Gabbro) through ptygmatic migmatites characteristic of Tikkergharsuk Peninsula to well-layered, recrystallized, and flattened gneisses. The three textures are seen to grade into one another and may constitute local deformational gradients. Both ptygmatic and agmatitic textures have granitic portions which are undeformed.

Age Relations

The Archaean age of the anorthosites has been well documented (FR 1973, pp. 12-16). The Okhakh Granite (2.4 Gyr) cuts the anorthosite and is, therefore, younger. The same relationship is observed in Tessiuyakh Bay. Zircon from Okahkh anorthosite yields an age $\geq$ 2.6 Gyr (FR 1973, p. 15).

A K-Ar age on hornblende from a migmatite in Tessiuyakh Bay yielded 2.566 Gyr $\pm$ 0.014 (Barton and Barton, in press). This date may represent uplift immediately following the final stages of metamorphism and migmitization.

The sequence of events involves deposition of the original migmatites (acid and basic volcanics?) and intrusion of the Tessiuyakh Gabbro. This was followed by high grade metamorphism and migmitization (at least upper amphibolite facies) accompanied by strong deformation around 2.5 Gyr. Granitic rocks were generated or emplaced about this time, some of which saw further flattening and recrystallization, others of which crystallized in a post-tectonic setting. Retrogression, shearing, and emplacement of diabase are the latest visible events.

Petrology

The green hornblende-plagioclase ($\sim An_{75}$) assemblage may reflect either emplacement as a wet magma with primary hornblende or hydration of norite during metamorphism. Amphibolite facies conditions have affected the surrounding country rocks and there is nothing to argue against these conditions in the gabbros and anorthosites. Detailed petrography and probe analyses may uncover original igneous trends in the plagioclase and hornblendes, as has been done in Greenland (Windley, 1971) and South Africa (Hor et al, 1972).

Conclusions

Comparisons with other Archaean anorthositic complexes is instructive. It has been suggested (Windley, 1969) that Archaean anorthosites were generated at two crustal levels, and that they represent Archaean crustal sections. The deep level complexes are characterized by granulite facies metamorphism, chromite layers, spinel peridotites, anorthosites and phase and graded layering. The high level complexes are homogeneous hornblende gabbro-anorthosites in areas of extensive migmitization, with agmatitic textures, no layering, little ultramafics, and phenocrysts of the plagioclase in the gabbro. They are brought to the surface in the cores of antiforms. The Tessiuyakh gabbro is identical to the high level complexes but for the presence of ultramafics in greater quantity and graded layering. Minor occurrences of pyroxenites at Okhakh Harbour (FR 1973) and serpentinized pyroxene granulites from Koghukulluk Bay, Nakharvik Brook, and Tessiuyakh Bay (Morse, 1974, personal communication) may represent locales of the deeper section. Primary lateral variations (Windley, 1969, p. 19) are described from Greenland and observed in Tessiuyakh Bay (see above).

The pre-continental drift fit of the continents partly closes the Davis Strait (Bullard, et al, 1965, p. 41) and brings the Atlantic Archaean craton into a roughly triangular massif 600 km on a side (Bridgwater et al, 1973). The sequence of events at Tessiuyakh Bay is not unlike the relevant part of Bridgwater's sequence in Greenland (Bridgwater et al, 1973, p. 496).

Future work should consider the possibility of an earlier isoclinal structure to the N or W along strike. The borders of the intrusion to the N and W should be delimited, and detailed mineralogy and petrology remains to be completed.

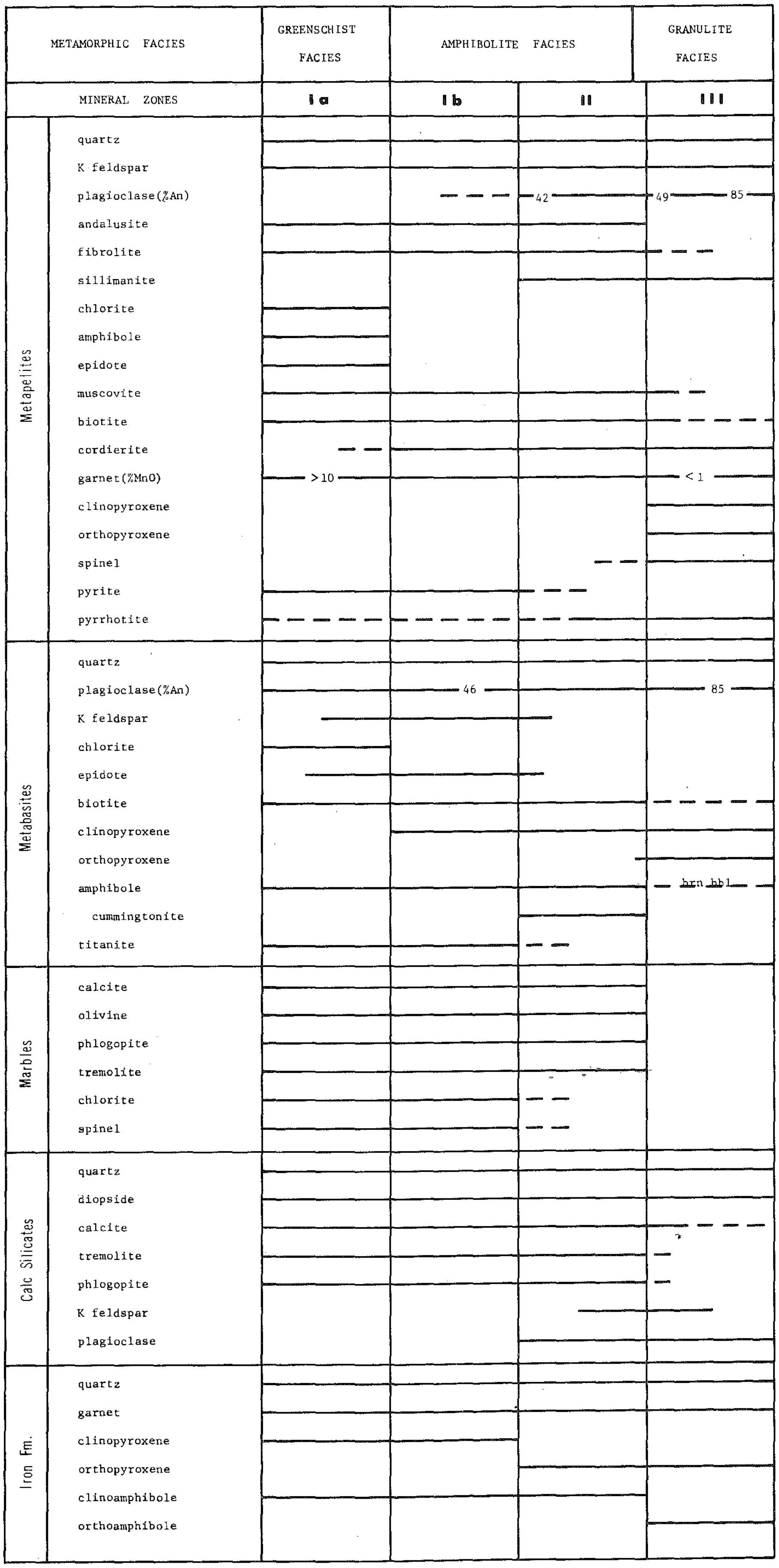

Fig. 5. Mineral changes in pelitic, basic, calcareous, and iron formation rocks of the Snyder Group with metamorphism.

THE CONTACT METAMORPHIC AUREOLE OF THE KIGLAPAIT INTRUSION

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Introduction

Since the last report (Speer, FR 1973), the major research effort involving the Snyder Group has been in regard to its metamorphism by the Kiglapait intrusion. Observations have also been made on the intermediate gneisses and Snyder Group in the contact aureole along the northern coast of the Kiglapait Mountains eastward from Snyder Bay to Perry's Gulch (Umiakoviktannak). This work doubles the length of the contact aureole under consideration to most of its accessible length.

Progressive Mineral Changes

The progressive mineral changes in the Snyder Group are summarized in Fig. 5. The contact aureole has been divided into four mineral zones, Ia, Ib, II, III, in order of increasing metamorphic grade. The major boundaries, Ib-II and II-III, have been chosen at the first appearance of sillimanite and the last appearance of andalusite respectively. These particular phases were chosen because they are easy to map in the Snyder Group and because the reactions involving them are presumed to be independent of a fluid phase.

Zone I has been further divided by the dehydration reaction:

$$\text{chlorite} + \text{muscovite} + \text{quartz} \rightleftharpoons \text{cordierite} + \text{biotite} + Al_2SiO_5 + H_2O \qquad (1)$$

which summarizes the reactions leading to the formation of cordierite, marking the beginning of the amphibolite facies, and the disappearance of chlorite with quartz or with quartz and muscovite, indicating the end of the greenschist facies. The Ia-Ib boundary is drawn at the last appearance of the assemblages chlorite + quartz or chlorite + muscovite + quartz. Because of probable variation in the relationships of bulk rock chemistry and of fluid pressure relative to total pressure, the dehydration reaction governing the appearance of cordierite appears to

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

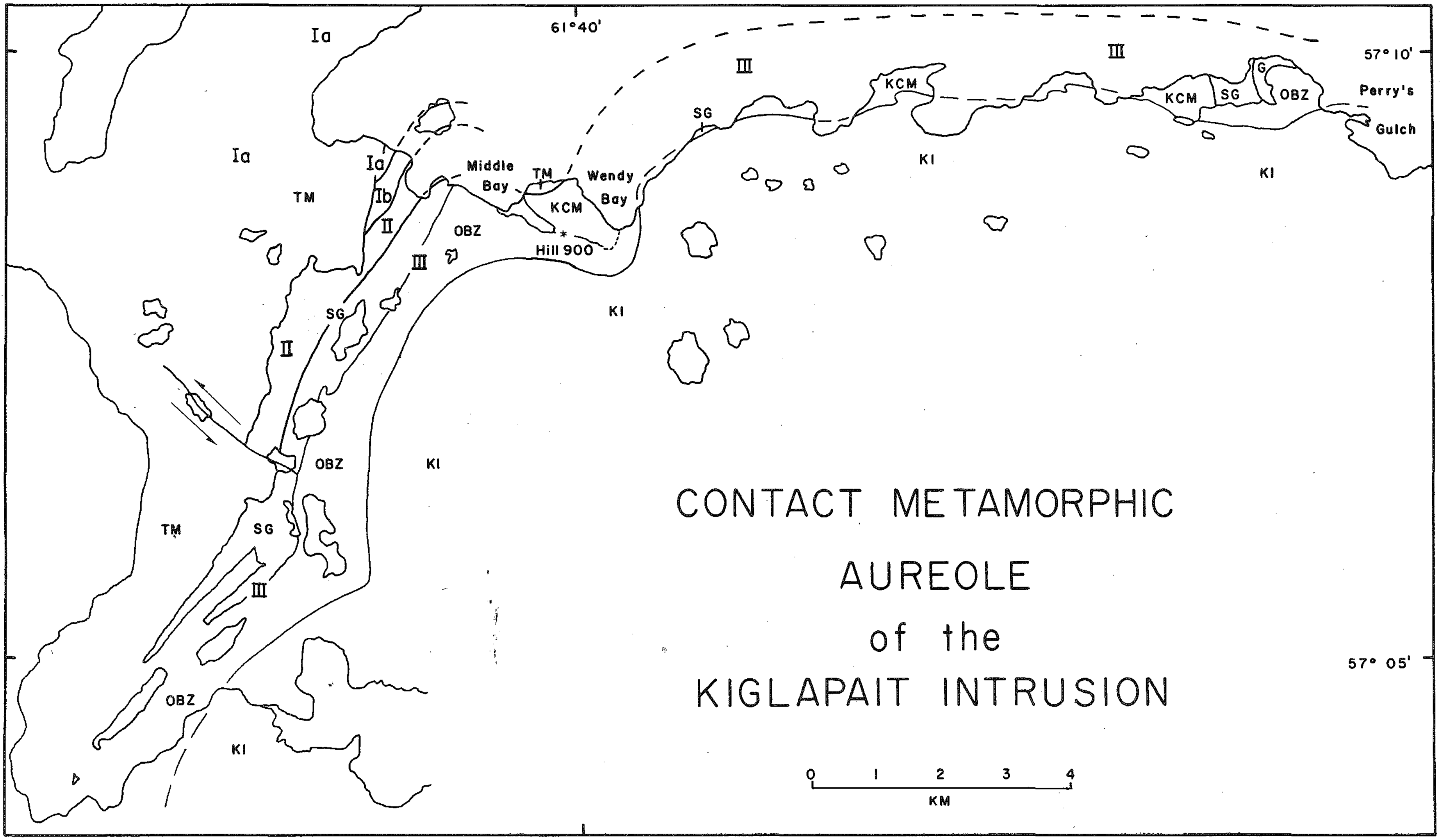

Fig. 6. Zones of metamorphism in the contact aureole of the Kiglapait intrusion. I-III represent zones I-III respectively in Fig. 5. KI is the Kiglapait intrusion, OBZ the Outer Border Zone, SG the Snyder Group, TM the Tikkegharsuk migmatites, KCM the Kiglapait Coast migmatites, and

take place over a considerable range of temperatures, making location of the associated isograd difficult.

A problem in terminology arises when we consider that the Snyder Group metamorphic rocks clearly represent an aureole of contact metamorphism, but that the mineral assemblages are equally representative of a low-pressure regional metamorphic facies series. By choice of mineralogic rather than genetic definitions of the metamorphic facies the terminology used in Fig. 5 is proper. The common low-pressure facies series of metamorphism, both regional and contact, is greenschist, amphibolite, granulite. The Kiglapait intrusion can be considered to have a contact metamorphic aureole containing andalusite at low grade and sillimanite and orthopyroxene at high grade with a facies series similar to that of a low-pressure regional metamorphism.

The following is a more detailed discussion of the progressive mineral changes with increasing metamorphic grade for each rock type.

Metapelites. Chlorite is common in the pelites of zone Ia, but a small amount of cordierite is everywhere present. This is taken to include either differing $\underline{P}_{aq}$ in adjacent beds or differing bulk rock chemistry. The uppermost boundary of zone Ia is drawn where chlorite ceases to be evident in any beds and presumably represents the completion of reaction 1. The quartzites and aluminous gneisses contain K feldspar, although it is not clear whether the mineral is an abundant detrital relic or a product of the dehydration reaction:

$$\text{quartz} + \text{muscovite} \rightleftharpoons \text{andalusite} + \text{K feldspar} + H_2O \qquad (2)$$

which may have proceeded at very low temperatures under conditions of $\underline{P}_{aq}$ less than $\underline{P}_{total}$. Single crystal X-ray photographs show the K feldspar to be a cryptoperthite of albite- and pericline-twinned plagioclase and a pseudo-monoclinic K feldspar. It is probable that these phases unmixed from what was originally a homogeneous monoclinic phase. The present K feldspar has microcline grid twinning indicating that it is triclinic. The apparent monoclinic symmetry shown in X-ray photographs is due to the very abundant fine-scale twinning on the albite and pericline twin laws. Muscovite is commonly greenish, suggesting a phengitic composition. A rather spessartine-rich garnet (16 wt. % MnO) occurs in zone Ia. In coarse cross-bedded quartzites, epidote and a blue-green amphibole occur.

Zone II is defined by the appearance of sillimanite in the presence of andalusite. Owing to numerous examples of andalusite-sillimanite intergrowths and the rather simple mineralogy of these rocks, sillimanite is regarded largely as having formed from the transformation of andalusite. The rather large (0.75 km) width of this zone is due either to the sluggish nature of this transformation or to an overprinting of a continuum of thermodynamic conditions. An andesine plagioclase regularly appears in this zone.

The highest temperature zone, zone III, is marked by the complete disappearance of andalusite in the pelites. It also coincides closely with the beginning of the granulite facies, shown by clinopyroxene and orthopyroxene in metabasites and orthopyroxene, almandine garnet, and cordierite in metapelites. The reaction

$$\text{muscovite} + \text{quartz} \rightleftharpoons \text{sillimanite} + \text{K feldspar} + H_2O \quad (3)$$

which is the second sillimanite isograd, appears complete in the beginning of this zone in rocks of greatest $\underline{P}_{aq}$. The dehydration of muscovite at lower grades has proceeded at lower values of P_{aq}. Biotite still remains, although its coexistence with quartz, K feldspar, and orthopyroxene indicates that the reaction

$$\text{biotite} + \text{quartz} \rightleftharpoons \text{orthopyroxene} + \text{K feldspar} + H_2O \quad (4)$$

is taking place in this zone. Plagioclase compositions are in the range labradorite to bytownite. The orthopyroxene is quite iron-rich (Fs_{67}) and locally is exsolved. Rarely the exsolved pyroxene is in itself exsolved to two pyroxenes. Amphibole is present and appears to be a retrograde product of a reaction involving pyroxene. Optically, much of the K feldspar is orthoclase, although X-ray examination shows it to be similar to zone Ia K feldspar.

Metabasites. In the lowest temperature zone, Ia, the metabasites show relict textures but their mineralogic recrystallization is virtually complete. It appears that the Snyder breccias were porphyritic with phenocrysts of plagioclase that have since been recrystallized to oligoclase + magnetite + calcite + quartz. The mafic portion of the metabasites has recrystallized to an assemblage of biotite + ferrohornblende (Leake, 1968) and subordinate chlorite + epidote.

With a further rise in temperature in zone Ib, chlorite disappears and is replaced by clinopyroxene. The associated plagioclase is andesine. Increasing metamorphism then begins to form abundant cummingtonite in zone II as the small amounts of epidote disappear. In the highest temperature zone, II, the cummingtonite disappears and an orthopyroxene-clinopyroxene-brown hornblende-bytownite-quartz assemblage with minor biotite dominates. Almandine garnet does not occur in the Snyder breccias; however, manganiferous garnets are present in some quartz-rich dikes. The cummingtonite contains exsolution lamellae of hornblende and the brown hornblende contains exsolution lamellae of cummingtonite. The clinopyroxene is exsolved to two pyroxenes.

<u>Iron Formation, Marbles, and Calc-silicates</u>. The progressive mineral changes of the iron formation are little understood at the moment and may only reflect changes in the bulk rock chemistry. The pyroxene present in zone I, a manganoan hedenbergite, is replaced in zones II and III by an orthopyroxene. Grunerite disappears after zone II, perhaps replaced by a ferroanthophyllite in zone III. The garnet remains manganese-rich throughout, becoming more grossular-poor, pyrope-rich with increasing metamorphic grade.

The details of the progressive metamorphism of the marbles and calc-silicates are obscured by sampling problems and more importantly by the apparent wide ranges in fluid pressure or fluid composition. This is shown by dehydration and decarbonization reactions taking place over a considerable range of temperature. However, by zone III, chlorite has disappeared in the marbles, and calcite, tremolite, and phlogopite have disappeared from the calc-silicates. At present, wollastonite has been found only in veins on Snyder Island. Its presence in these veins is thought to indicate very water-rich fluids moving through cracks, allowing the reaction of calcite and quartz to form wollastonite to proceed at relatively low temperatures. Preliminary work on the high-grade calc-silicates from the north coast of the Kiglapait Mountains shows the assemblage enstatite + diopside + quartz + phlogopite ± calcite. This assemblage in zone III is equivalent to a tremolite-bearing assemblage at lower temperatures or higher water pressures.

Partial Melting in the Contact Aureole

The Snyder Group affords little volume of material of appropriate composition for partial melting. In contrast, the Tikkegharsuk migmatites contain large volumes of such material as evidenced by anatexis during one or more pre-Snyder Group metamorphisms. Textural and mineralogic evidence from Hill 900 between Middle and Wendy Bays suggest that the Tikkegharsuk migmatites have undergone another anatexis as the result of the intrusion of the Kiglapait to produce the Kiglapait Coast migmatites. These were mapped as intermediate gneisses by Morse (1969) and were similarly concluded to be of rheomorphic origin. They crop out from Wendy Bay almost to Perry's Gulch. Only Hill 900 has sufficient outcrop perpendicular to metamorphic grade to observe the transition between the Tikkegharsuk migmatites and the Kiglapait Coast migmatites.

Two features lend sharp contrast to the distinction between the Tikkegharsuk migmatites and the Kiglapait Coast migmatites: deformation and mineralogy. A traverse toward the Kiglapait intrusion shows the following stages:

1a. Tikkegharsuk migmatites: typically white and pink, highly contorted and plastically deformed migmatites, having undergone deformation and anatexis during an Archean regional dynamo-thermal metamorphism. They are biotite- and amphibole-bearing, suggesting amphibolite facies metamorphism.

1b. Tikkegharsuk migmatites: typical except that the rocks are tan and contain orthopyroxene. These are evidently effects of the contact metamorphism of the Kiglapait intrusion. The granulite facies boundary corresponding closely to the II-III boundary is drawn at the boundary between these rocks and the typical Tikkegharsuk migmatites.

2. Kiglapait Coast migmatites: migmatitic structures, such as stromatic (layered) and folded structures, schlieren structure, schollen (raft) structure, and igneous breccias are spectacularly exhibited by these rocks. On the whole, the Kiglapait Coast migmatites are not highly contorted. Their foliation is strong and regular and appear conformable to the border of the Kiglapait intrusion. The rocks, according to modal analyses by Morse (1969) and work by

Wheeler (pers. comm.), are hypersthene granodiorites and tonalites (Johannsen numbers 227 and 228). According to de Waard (FR 1972), these would be opdalitic and enderbitic granulites. The melanocratic rocks are mixtures of orthopyroxene, cordierite, biotite, and some felsic minerals.

While the migmatite structures of the north coast are diverse and generally intermingled, they appear to be mappable and could be presented as a distribution of various rock/melt ratios either as a function of initial composition or the amount of melt due to increased temperatures. For example, agmatites constitute only a small percentage of the volume of the migmatites present and are developed only near the contact of the Kiglapait intrusion. This is no doubt due to rock compositions capable of producing large amounts of melt doing so only near the hotter contact.

Embedded within the Kiglapait Coast migmatites are rocks which appear to be originally ultrabasic rocks, basic rocks, calc-silicate rocks, and quartzites. One group of such rocks lies on the point just east of Wendy Bay and contains fragments of Snyder Group (quartzites, iron formation, marble, calc-silicate rocks, and graphitic sulfide-bearing hornfels). Another, larger area of such rocks, just west of Perry's Gulch, consists of massive quartzites and a few marble beds. Equivalence of these rocks with the Snyder Group is more problematical and is tentatively concluded but not strenuously maintained until a further study can be made of the area. This area mapped as underlain by possible Snyder Group (Fig. 6) lies just east of the area mapped as possible Snyder Group by Morse (1969).

Determination of the Conditions of Metamorphism

After characterization of a metamorphic facies series it is useful to inquire into the absolute values of the parameters of metamorphism. By making simplifying assumptions that fluid pressure = water pressure = total pressure and that all phases have ideal end member compositions, a petrogenetic grid (Fig. 7) can be constructed for the metamorphic rocks of the Kiglapait contact aureole.

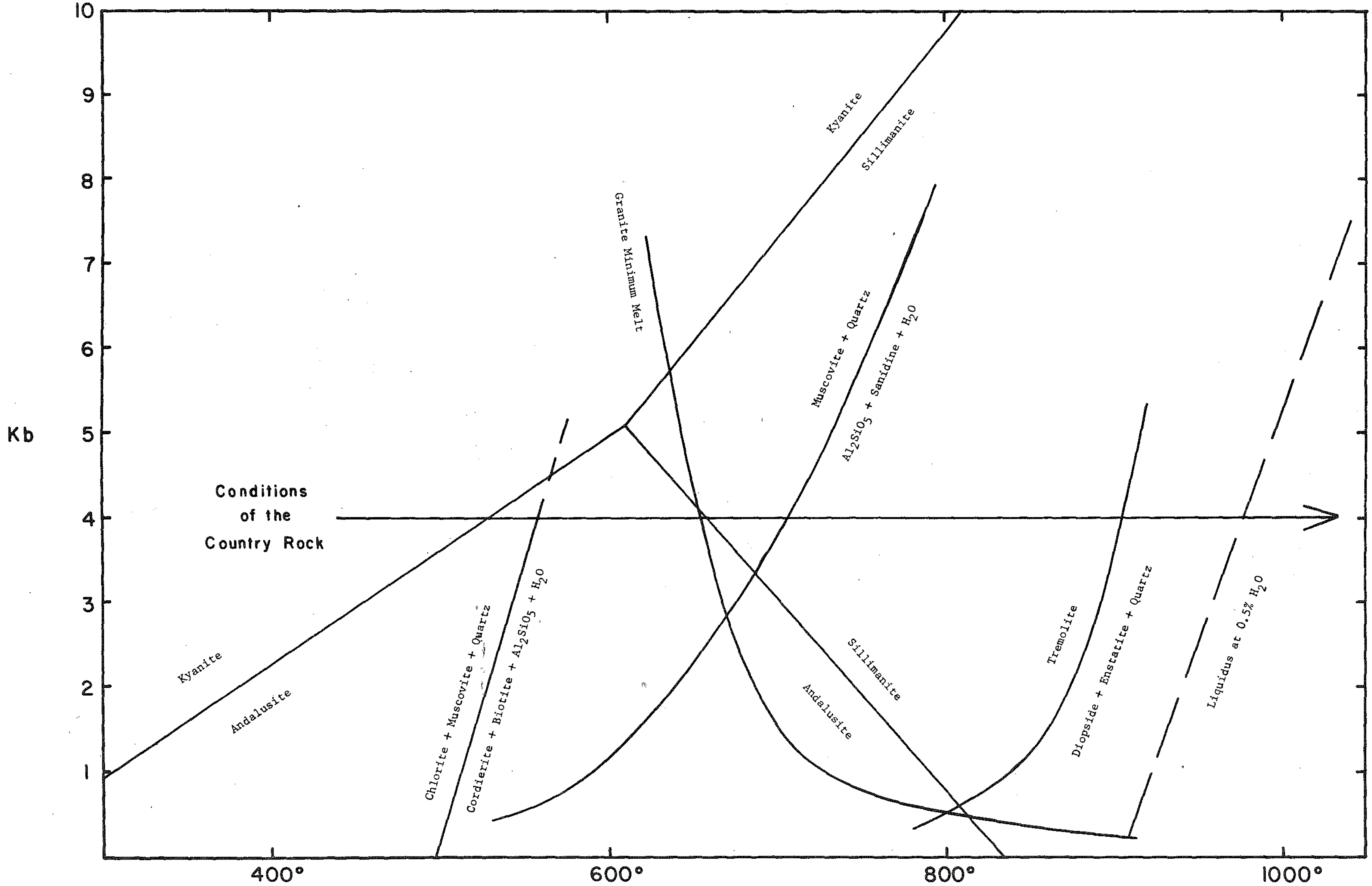

Fig. 7. Pressure-temperature grid showing univariant equilibria pertinent to the Kiglapait contact metamorphic aureole. Experimental data from Tuttle and Bowen (1958), Boyd (1959), Evans (1965), Hirschberg and Winkler (1968), and Richardson et al (1969).

Two restrictions on the possible pressures of metamorphism can be derived using this grid and the following observations from the rocks:

1) the Al_2SiO_5 polymorph transition is andalusite to sillimanite. The best estimate of the aluminum silicate triple point (M.C. Gilbert, pers. comm.) is 601° C and 5.1 kbar, which gives an upper pressure limit.
2) the assemblage muscovite + sillimanite + quartz + K feldspar is stable in part of the area. Evans' (1965) experimental determination of the stability of muscovite in the presence of quartz crosses the Richardson et al (1969) experimentally determined andalusite-sillimanite transition at about 3.5 kbar, which is a lower pressure limit.

This yields a possible pressure range of from 3.5 to 5.1 kbars. As the first and second sillimanite isograds lie close together (0.15 km) in the contact aureole, it is suggested that the lower end of this interval represents the pressure during metamorphism. At the present erosional surface, the pressure and temperature gradients reached during the Snyder Group metamorphism are essentially orthogonal so that the line representing increasing metamorphic grade is a horizontal isobaric line on the P-T grid.

Determination of temperature limits in the contact aureole is a little more difficult. The Snyder breccia and undeformed basic dikes on Tikkegharsuk Peninsula have mineral assemblages similar to those of zone Ia. These rocks are too distant (up to 6 km) to be considered part of the Kiglapait contact aureole; therefore, at the time of the emplacement of the Elsonian plutons, the country rocks were probably undergoing a regional thermal metamorphism in the low-pressure greenschist facies. The lower temperature limit of the greenschist facies is usually taken to be between 300° and 400°C if $P_{fluid} = P_{total}$ (Winkler, 1967).

The upper temperature limit is again difficult to specify because of the relationships between P_{fluid} and P_{total}. However, if the pressure is correct, the andalusite-sillimanite transition puts the temperature at the sillimanite isograd equal to about 680 ± 40°C. An assemblage of hypersthene + K feldspar + quartz + biotite in a very biotite-rich rock at Middle Bay indicates a limit of more than 700°C in zone III (Hess, 1969). The assemblage enstatite + diopside + quartz instead of tremolite suggests temperatures upwards of 900°C if $P_{fluid} = P_{total}$ (Boyd,

from Tuttle and Bowen (1958), Boyd (1959), Evans (1965), Hirschberg and Winkler (1968), and Richardson et al (1969).

1959). Tuttle and Bowen (1958) show that dry granites or charnockites (water content less than 0.5%) melt over a large temperature interval of 650° to 1000°C at 4 kbar. To produce nearly complete melts, as evidenced by the nebulitic and agmatitic textures of the Kiglapait Coast migmatites, the upper temperature limits of this range must have been reached. An upper temperature limit can also be estimated by consideration of heat conduction theory. For contact metamorphism according to Jaeger (1967), an equation of interest is for a semi-infinite solid in the transient state with unidirectional heat flow. One result is that if we assume the instantanous emplacement of a magma at temperature T_o into a country rock at temperature T_c, then the temperature after emplacement is initially at the value $\frac{1}{2}$ $T_o + T_c$ and will gradually decline. Thus for basaltic magma with a liquidus temperature of 1200°C and T_c between 300° and 400°C, the maximum metamorphic temperature would be 900° to 1000°C. A convecting gabbroic magma could sustain such temperatures for some period of time.[2]

From the above arguments, the contact metamorphic aureole represents a metamorphism at a pressure of 4 ± 1 kbar with temperatures ranging from 300° to 400°C in the country rocks to perhaps 900° or more at the intrusion contact. This in excellent agreement with Berg's (FR 1973, p. 36) P-T estimates in the contact aureole of the Hettasch intrusion. To make the experimental reactions comply directly with the rocks in question, critical evaluation would have to be made of bulk rock or mineral chemistry, relationships of P_{fluid}, P_{water}, and P_{total}, and other factors such as surface effects.

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[2]The approximate formula cited here requires that $T_c << T_o$, which is rather far from the case when $T_c = 400°C$. On the other hand, for a very large volume of strongly convecting magma, it is possible that T approaches T_o rather closely after a long time. (Ed.)

NEW STRATIGRAPHIC SEQUENCE ABOVE THE SNYDER GROUP

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Introduction

Detailed mapping indicates that the rocks which were formerly known as the Outer Border Zone (OBZ) of the Kiglapait layered intrusion (Morse, 1961, 1969; Berg, 1971) actually consist of a whole sequence of metamorphosed sedimentary rocks and fine-grained basic granulites of problematical origin. These rocks overlie or intrude the Snyder Group and have been metamorphosed by the Kiglapait intrusion for the most part at a grade considerably above the breakdown of muscovite + quartz (Speer, FR 1972).

The marked sedimentary character of these rocks was not previously recognized because the metamorphosed sedimentary units are easily weathered and do not generally form outcrops, whereas the basic granulites are resistant and tend to form outcrops. Thus a reconnaissance mapping and sampling survey reveals only the rocks of basic igneous composition.

The stratigraphic column (Fig. 8) shows that this unnamed sequence of rocks occurs above an apparently significant erosional unconformity which developed after deposition of the uppermost unit of the Snyder Group, the Upper Quartzite (Speer, FR 1972). The unconformity is postulated from the fact that commonly the basal units of the unnamed sequence directly overlie any of the Snyder Group units: Sulfide Hornfels, Marble, Silicate Iron Formation, or even Lower Quartzite.

The most complete exposure of the new sequence occurs along Falls Brook, which empties into Middle Bay to the east of the second and larger brook (Lakes Brook) entering Middle Bay (Fig. 9). The base of the sequence occurs about 175 m upstream from the mouth of Falls Brook. However, several sills of the basic granulite occur below this point in both the Snyder Group and the Archaean basement.

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

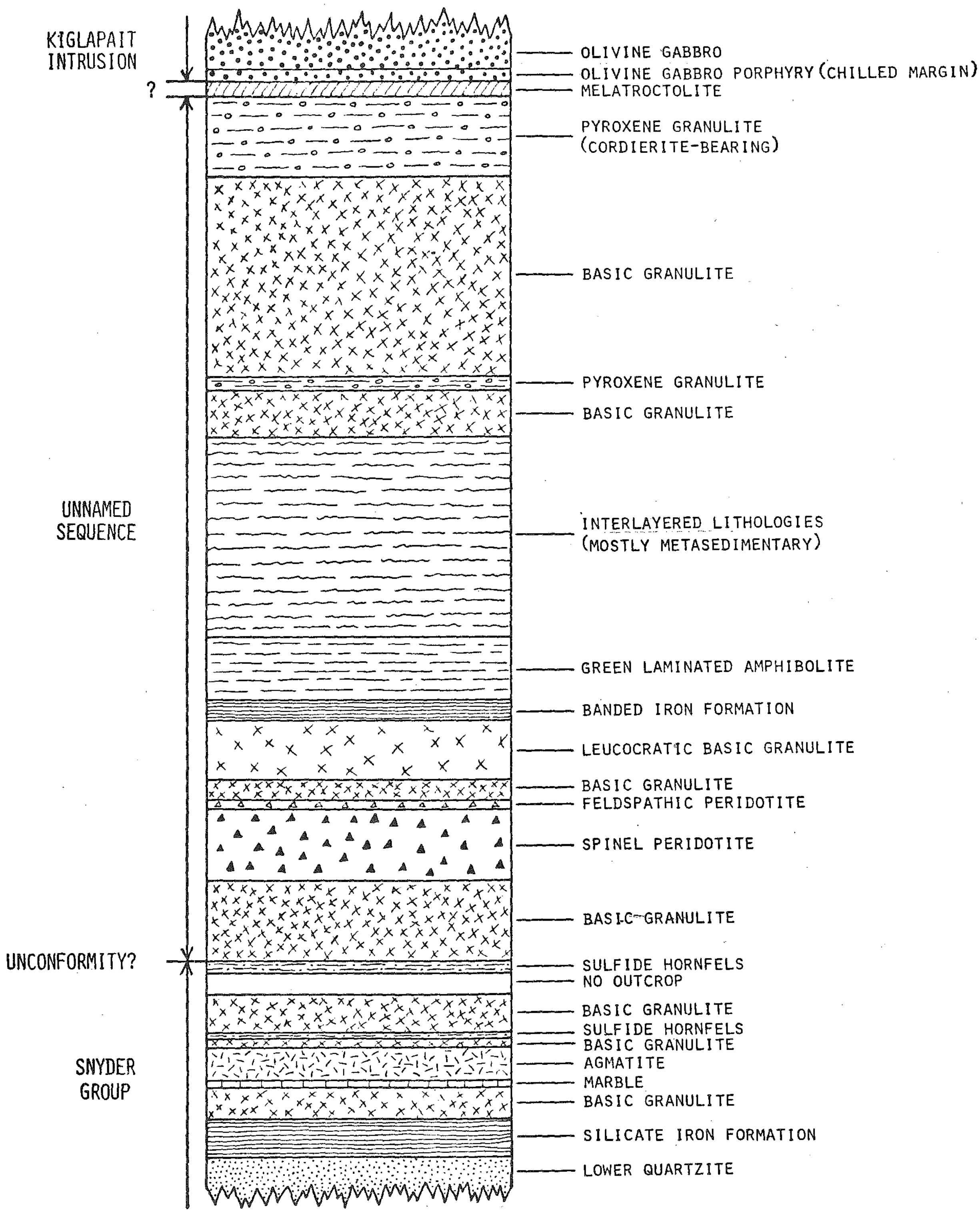

Fig. 8. Stratigraphic column along the Falls Brook section.

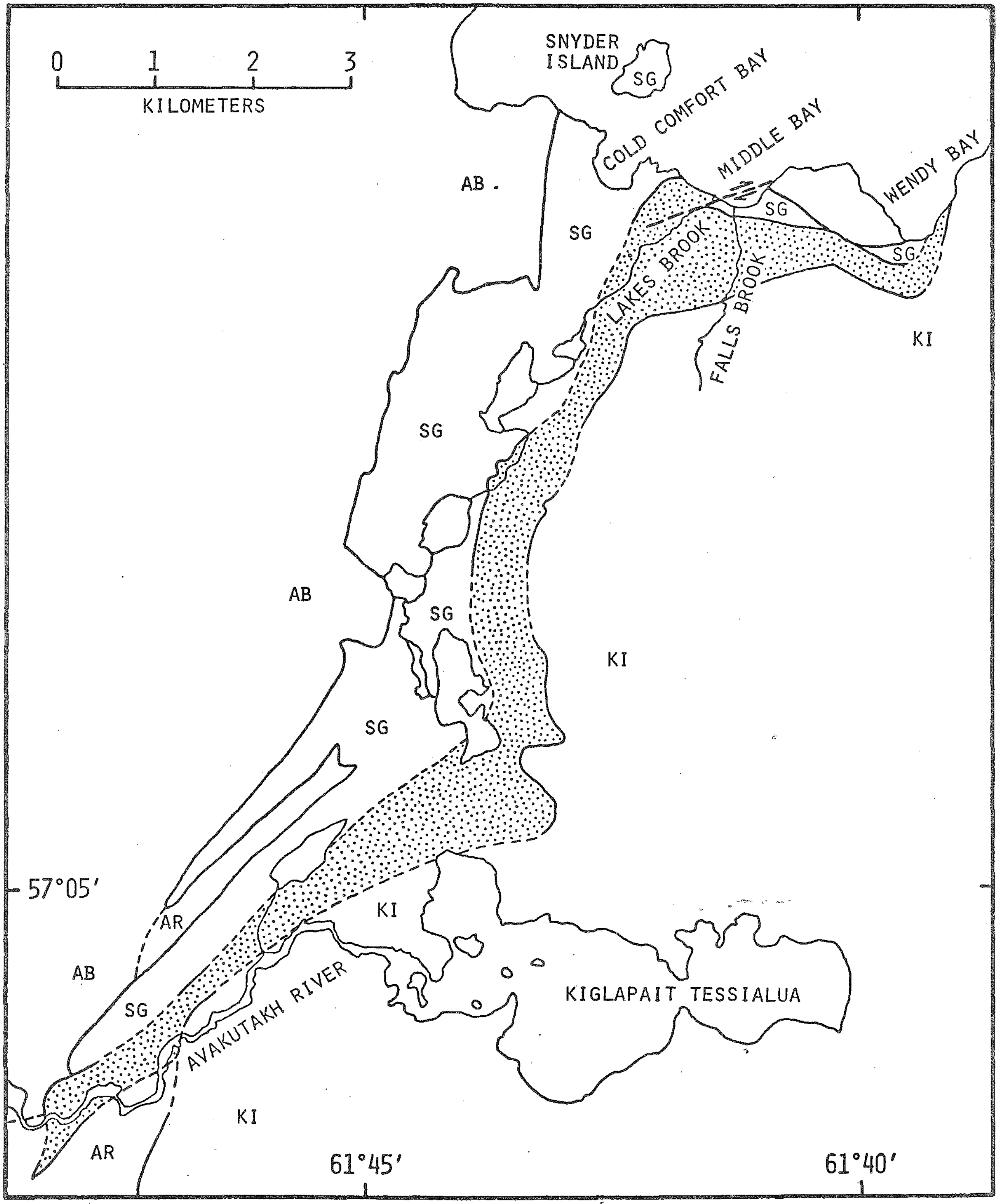

Fig. 9. Simplified geologic map of the northwestern contact zone of the Kiglapait layered intrusion. AB = Archaean basement, SG = Snyder Group, stippled area = unnamed sequence, AR = anorthositic rocks, KI = Kiglapait layered intrusion.

Above this point the basic granulites present a problem. They typically consist of plagioclase, brown hornblende, olivine, augite, orthopyroxene, apatite, titano-magnetite, and ilmenite, and many are demonstrably intrusive (i.e., sills). However, higher up in the sequence some of them display what may be relict pillows: dark biotite-rich rinds around lighter granulite having shapes similar to that of a biconvex lens. At this time it is impossible to determine the origin (intrusive vs. extrusive) of every unit of basic granulite.

Modal variation across the strike of these basic granulites has been documented by Berg (1971). He showed that brown hornblende decreases toward the Inner Border Zone (IBZ) of the Kiglapait intrusion; concomitantly, olivine and pyroxene increase toward the IBZ. In addition, most of the silicates in the basic granulites show a progressive change in composition, generally becoming more refractory toward the IBZ. All of these phenomena occur in basic granulites that have a nearly constant bulk chemical composition (unpublished data). Based on the knowledge of the field relations at that time, Berg (1971) was able to reconcile these data and the granular texture with a contaminated chilled-margin model. But now that it is clear that the basic granulites are a group of individual units, separated from each other by metasedimentary units or other basic granulite units, it seems likely that the modal and compositional variation of the minerals and the granular textures reflect a gradient of progressive metamorphism. Thus, whatever the origin of the basic granulites, they apparently have undergone the same contact metamorphism by the Kiglapait intrusion as the metasedimentary units.

Stratigraphy

Along Falls Brook, the top of the Snyder Group is represented by a thin sliver of Sulfide Hornfels. Most of the Sulfide Hornfels and all of the Upper Quartzite are missing. Above the Sulfide Hornfels outcrops there occur about 20 m of moderately foliated basic granulite. This granulite contains abundant eyes or knots of coarser grained olivine and plagioclase.

The overlying unit is a spinel peridotite which is ∿ 20 m thick; it is unknown whether the peridotite is intrusive or extrusive. The mineralogy is olivine (Fo_{80}), pale-green calcic amphibole, orthopyroxene (En_{81}, Al_2O_3 1.88 wt%), colorless Mg-chlorite (clinochlore), chromian spinel, chromian magnetite, ilmenite, anorthite (An_{99}), cummingtonite, and pyrrhotite. This unit has numerous leucocratic veins which locally contain very coarse green and brown amphiboles. The top of the peridotite is somewhat feldspathic and is intruded by a sill of foliated basic granulite. The basic granulite is ∿ 5 m thick and contains numerous boudinaged xenoliths of the feldspathic periodotite. The top of this sill in turn intrudes a rock which resembles the feldspathic upper part of the peridotite and which grades upward into a leucocratic basic granulite. This leucocratic basic granulite is ∿ 15 m thick. Although conclusive evidence is lacking, it may be that the leucocratic basic granulite and the spinel peridotite were crystallized from a single very basic sill or flow, the spinel peridotite representing the basal cumulates.

Above the leucocratic basic granulite is a very striking banded iron formation. This unit consists of alternating layers dominated by any of the minerals: magnetite, quartz, fayalite (Fo_7), grunerite, hedenbergite, or apatite. The magnetite-rich layers vary in thickness from 1 mm to about 2 cm. The other layers are typically of comparable thickness, but locally are somewhat thicker (3-5 cm). The unit is about 5 m thick, but magnetite layers are rare in the upper 1-2 m. Near the top is a layer of cordierite-hypersthene-garnet granulite which varies in thickness from 5-30 cm. Small sills of basic granulite are locally present.

Directly above the banded iron formation is a green laminated amphibolite to hornblendite. It consists mainly of a greenish amphibole, but also minor olivine, clinopyroxene, opaque minerals, and plagioclase. Locally, the fine layering or lamination is almost varve-like. Thin, boudinaged layers of calc-silicate material (diopside, epidote, titanite, etc.) are ubiquitous. This unit is approximately 15 m thick.

The next 50 m consist of several interlayered or interbedded lithologies. These include garnet-cordierite-biotite-feldspar schist, biotite-olivine-spinel-feldspar schist, pyroxene granulite, diopside-titanite-amphibole-plagioclase granulite, biotite-plagioclase granulite, garnet-hypersthene-olivine-andesine granulite, olivine-hornblende-pyroxene-biotite granulite, and green laminated amphibolite.

The succeeding unit is composed of interlayered, foliated basic granulite and basic granulite containing the "pillow-like" structures. As mentioned above these structures are defined by the presence of dark, biotite-rich, 3 cm rinds around lighter basic granulite. Although they are variable in size, the typical dimensions are perhaps 15-20 cm x 40-60 cm. This interlayered unit is $\sim$ 12 m thick and underlies a zone of pyroxene granulite and minor biotite schist which is only $\sim$ 3 m thick.

Above this is a thick ($\sim$ 50 m) zone of moderately foliated to massive basic granulite. It appears to be rather homogeneous and is overlain by a pyroxene granulite which is locally rich in cordierite and biotite. This poorly exposed pyroxene granulite is the uppermost unit in the sequence and is estimated to be $\sim$ 20 m thick. Typically, it is quite leucocratic, although quartz is rare. The Kiglapait intrusion has presumably removed much of the unit in this area, because further to the south the pyroxene granulite unit is at least 50 m thick.

Igneous Breccia

Common throughout the sequence of metasedimentary rocks and basic granulites are irregular sills and dikes of a biotite-pyroxene-quartz-feldspar granulite, which typically contain subangular to subrounded xenoliths of amphibolite, quartzite, and basic granulite. This unit does not appear to intrude the Kiglapait intrusion; therefore it is apparently older than the Kiglapait body but younger than the sequence of metasedimentary rocks and basic granulites. The igneous matrix of the breccia cannot be derived locally (or *in situ*) as an anatectite, because it contains amphibolite fragments that have obviously been derived from the Archaean basement rocks.

Kiglapait Margin

The above sequence is terminated by the contact of the Kiglapait layered intrusion. Along the Falls Brook traverse, there is a zone of fine-grained melatroctolite (3-5 m thick) at the contact. The mela-troctolite is followed by a zone of fine-grained olivine gabbro containing dark plagioclase phenocrysts. This zone grades rapidly (within a few meters) into coarse-grained Inner Border Zone olivine gabbros (Morse, 1961, 1969; Berg, 1971), although locally the coarse-grained gabbros stope the fine-grained gabbros. Along other traverses, the contact sequence is much the same, but the melatroctolite is commonly absent.

Discussion

The identification of this sequence of metasedimentary rocks and basic granulites is an interesting development especially in terms of regional correlations. These units are probably Aphebian in age, and eventually they might be useful in correlations with the Labrador Trough or with Greenland. Further study of the rocks is imperative as there is still lively discussion as to the origin of the basic granulites. One possibility is that they represent plutonic "precursor" sills of the Kiglapait intrusion (Morse, personal communication). The other hypothesis is that they are hypabyssal sills and lava flows of an earlier event.

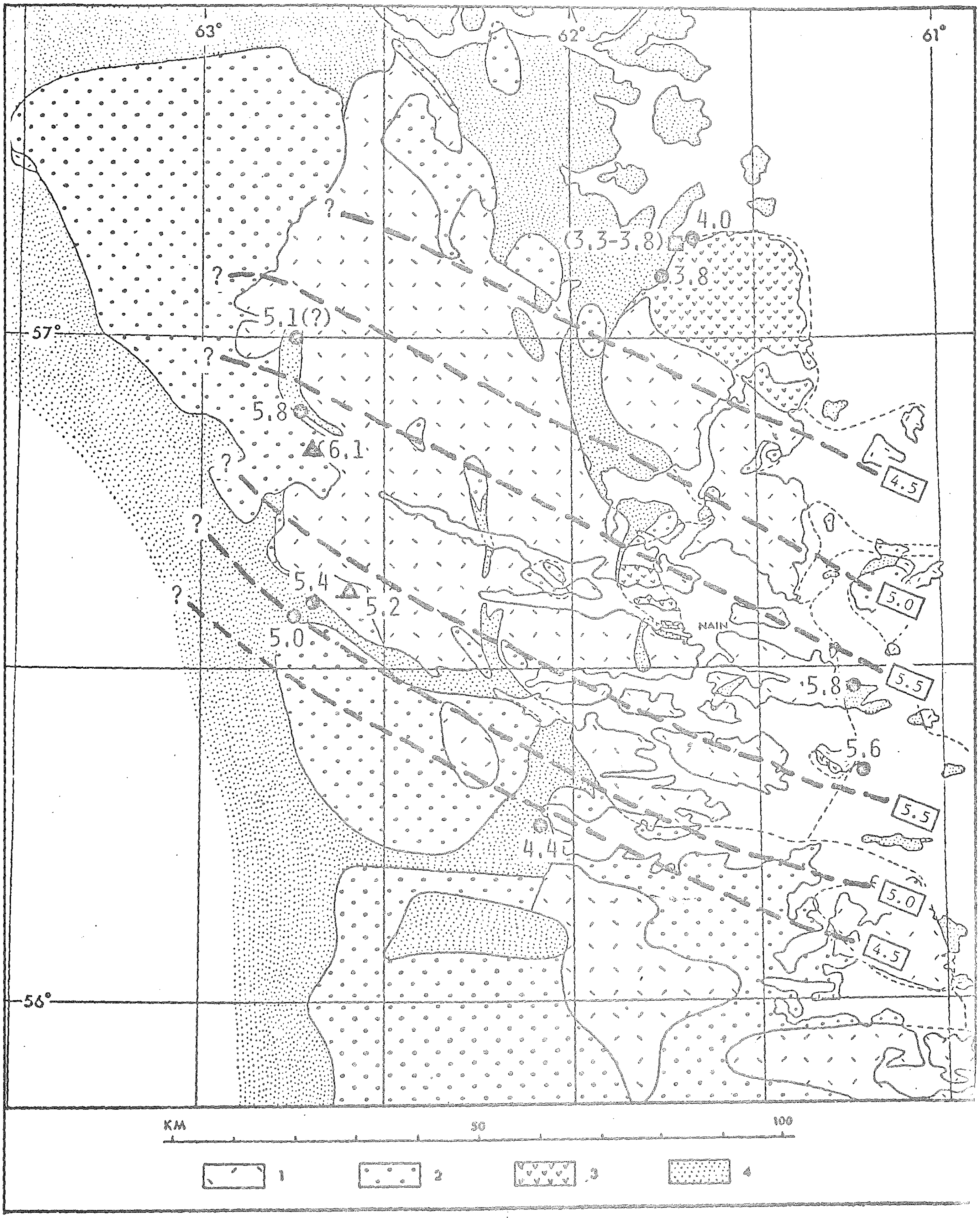

Fig. 10. Paleogeobarometric map of the Nain complex. Numbers indicate paleo-pressures in kilobars. Circles: garnet + cordierite (+ opx + quartz) data; triangles: iron-rich opx + olivine + quartz data (adamellites); square: iron-rich opx + olivine + quartz data (metamorphic country rocks). Heavy dashed lines represent paleo-isobars. Rock types: 1 = anorthositic rocks, 2 = adamellitic rocks, 3 = troctolitic rocks, 4 = Archaean country rocks.

NAIN COMPLEX: GENERAL

PALEOGEOBAROMETRIC MAP OF THE NAIN COMPLEX

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Several studies, in progress or completed, have contained contributions to our knowledge of the P-T environment in which the Nain complex was emplaced (Smith, 1974; Speer, FR 1974; Berg, 1974; FR 1973). However, none of these studies has yielded detailed results applicable to the whole complex. In an attempt to acquire quantitative P-T data covering the whole Nain complex, samples ideally suited for geobarometry and geothermometry were sought among the collections of the writer, E.P. Wheeler II, D. de Waard, and H.M. Davies.

The principal geobarometer used in this study is the Mg/Fe partitioning between garnet and cordierite in rocks of the contact aureole having the assemblage garnet-cordierite-hypersthene-quartz (Hensen and Green, 1973). The method is well-suited for this study because the conditions under which these rocks equilibrated were apparently very similar to the experimental conditions (low fO_2, $P_{H2O} \ll P_{Total}$; Berg, in preparation).

All compositions were determined with a MAC 400 electron microprobe. Pressures and temperatures were estimated from the curves of Hensen and Green (1973). A detailed discussion of the analyses and resulting data will be published elsewhere.

Fig. 10 is a simplified geologic map of the Nain region, after Wheeler (1968), with the pressure results and some tentative paleo-isobars superimposed. Although the experimental calibration of the garnet-cordierite data is subject to possible revision, the relative values must be essentially correct, and it is evident that emplacement of the Nain complex took place at a variety of pressures.

There is evidence from another reaction which corroborates not only the relative sense of the garnet-cordierite data, but also the calibration. The two triangles in Fig. 10 represent adamellites which were studied by Smith (1974). Using the experimentally determined breakdown of iron-rich orthopyroxene to olivine + quartz (Smith, 1971) and assuming 950°C as a reasonable

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

temperature based on the clinopyroxene solvus (Smith, 1974), the data for the adamellites yield pressures of 5.2 kbar and 6.1 kbar where the smoothed garnet-cordierite data predict pressures of $\sim$ 5.4 kbar and $\sim$ 5.8 kbar, respectively. This is surprisingly good agreement considering that the two methods are mineralogically and experimentally independent. The square in Fig. 10 is an andesine-ilmenite-garnet-orthopyroxene-olivine-quartz granulite which is very near the contact of the Kiglapait layered intrusion. Again using the data on iron-rich orthopyroxene and assuming a temperature of 850°-900°C, the indicated pressure would be 3.3 - 3.8 kbar whereas the garnet-cordierite data predict 3.8 - 4.0 kbar; the agreement is again excellent. Both results are consistent with the Abukuma-type metamorphism of the Snyder Group discussed by Speer (this volume).

From these data, it is possible to conclude that the Nain complex was emplaced at a pressure which ranged from about 4 to 6 kbar, or about 14 - 21 km depth. Berg (1974; FR 1973) estimated 3 - 4 kbar for emplacement pressure based on the widespread association of cordierite + spinel. This was based on extrapolation from the pure MASH system; apparently the presence of iron enlarges the stability field of cordierite + spinel, and thus the previous pressure estimate should only be considered as a minimum.

The paleo-isobars indicate the presence of a NW-SE trending arch or elongate dome in the ancient pressure surfaces. Sequential emplacement during uplift or burial is not likely to have caused the domal feature because cross-cutting field relationships show no systematic relationship between the relative ages of the intrusions and the domal pattern of the paleo-isobars. Thus, although the Nain complex was probably emplaced over a period of time exceeding 100 Myr (Barton, FR 1973; Krogh and Davis, 1973), the coherency of the paleogeobarometric data suggests that the time of emplacement must have been effectively instantaneous relative to the rate of uplift or burial. If this was true, the next logical question is whether diapiric rise of the anorthositic Nain complex caused the dome, or whether a domal flexure in the earth's crust exposed the complex in its core. This question cannot be answered at this time.

NAIN COMPLEX: CONTACT ZONES

GEOLOGY OF NORTHERN TUNUNGAYUALOK ISLAND AND VICINITY

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Introduction

Field work was initiated in the area of Tunungayualok Island in order to examine the form and content of adamellite and intermediate intrusions and the relations among adamellite, intermediate rocks and anorthosite. A somewhat simplified map of the area studied is shown in Fig. 11.

A detailed map and cross sections of a diorite-adamellite intrusion, here called the Goodnews intrusive complex, are given in Figs. 12 and 13. Superb exposure of the contacts of this complex make it ideal for detailed study.

Archaean Basement

In the north, on Ighlokhsoakhtalialuk Island, the Archaean basement consists of highly deformed, layered, basic granulites and metapsammites with minor pelitic interbeds. A complex structural history is indicated by the presence of granitoid rocks which appear to have been intruded into the layered sequence and subsequently to have been multiply deformed. Basic rocks contain plagioclase, epidote, hornblende, and biotite with scarce relict pyroxene. Pelitic interbeds contain andalusite, garnet, biotite, chlorite (after garnet), quartz, and feldspar. Garnet is commonly enclosed by andalusite.

On Akhpiktob Kitta Island, Archaean basement consists dominantly of fine-grained basic pyroxene granulite and gneissic leucocratic granitoid rocks. Much of the granitoid rock appears intrusive into basic granulite, forming extensive areas of deformed agmatite. Inclusions of similar basement rock occur in adamellite on Akhpiktokh Island.

Archaean basement which lies at the southeastern edge of the map area is also a variable mixture of gneissic quartzo-feldspathic and basic rocks. No pelitic interbeds were noted. Similar basement also occurs as mostly angular blocks in adamellite. These blocks are

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

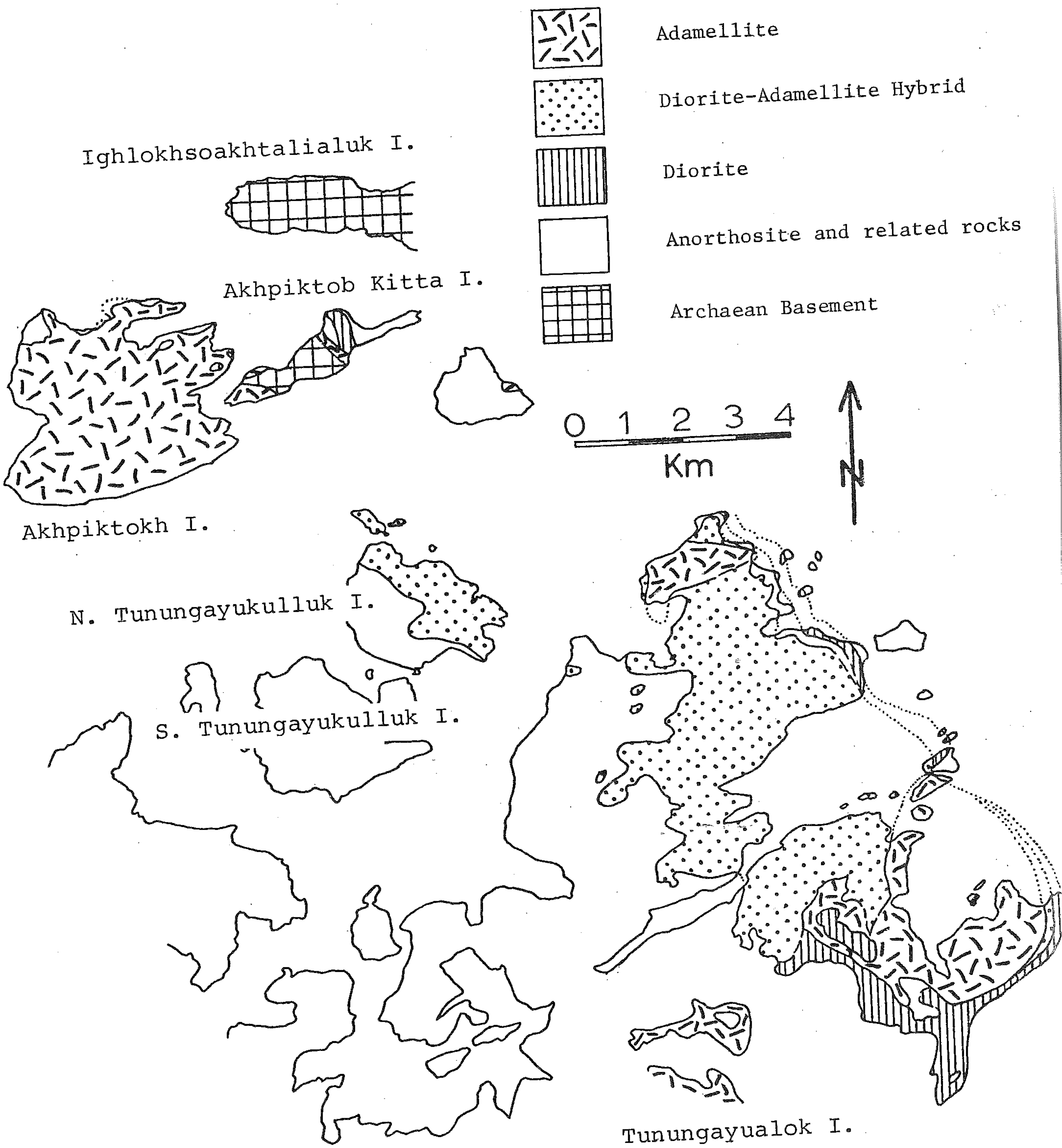

Fig. 11. Geologic map of northern Tunungayualok Island and neighboring islands.

most common near the intrusive contacts even where adamellite is not in contact with basement at the present level of exposure.

Anorthosite and Related Rocks

Lithology. The area mapped as "anorthosite and related rocks" is mostly leuconorite according to the classification presented by Streckeisen (1973). Plagioclase is the dominant phase; color index is mostly between 10 and 20 with extremes near 0 and 40. The mean plagioclase compositions of three samples range between An_{50} and An_{52}. Orthopyroxene is the dominant mafic phase; magnetite, ilmenite and biotite are minor phases. Clinopyroxene may be locally abundant, but its presence was not verified. In some areas minor fine-grained interstitial quartz and alkali feldspar are ubiquitous; coarser patches occur only within crosscutting noritic veins.

Textures are extremely varied. The most common textural variety is dominated by plagioclase varying in size between 1 and 5 cm with minor amounts of subophitic orthopyroxene. Somewhat less common are leuconorites with even-grained plagioclase averaging about 2 cm. Coarser anorthositic rocks with seriate porphyritic textures (plagioclase up to 25 cm) form homogeneous mappable areas, up to 1.5 km across. Plagioclase in this last variety is characterized by prominent zoning and iridescence. A widely occurring textural variety consists of a mixture of equant to lensoid patches of fine-grained plagioclase with prominent subophitic orthopyroxene in a matrix of coarser grained mafic-poor anorthosite. Uncommonly some anorthositic rocks contain poikilitic orthopyroxene up to 25 cm in diameter. Small (1-2 cm), equant subhedral pyroxene occurs rarely.

Structure. Most of the anorthositic rocks are massive. There are, however, some prominent areas of steeply inclined lamination usually characterized by a variable amount of granulation of grain boundaries. Such a lamination in leuconorite occurs oriented parallel to the eastern contact with Archaean basement. Uncommonly, subtle compositional and textural layering occurs parallel to steep lamination.

Angular blocks of older anorthosite occur in well over half of the outcrops visited. The blocks are generally angular and lack the mafic rinds commonly noted on Nukasorsuktokh Island (Runkle and Saunders, FR 1973, p. 121). Typically, blocks in a given area have textures

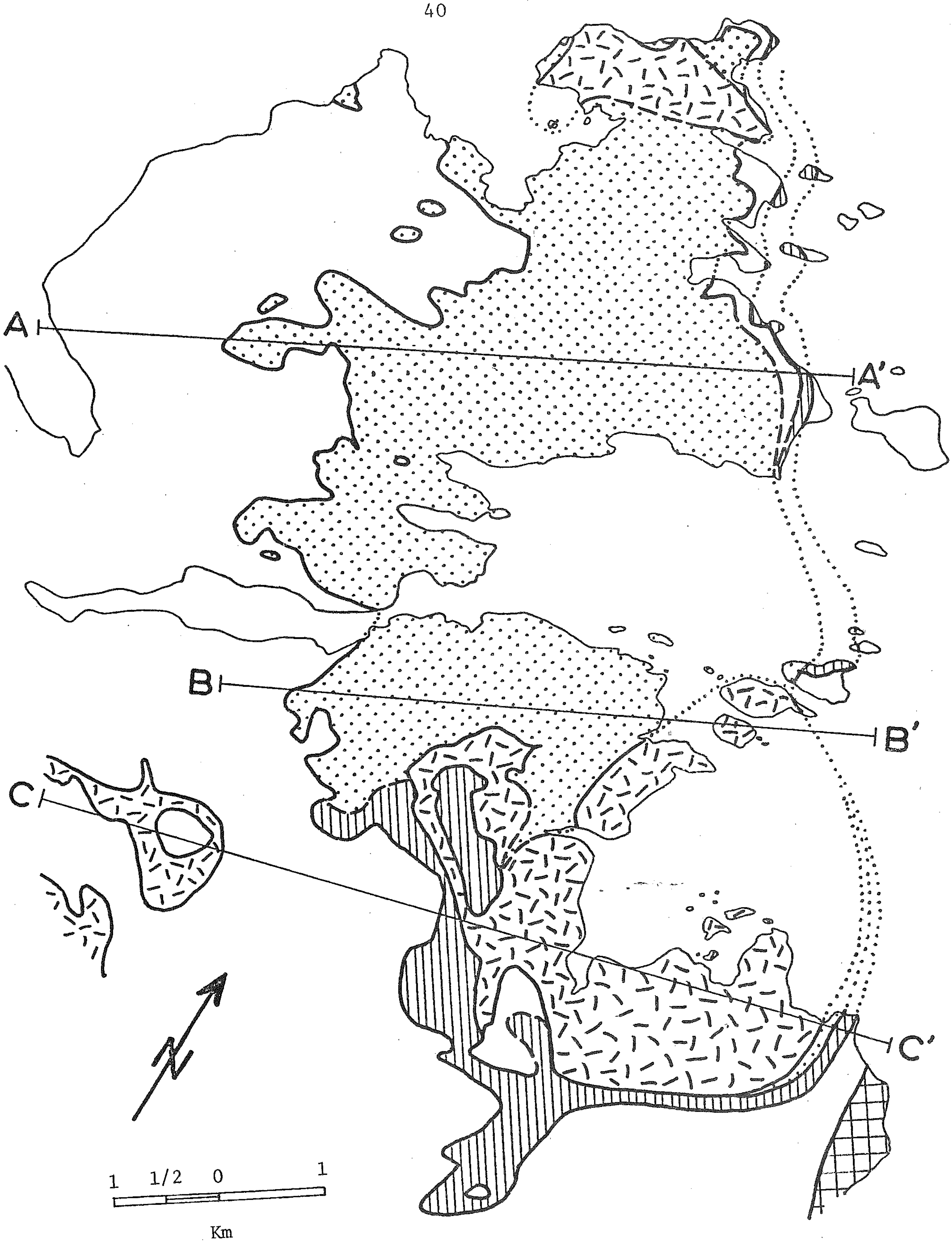

Fig. 12. Geologic map of the Goodnews intrusive complex. Patterns of map units as on Fig. 11.

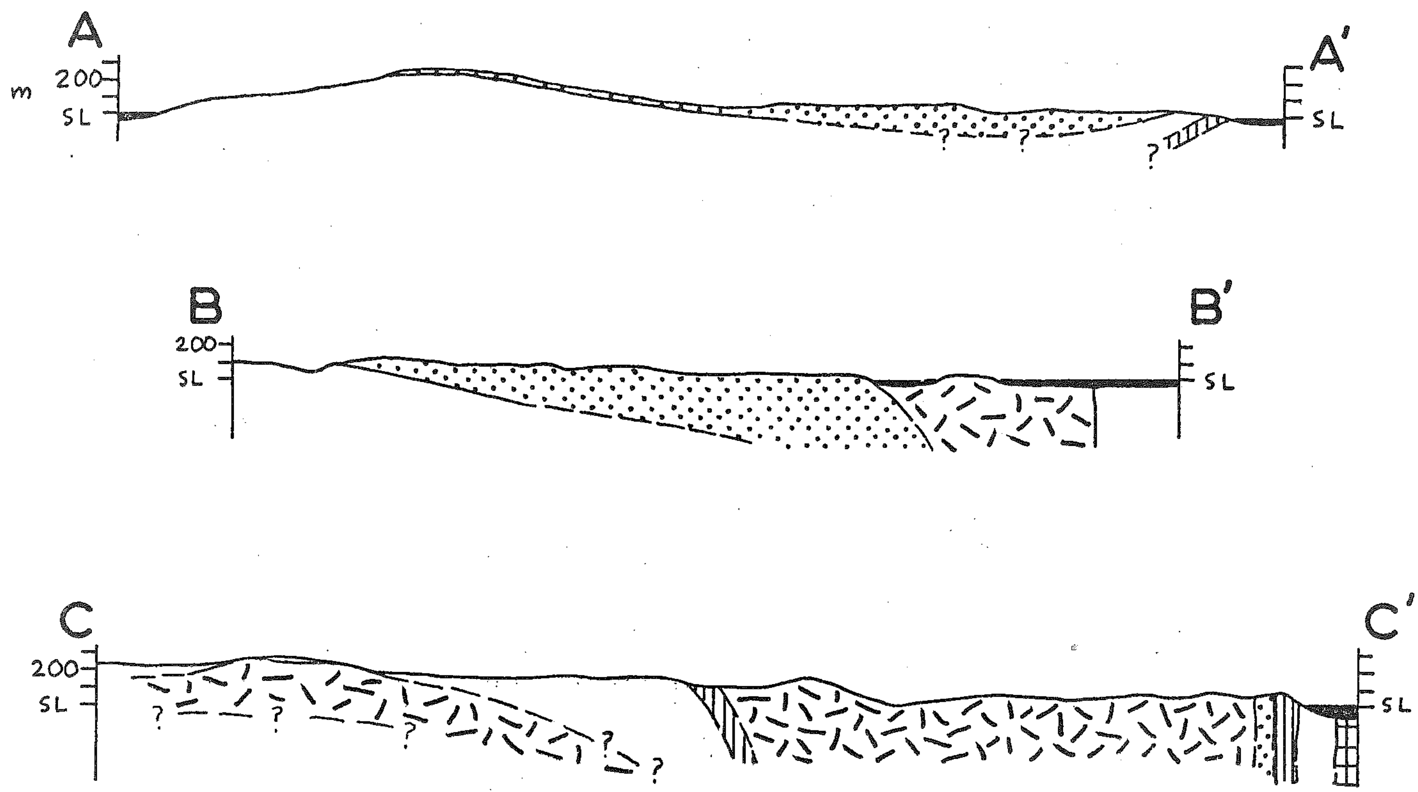

Fig. 13. Cross sections of the Goodnews intrusive complex. For section lines see Fig. 12 . Patterns as in Fig. 11 . Sections drawn with no vertical exaggeration.

which resemble each other and those of nearby homogeneous anorthosite. However, some nearly pure anorthosite blocks have no locally recognized source. Locally it can be shown that the number of blocks increases gradually from less than 10 percent toward a homogeneous anorthositic body of identical texture which is veined by leuconorite. The volume of leuconorite veins appears to increase toward the anorthosite which includes the blocks. In one section this gradation from veined anorthosite to anorthosite with blocks took place over a distance of about 1.5 km.

Veins of leuconorite and norite are widespread in some areas of anorthosite. These are commonly pegmatitic and locally contain abundant magnetite, ilmenite, hornblende and granophyre. Biotite is a common accessory. Coarse quartz and alkali feldspar occur very sparsely.

It has not been possible to map individual plutons within the massive anorthosite, but some internal contacts (gradational through wide zones of veining and block structure) have been recognized. One individual leuconorite intrusion is as narrow as 1 km in one dimension.

Diorite

The largest homogeneous body of diorite occurs at the southern end of the Goodnews complex. A narrow band of similar diorite enclosing abundant blocks of anorthosite trends along the northeast margin of that complex and may form a continuous band all the way to Akhpiktob Kitta Island. Contacts of the southernmost diorite are steep, while the narrow band of diorite dips 20° to 40° to the southwest. Concordant layering occurs within this band.

The diorite is medium to fine grained and has a color index between 20 and 40. Plagioclase and subcalcic ferroaugite are the major phases. Hornblende and opaque oxides are locally prominent. Interstitial quartz and alkali feldspar are ubiquitous. Some of the diorites have a subophitic texture. Layering, where developed, is rhythmic and marked by variations in ratios of feldspar to mafic phases. Anorthosite blocks strongly disturb this layering.

Adamellite

Adamellite in the restricted compositional sense defined by Johannsen (1939) occurs in two relatively large bodies and several smaller ones. In all of these areas the rock is medium grained with a color index between 10 and 25. Quartz, plagioclase, and alkali feldspar occur in roughly equal amounts. Hornblende is the major mafic phase; lesser but variable amounts of fayalitic olivine, subcalcic ferroaugite, biotite and opaque oxides are generally present. Mafic phases commonly occur in clusters with Fe-rich olivine rimmed by hornblende. Areas of adamellite with prominent equant quartz are common.

The adamellite bodies locally have very weak foliation near steep contacts with anorthosites or Archaean basement. Contact zones of adamellite generally contain abundant inclusions of anorthosite or Archaean basement. A wide belt of inclusions occurs along the north and east margins of the adamellite pluton on Akhpiktokh Island.

Clear examples of layering formed by accumulation of plagioclase and pyroxene were noted only on the western margin of the main adamellite pluton of the Goodnews complex. There, layering dips at about 30° to the east, and medium-grained rocks grade from diorite to adamellite within 50 meters of section. This sequence is repeated at least once.

Diorite-Adamellite Hybrid

A heterogeneous mixture of diorite and adamellite occurs in two map areas: as a major portion of the Goodnews complex and on North Tunungayukulluk Island. In its simplest development, the hybrid unit is a mixture of rounded, chilled, fine-grained inclusions of diorite in a matrix of typical medium-grained adamellite or monzonite. The inclusions are for the most part poorly sorted and the average size is variable. Most inclusions lie within the range 10 cm to 5 meters. Uncommonly, chilled diorite bodies have one dimension up to 100 meters. Near some contacts of this map unit with anorthosite the inclusions are ellipsoidal and define a fabric which dips 30° to 60° away from the anorthosite.

The diorite inclusions commonly contain abundant poikilitic hornblende up to 6 cm in diameter. This hornblende is clearly concentrated on the margins of many inclusions. Small, sharply deformed ellipsoidal clusters of poikilitic hornblende in the monzonite-adamellite host probably represent diorite inclusions.

Goodnews Intrusive Complex

Relative Age Relations. The Goodnews intrusive complex includes homogeneous bodies of diorite and adamellite, and a major area of hybrid rocks. All phases of the complex cut the anorthosite. Contacts between anorthosite and the southernmost diorite are in general sharp, but the adjacent anorthosite is both compositionally and texturally variable and locally appears to grade to gabbroic or dioritic rocks. All other rocks of the complex have sharp contacts with anorthosite.

Homogeneous adamellite is the youngest phase of the intrusion and clearly cuts both the diorites and the hybrid mixture of adamellite and diorite. Some quartz-rich adamellite also occurs as inclusions in monzonite and adamellite of the hybrid complex. Some angular blocks of layered diorite are also present. These relations indicate that adamellite was emplaced and solidified before, during, and after the formation of the hybrid diorite-adamellite unit.

Structural relations. The structural relations of this complex are displayed in the cross sections (Fig. 13). A structure contour map for a part of the base of the intrusion is given in Fig. 14.

The main structural features of the complex can be briefly summarized. Adamellite forms a roughly equant body at the southern end of the complex. The contacts of this body are nearly vertical except on the northwest side where layering dips as gently as 30° inward. Hybrid rocks lie beneath the adamellite here. The adamellite to monzonite component of the hybrid unit appears to grade to the homogeneous adamellite body. Also on that side, curved, sheet-like bodies of adamellite cut the hybrid unit within a mile of the main adamellite contact and dip about 20°-30° toward the axis of the adamellite body. These sheet-like bodies could be termed partial cone sheets. A small adamellite body at the northern end of the complex appears to have steep contacts where they could be observed.

The main mass of hybrid rock could best be described as a tongue which extends outward and upward to the northwest from the axis of the southern adamellite body. The 300 meters of relief on the island

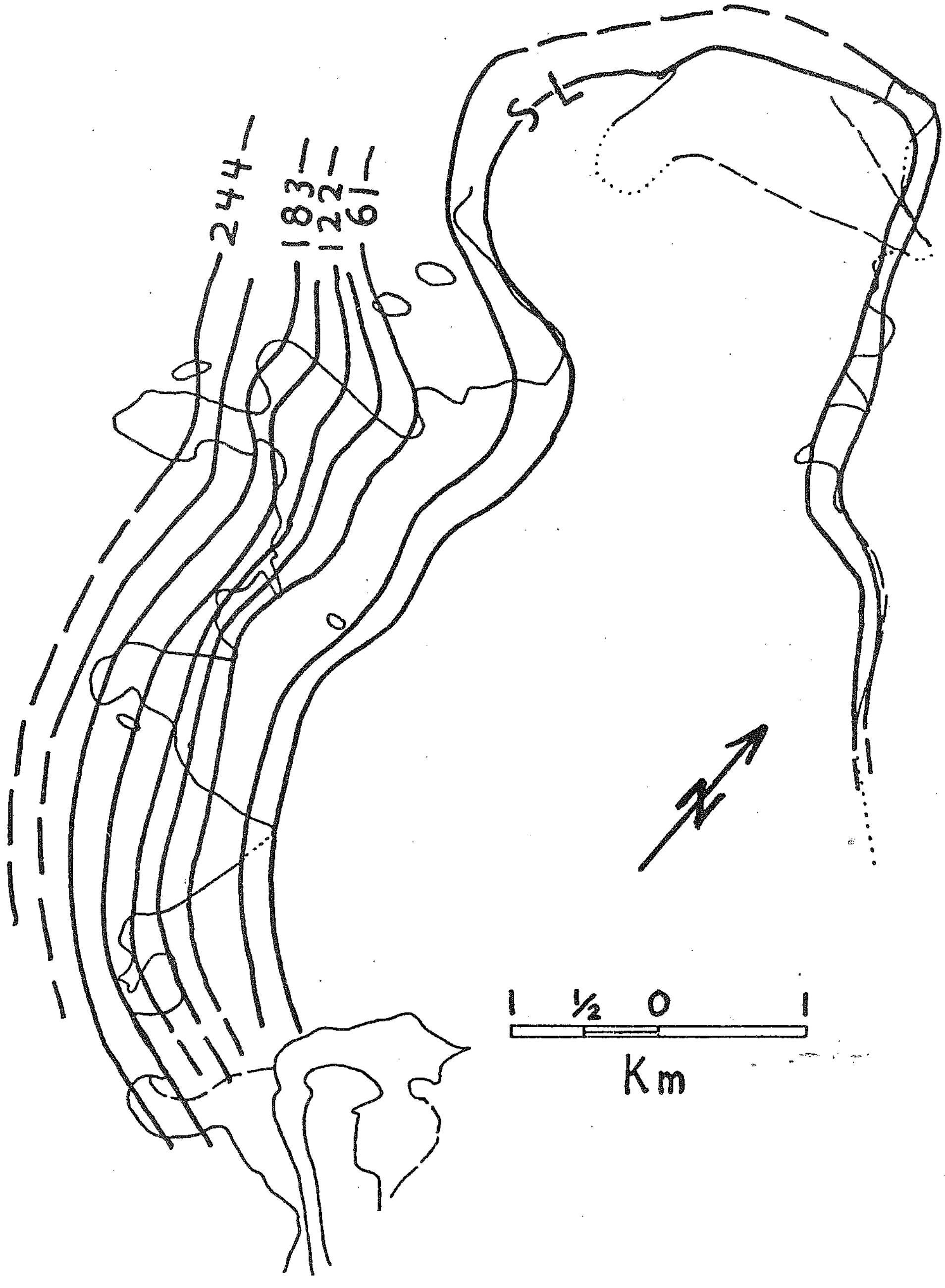

Fig. 14. Structure contour map of the base of the hybrid tongue of the Goodnews complex. Contour interval is 30.5 meters.

provide adequate control on the configuration of part of the base of this body. Fig. 14 is a structure contour map of this basal contact. The floor dips gently toward a NNW-trending axis. It is not clear if the northern part of the hybrid unit is completely floored or steepens into a dike-like body below. Neither is there any control on the thickness of the hybrid unit.

Two small areas of adamellite occur in anorthosite to the southwest of the Goodnews complex. The anorthosite appears to lie everywhere above the adamellite. This adamellite may represent the roof of another tongue which could connect at depth with the main adamellite body. This interpretation is shown in Fig. 13, cross section C-C'.

Discussion

Many of the diorite inclusions within the hybrid unit have features which strongly suggest that they were in a liquid state when they first came into contact with adamellite. The most widespread of these features are chilled margins and delicate curved crenulate margins. In the larger inclusions grain size increases gradually inward for distances of more than one meter. The width of the gradation can be more readily explained by chilling than reaction since there is essentially no evidence of reaction in the adjacent adamellite. The crenulate convex-outward boundaries are characteristic of the higher temperature magma in situations where co-mingling of two magmas has been demonstrated (Wiebe, 1974).

The adamellites and diorites show no evidence of penetrative deformation. The preferred orientation and ellipsoidal shapes of diorite inclusions near some contacts suggest that the inclusions were "soft". In one outcrop of hybrid rocks a rounded and crenulate diorite inclusion has been partially molded against a corner of an angular inclusion of Archaean gneiss, clearly demonstrating its fluidal condition.

The dominance of adamellite over diorite within the hybrid unit suggests that adamellite may have engulfed the diorite and acted as the emplacement vehicle of the hybrid tongue. In some areas the hybrid unit consists of adamellite and widely scattered diorite inclusions; in these areas at least, adamellite was the intrusive phase. The structural and age relations of adamellite and diorite at the southern end of the complex are also compatible with the suggestion that adamellite encountered and disrupted previously emplaced diorite magma.

On the basis of field work alone, one model for the development of the Goodnews complex is presently preferred. Primary assumptions are that, regardless of their origins, the diorite and adamellite existed at the exposed level as two different magmas having different compositions and temperatures. Adamellite magma rose through the anorthosite in a steep cylindrical conduit. Because of structural controls, such as the depth of emplacement and the position of anorthosite-basement contact, magma began to spread laterally in tongues. At some point in or near its conduit the adamellite encountered diorite magma. These two magmas mixed together in extremely heterogeneous fashion marked by chilling of much diorite and contamination of adamellite. The mixture then spread laterally and formed the major tongue at the present level of exposure.

The field relations described here and the preferred model for the emplacement of the Goodnews intrusive complex suggest that diorite and anorthosite may be related by differentiation of an unknown parent magma. The relations of adamellite to anorthosite and the main bodies of diorite seem most compatible with derivation of adamellite from a separately generated magma. Minor amounts of diorite may have formed from this latter magma by fractional crystallization.

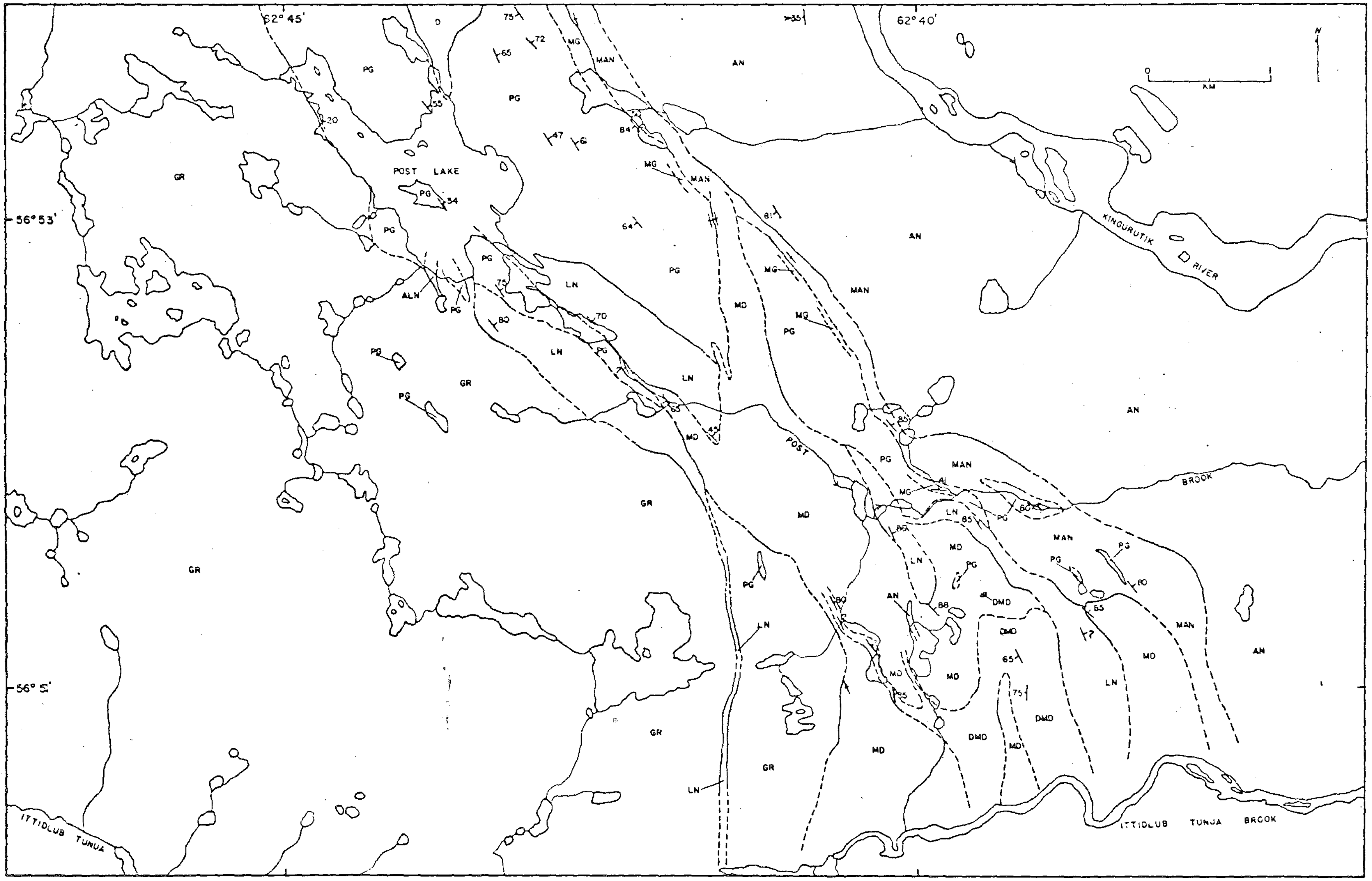

Fig. 15. General geology of the Lower Khingughutik River area, Labrador. Key, from oldest to youngest. PG, paragranulite; MAN, marginal anorthosite; AN, anorthosite; LN, leuconorite; MD, monzodiorite; DMD, dark monzodiorite; D, quartz diorite; GR, pyroxene granite. ⟍ foliation, ⟍ igneous layering.

THE GEOLOGY OF THE LOWER KHINGUGHUTIK RIVER AREA

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Introduction

Mapping in the contact zone of the pale anorthosite at the western boundary of the Nain Complex has been completed. This zone consists of pale anorthosite, buff-weathering anorthosite, adamellite and country rock (Fig. 15). Previously (FR 1973, p. 73-77) the rocks within this zone were discussed in general terms; in this report specific names are used following I.U.G.S. recommendations (Streckeisen, 1973).

In general the intrusive rocks of this western boundary may be assigned to 3 major types:

i) Anorthositic: Marginal anorthosite, anorthosite, leuconorite,

ii) Intermediate: Monzodiorite, dark monzodiorite, quartz diorite,

iii) Granitic: Pyroxene granite.

This association is similar to that observed in the eastern contact zone on Dog Island (de Waard, FR 1973).

Anorthositic Rocks

Marginal anorthosite. The marginal anorthosite unit lies between anorthosite on the east and paragranulite, leuconorite and monzodiorite on the west. The contact with the paragranulite is steep and sharp whereas that with the anorthosite is transitional. The region mapped as marginal anorthosite ranges from 150 to 600 meters in width. The unit is distinguished from anorthosite by its higher color index and finer grain size.

The rock type is variable in grain size, ranging from coarse to fine. Plagioclase, pyroxene and opaque oxides are the major constituents, with minor quartz. On fresh surfaces the plagioclase varies from light bluish gray (similar to that of typical anorthosite) to light brown to white. Although the grain size throughout the outcrop is variable there is a general increase in grain size towards the anorthosite. Foliation is present and is best displayed by the orientation of the mafic minerals. The foliation is parallel to the trend of the contact and dips steeply. Subophitic pyroxene occurs locally in the coarse-grained zones, whereas stretched pyroxene crystals are visible near the contact with paragranulite.

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

Anorthosite. This rock, mapped by Wheeler (1968) as pale anorthosite, underlies the region east of the marginal anorthosite. Antiperthitic plagioclase and orthopyroxene are the common minerals, with minor quartz. Overall the rock is coarser than the marginal anorthosite. Orthopyroxene is only locally important and is usually subophitic. However, when it does occur in quantity it tends to represent more than 10% of the rock and to produce a distinct layering that is best seen from a distance. Except for these segregations of orthopyroxene the rock is almost entirely devoid of mafic phases.

Leuconorite. The leuconorite unit (bl of FR 1973, p. 75) occurs in two areas, one to the southeast of Post Lake and the other at the contact with the marginal anorthosite between Post Brook and Ittidlub Tunua Brook.

Plagioclase and orthopyroxene are present with minor amounts of clinopyroxene in a coarse-grained subophitic texture. The color index is approximately 20-35. Dark plagioclase megacrysts are present. The weathered surface has the distinctive buff color, and the fresh surface the greenish-brown color, of Wheeler's buff-weathering anorthosite (Wheeler, 1960; FR 1973, p. 48). As in the case of the other anorthositic rocks, the leuconorite is a very tough rock from which it can be difficult to retrieve a substantial sample.

Intermediate Rocks

The intermediate rocks occur spatially between the anorthosite and the granite. Three subdivisions: monzodiorite, dark monzodiorite, and quartz diorite, are now recognized.

Monzodiorite. The name monzodiorite is used here in place of buff-weathering anorthosite of the 1973 field report. This rock is fine to medium grained and is composed of scattered megacrysts of plagioclase in a matrix of plagioclase, orthopyroxene (20-35%), apatite (3%) plus minor amounts of clinopyroxene, orthoclase and opaque minerals. The orthopyroxenes are granular and not subophitic in texture. Although very fresh surfaces are dark charnockitic green in color, alteration to yellowish brown by weathering is common until the entire surface appears a buff color.

Xenoliths of medium- to coarse-grained anorthosite are abundant in the monzodiorite near Ittidlub Tunua Brook. Most of these xenoliths are confined to the area between the dark monzodiorite and granite.

Minor occurrences of similar xenoliths are present to the north of this area and west of Post Brook.

Dark Monzodiorite. This is the first report of this rock type in this region. Generally, the rock is medium to coarse grained and on weathered surfaces it has a "maggoty" appearance from the manner in which white plagioclase phenocrysts are set in a dark matrix. Mineralogically, this unit is similar to the monzodiorite except that the color index is higher ($\sim$ 35-50). The darkness of the rock and the texture of the weathered surface permit the unit to be mapped separately from the monzodiorite.

In many places the plagioclase phenocrysts are lineated. In several areas this lineation and a possible foliation of plagioclase occurs within compositional layers. These layers range in thickness from 5 to 25 cm.

Quartz diorite. A small, localized intrusion of quartz diorite occurs in the paragranulite zone to the northeast of Post Lake. This intrusion is about 1200 m long by 500 m wide. It is medium to coarse grained, brownish white on weathered surfaces and dark green on a freshly broken surface. Dark plagioclase megacrysts as large as 3 by 8 cm occur in a matrix of plagioclase, quartz and scattered pyroxenes. Locally, at a point near the contact, the pyroxenes occur in a subophitic texture which yields a surface appearance that is strikingly similar to that of the leuconorite. However, in the quartz diorite the pyroxene weathers more rapidly than the plagioclase, the exact opposite of the leuconorite. At the contacts there is a very distinct chill zone that appears to be of the same mineralogy as the bulk of this intrusion.

No cross-cutting relationships between this or other intrusions were observed. However, the absence of metamorphic effects in the quartz diorite places it as post-paragranulite in age.

Granitic Rocks

Pyroxene granite. This rock, referred to as adamellite in FR 1973, is fine to coarse grained and contains large megacrysts of K feldspar. The major minerals are microperthite (44%), quartz (31%), plagioclase (12%), clinopyroxene (6%) and orthopyroxene (4%). Near the monzodiorite, leuconorite, and paragranulite contacts the quartz content decreases. Minor or accessory minerals include opaque minerals, rutile, zircon and microcline.

The pyroxene granite is buff colored on weathered surfaces and is similar in this respect to the monzodiorite. Furthermore, the fresh pyroxene granite surfaces also appear similar to the monzodiorite. These characteristics plus the fact that quartz decreases in amount as one approaches a contact obscures important field relationships. No clearly visible contact has yet been observed between the pyroxene granite and monzodiorite, which suggests the possibility that a transition zone is present.

The distinct ovoidal texture discussed by Wheeler (FR 1973, p. 56) is locally present in the granite but is absent at or near the contact (or transitional) zone.

Scattered throughout the granite are xenoliths of paragranulite with foliations similar to that of the major body of paragranulite. Foliation is absent in the granite except for a very weak, somewhat ill-defined mafic mineral orientation along the leuconorite and paragranulite contacts.

Marginal Granulite

A pyroxene granulite occurs sporadically along the western contact of the anorthosite. This rock unit has been termed "granulite of uncertain origin" by Wheeler (1968). In width the granulite is between 50 to 190 m. It is fine grained, granular, and is composed of plagioclase, pyroxene and minor biotite. This mineralogy is similar to that of the granulites found within the main paragranulite body. Foliation is commonly well developed and parallels the foliation in the paragranulite (basement rock) as elsewhere in the Nain region (Davies, FR 1973, p. 86); however, the anorthosite contact is also concordant with the foliation in the paragranulite. The marginal granulite, as elsewhere, is completely missing from the pyroxene granite-paragranulite contact.

Field relations (i.e. sporadic occurrence, foliation consistencies, similar rock units within the paragranulite unit) suggest that the marginal granulite is part of the paragranulite body.

Paragranulite

Granulite facies rocks of the basement complex are exposed to the north-northeast and south-southeast of Post Lake. The major rock types include gneisses, granulites, quartzites and other metasedimentary rocks. In this unit garnet, cordierite and hercynite are widely distributed.

Graphite is locally present in disseminated form as well as on joint surfaces. These features suggest that the original rocks were sedimentary rather than igneous prior to metamorphism.

The foliation trend in the paragranulite is consistently north-northwest. Small minor folds occur which have axial planes parallel to the main foliation, and fold axes with shallow to steep plunges.

Linears

Numerous linears cross the map area in various directions (Fig. 16) all having a profound affect on the topography. The linears are generally represented by large trench-like depressions and valleys often containing strings of lakes which further emphasize the linearity.

The largest of these linears, part of the family of linears that traverse across the Nain region in a near east-west direction, forms the drainage for the Ittidlub Tunua Brook. According to mapping by Wheeler (1968), this linear has approximately two kilometers of right-lateral displacement. This type of movement is unique in that the other linears of this east-west set display left-lateral movement of up to several kilometers. The less intense linears appear to have little if any displacement. No dike material, such as diabase or granite, was found in or around the linears.

Structure

Field evidence indicates that the anorthosite dips to the west-southwest. The small section of anorthosite, if considered as part of the Bird Lake massif (Morse, FR 1973), may be a portion of a large regional curvilinear feature that continues to the southeast. The dips at the west end of Tikkoatokhakh Bay are to the south-southeast (Morse, FR 1973).

The leuconorite contains localized areas in which foliation is defined by alignment of the orthopyroxene. Measurements on this foliation are highly consistent, striking to the northwest and dipping to the northeast. The strip of leuconorite within the granite (Fig. 15, 56-51N, 62-41.5W) is probably an inclusion. Although no cross-cutting relations of the granite have been seen in this leuconorite strip, there is a chilled border zone in the granite.

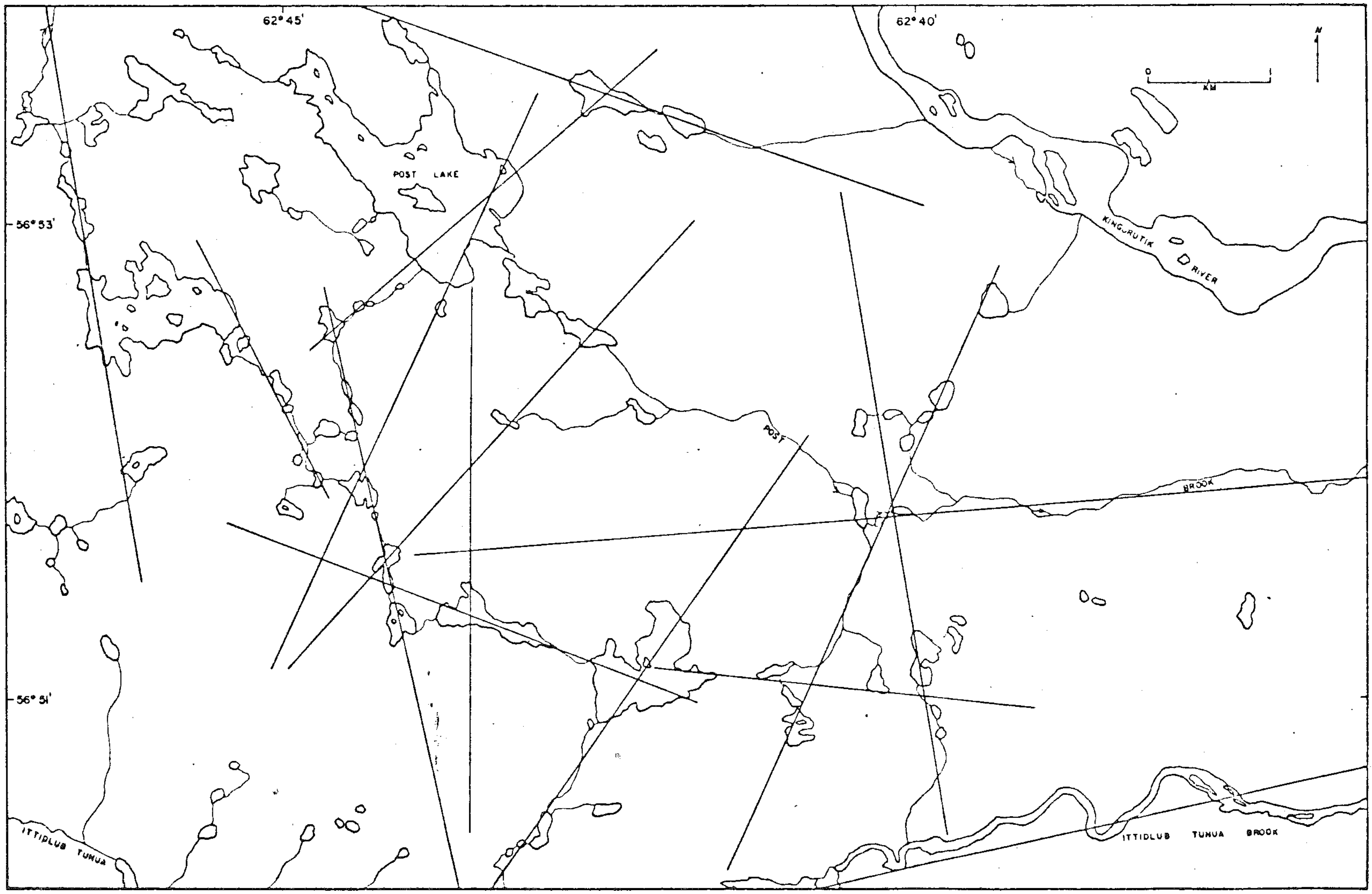

Fig. 16. Map of the Lower Khinghughutik River area showing linears traced from topographic map.

The monzodiorite is devoid of any major foliation except for a weakly developed orientation of the orthopyroxene near the leuconorite contact. In contrast, the dark monzodiorite possesses lineation of plagioclase crystals throughout the entire unit and also localized flow structure presumably indicating that it intruded as a crystal mush. Fig. 15 indicates the possibility of a synclinal structure between the large bend in Post Brook and Ittidlub Tunua Brook, the axial trace of which trends northwest.

Evidence of flow movement in the pyroxene granite was not seen. The foliation within paragranulite inclusions in the granite lies parallel to the foliation trend of the paragranulite body and parallel to the contact. Thus, the xenoliths of paragranulite show no evidence of rotation. This probably indicates that the magma crystallized undisturbed with little or no internal movement.

Age Relations and Discussion

The oldest intrusive rock, the marginal anorthosite, was intruded by anorthosite. The contact between both units is transitional. However, anorthosite can be seen intruding the marginal anorthosite on a cliff face north of Post Brook. At this locality the marginal anorthosite begins to increase in width. The anorthosite is succeeded in time by the intrusion of the leuconorite, which in turn is intruded by the monzodiorite. It appears the monzodiorite was emplaced within an area that was originally largely leuconorite, and thus the leuconorite has been separated into two bodies. Intruding the monzodiorite is the dark monzodiorite, which has the appearance of a dike-like intrusion. There are no cross-cutting relations between this unit and the granite (youngest), but the mineralogical and structural relationships between the monzodiorite and the dark monzodiorite suggests that both are pre-granite. Fig. 17. shows the inferred age relations among the above rock types.

Since no known intrusive relations exist between the quartz diorite and the other intrusives, its stratigraphic position is unknown, except that it is younger than the paragranulite.

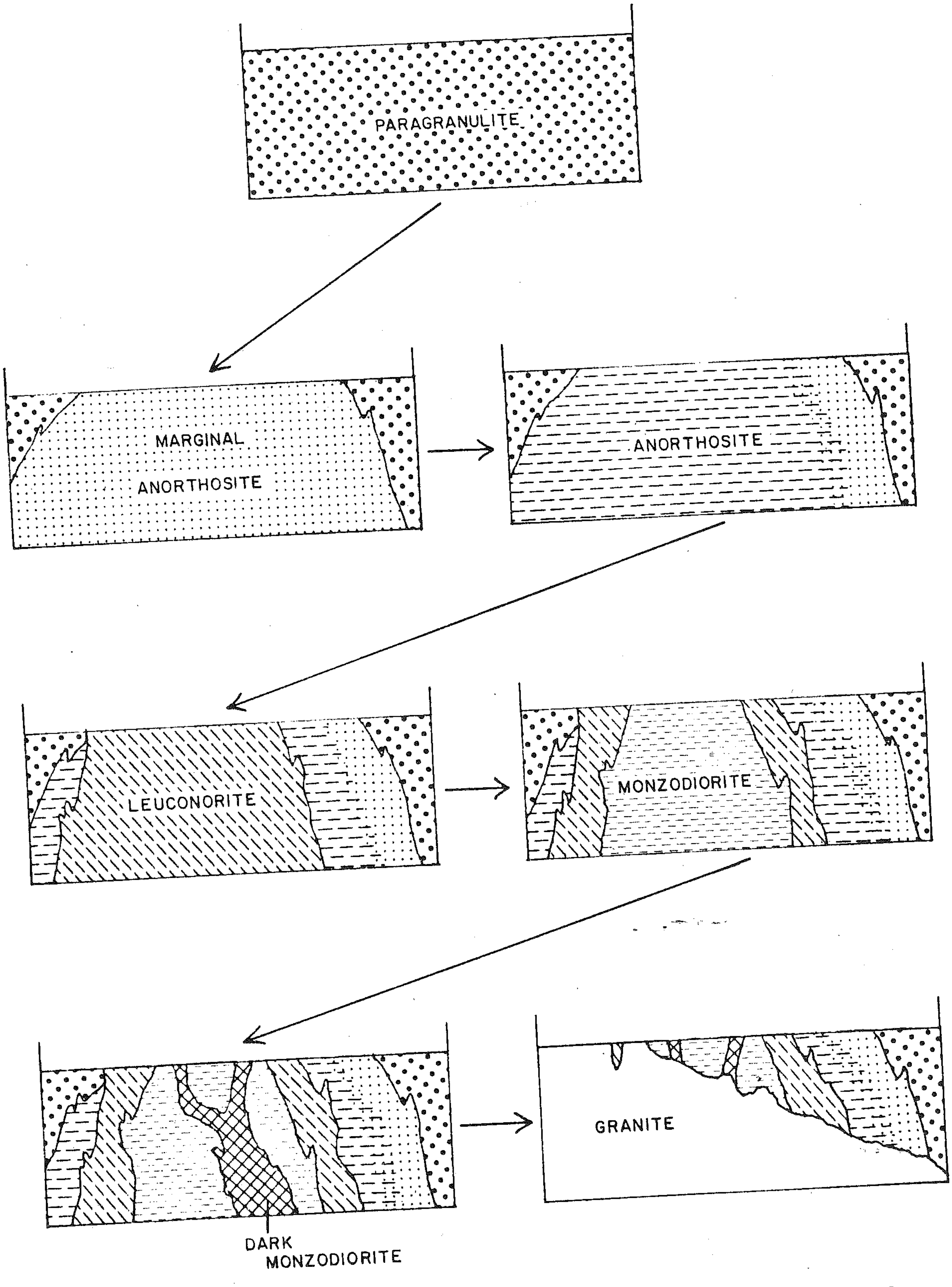

Fig. 17. Possible age relations at the western contact zone of the Nain complex.

On the basis of field evidence there is a strong suggestion that the rocks described above are all differentiates of a single magma. The order of intrusion, structural relationships, and the types of contacts all may be cited in support of this hypothesis. Unfortunately the finer grain size of the intermediate rocks (monzodiorite and dark monzodiorite) positioned between the anorthosite and granite does not in general conform to the concept of consanguinous differentiation of a single magma. Morse (FR 1973, p. 78) suggests that the anorthositic and granitic rock types may have formed from separate magmas.

Acknowledgments

This research is supported in part by a David Ross Grant from Purdue University.

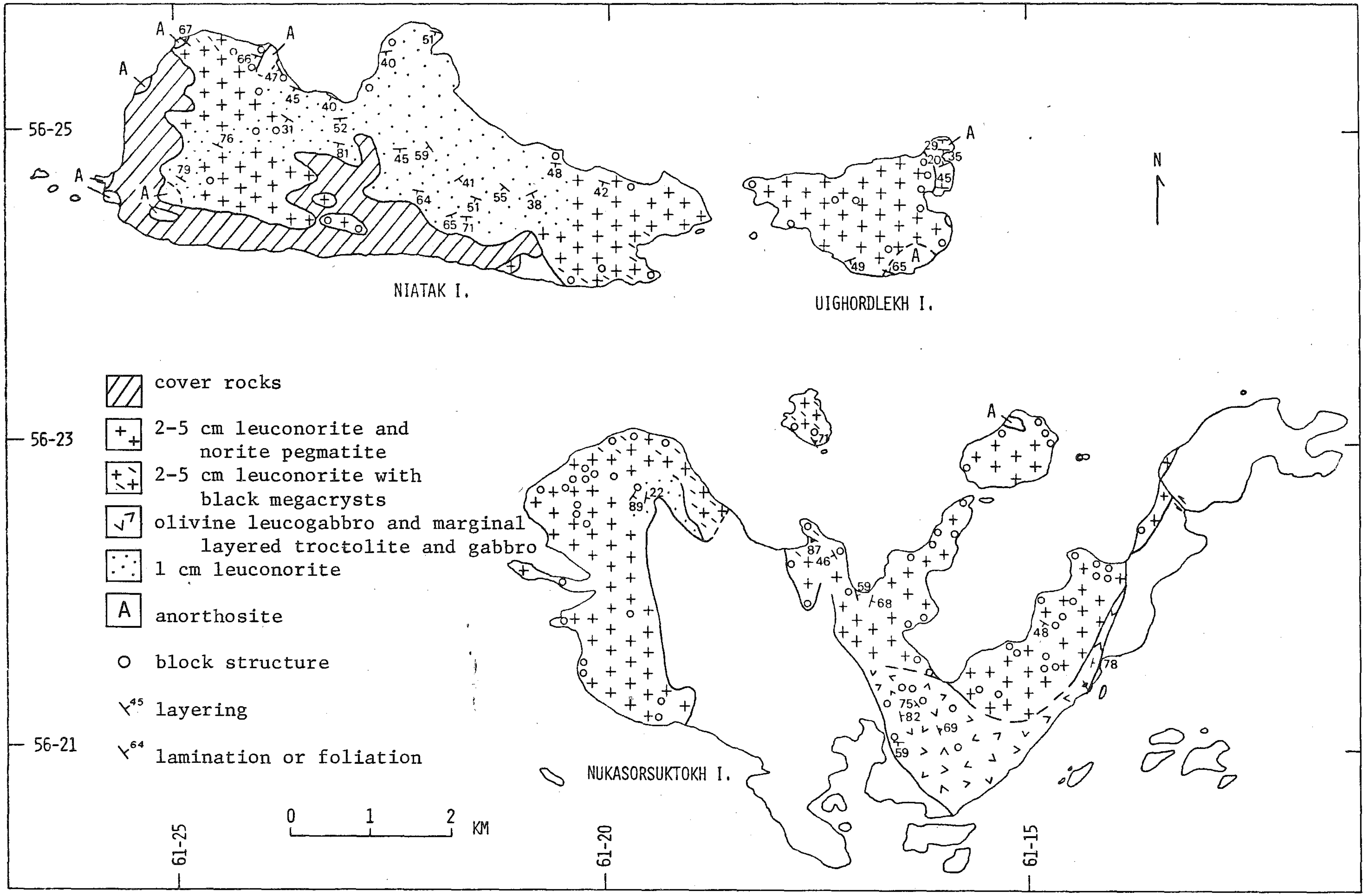

Fig. 18. Lithologic map of anorthositic rocks showing block structure localities.

EMPLACEMENT SEQUENCE OF ANORTHOSITIC ROCKS IN THE SOUTHEASTERN PORTION OF THE NAIN COMPLEX

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Introduction

The anorthositic rocks described below occur on Nukasorsuktokh, Niatak, and Uighordlekh Islands, approximately 25 km southeast of Nain, Labrador (see Fig. 1). It is extremely difficult to decipher the geologic relations among the anorthositic rocks due to the variety of rock types and to the scarcity of discrete contacts between these rocks. Xenoliths or blocks are common in most of the anorthositic rocks in the study area. A distinct rock type may occur both as a host rock and as a block in another rock type. Because a block may be located kilometers from its source rock, the grounds for correlation are necessarily lithologic. Correlation of blocks with their source rock allows age relations between units to be deciphered in areas where block structure occurs.

The above scheme was used to develop the sequence of anorthositic rocks which is outlined below from youngest to oldest.

5. 15-50 cm norite pegmatite
4. 2-5 cm leuconorite:
   a) without black megacrysts
   b) with black megacrysts
3. 1 cm olivine leucogabbro
2. 1 cm leuconorite
1. $\leq$ 1 cm anorthosite

Rock Descriptions

Fig. 18 is a map of anorthositic rocks and block structure localities on Nukasorsuktokh, Niatak, and Uighordlekh Islands. These rocks are classified below on the bases of grain size, mafic mineral content, and texture. Several rock types agree with de Waard's classification of anorthositic rocks in the nearby Ford Harbour area (FR 1971, p. 19-20). This suggests considerable continuity in lithologies throughout the southeastern part of the Nain complex.

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

Fig. 18. Lithologic map of anorthositic rocks showing block structure localities.

1. ≤ 1 cm anorthosite includes two varieties of pale anorthosite. 1 cm pale gray anorthosite contains less than 5% mafics, which consist of clinopyroxene or orthopyroxene, and magnetite, in order of decreasing abundance. The plagioclase composition is commonly near An_{60}. This rock is equigranular, shows granulated feldspar margins, and is commonly layered. The layering is distinctive from a distance, consisting of thin mafic mineral concentrations. Locally the anorthosite is much finer grained with a color index near zero. < 1 cm anorthosite may contain very thin mafic layers or contain no mafics, but shows pale-green banding. The banded rock is similar to "ribbon rock" described by Morse (FR 1972, p. 105). The fine-grained anorthosites have An contents near 70. Both 1 cm and < 1 cm anorthosite occur as blocks in all anorthositic rocks described below with the exception of the marginal layered troctolite and olivine gabbronorite[1] (previously described as marginal layered gabbro, Davies, FR 1973, p. 86) on Nukasorsuktokh Island. These ≤ 1 cm anorthosites are found in relatively small masses on all three islands (see Fig. 18).

2. 1 cm leuconorite contains 10-20% orthopyroxene. This rock is characterized by a clotted appearance caused by 8 cm patches of ophitic pyroxene. Lamination of plagioclase is common. 1 cm leuconorite interlayered with 1 cm anorthosite creates a distinctive layering which strikes approximately E-W on Niatak Island (see Fig. 18).

3. Olivine-bearing anorthositic rocks have been found primarily at the margins of the Nain complex where they are in contact with the Ford Harbour Formation.[2] From the contact into the anorthositic rocks there is a sequence of layered olivine gabbronorite and troctolite followed by olivine leucogabbro (previously described as olivine leuconorite, Davies, FR 1973, p. 87). The olivine leucogabbro contains poikilitic olivine and clinopyroxene grains approximately 8-10 cm in diameter. The plagioclase enclosed in the clinopyroxene has a composition of An_{51}, whereas the plagioclase associated with the olivine has a composition of An_{58}. The rock is easily recognized in the field because an orange lichen tends to cover only the olivine grains (cf de Waard and Hancock, this report). Plagioclase lamination is common. Locally, olivine is rimmed by magnetite.

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[1]The term olivine gabbronorite follows the classification suggested by the IUGS Subcommission on the Systematics of Igneous Rocks (Streckiesen, 1973).

[2]Marginal pyroxene granulite described by Davies (FR 1973, p. 86) is included here with rocks of the Ford Harbour Formation.

4a. 2-5 cm leuconorite is a common rock type around North Bay, Nukasorsuktokh Island (see Fig. 18). It contains 15-20% subophitic orthopyroxene with accessory magnetite. The average plagioclase composition is An_{53} (Runkle and Saunders, 1974). The plagioclase may show blue iridescence. The rock displays an uneven, pale-gray weathered surface. Locally it contains coarse 15 cm gabbro dikes. 2-5 cm leuconorite rarely exhibits mineral lineations and foliations. Regional primary layering is difficult to recognize or measure. This coarse leuconorite contains a large variety and number of blocks (Runkle and Saunders, FR 1973, p. 120-127). The most abundant block type found is 1 cm anorthosite.

4b. This variety of 2-5 cm leuconorite contains 5 cm black plagioclase megacrysts which may make up as much as 50% of the rock, giving it a very dark appearance.

5. Norite pegmatite contains 15-50 cm plagioclase and orthopyroxene crystals with accessory magnetite. The plagioclase is zoned and contains red iridescent cores, blue margins, and the spectrum of colors between. There is normal and oscillatory zoning. The iridescence is spectacular. The pyroxene is commonly skeletal, enclosing plagioclase. The norite pegmatite may contain granophyre patches 5-75 cm in diameter, which contain K feldspar, quartz, plagioclase, and actinolite.

Age Relations

Fig. 19 summarizes block-type occurrences in the five rock types described above. Arrows point from block types to the host rocks within which they have been identified. Anorthosite blocks occur in all anorthositic rocks studied except the marginal troctolites and gabbros on Nukasorsuktokh Island (see Fig. 18). Layered anorthosite terrains on nearby Nukasorsuktokh, Niatak, and Uighordlekh Islands are logical source areas for the blocks.

1 cm leuconorite is older than either of the 2-5 cm leuconorite varieties because blocks of the former occur in the latter (see Fig. 19). Olivine leucogabbro is considered to be older than 2-5 cm leuconorite around North Bay, because it is part of the olivine-bearing marginal rocks. Age relations between olivine leucogabbro and 1 cm leuconorite are unknown because they are seldom found in contact with one another. These two units were placed in their present stratigraphic position because of the close association of olivine leucogabbro with the 2-5 cm leuconorite and the association of 1 cm leuconorite with anorthosite.

The youngest rock observed is very coarse 15-50 cm norite pegmatite, which cuts both massive anorthosite and 2-5 cm leuconorite.

Block Variety

Fig. 19 shows a relationship between the variety of blocks present in a particular host rock and the age of the host rock. For example, younger 2-5 cm leuconorite consistently contains a greater variety of block types than 1 cm leuconorite or olivine leucogabbro. This suggests that later magmas were emplaced through several solid anorthositic rocks.

Block Abundance

For each block structure locality the percentage of an area covered by blocks was classified as either rare to moderate (<20%), abundant (>20 <40%) or very abundant (>40%). These intervals are shaded on the map shown in Fig. 20. All block structure localities whose area contains greater than 20% blocks occur in 2-5 cm leuconorite (see Figs. 18 and 20). The older rock types contain lower block abundances, which implies that fewer anorthositic units were solid and available for stoping at the time of their emplacement.

Plagioclase Compositions

A histogram of the An contents of 45 blocks is plotted in Fig. 21. The host rock for all but two of the blocks is 2-5 cm leuconorite. The spread in compositions is consistent with the great variety of blocks seen in 2-5 leuconorite. Two calcic anorthosite blocks shown are located in an olivine leucogabbro host rock. These two blocks are considered representative of all blocks found in that host rock. Also of interest is the fact that all calcic plagioclase ($\geq An_{60}$) blocks are anorthosites.

Fig. 22 is a histogram of 32 host rock plagioclase compositions. Disregarding the low An contents of marginal troctolites and olivine gabbronorites, the total range of host rock compositions compares closely with that of the blocks, although very calcic compositions are much scarcer. This observation, along with field data, suggests that the blocks are samplings of older host rock units. The anorthosite host rocks show the range of compositions of most anorthosite blocks in Fig. 21. This suggests that the anorthosite blocks originated from anorthosite masses nearby.

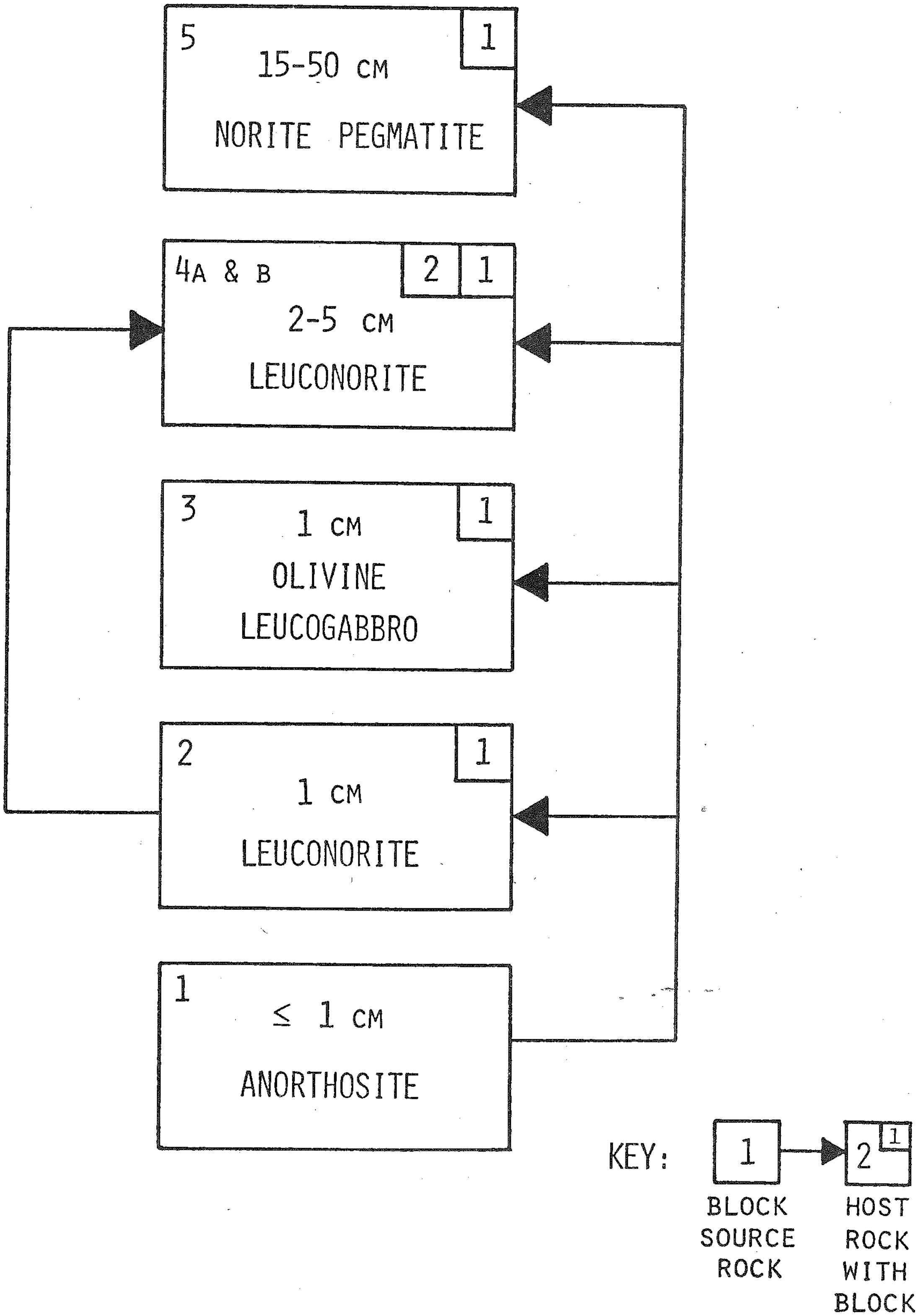

Fig. 19. Relationships among host rocks and block types.

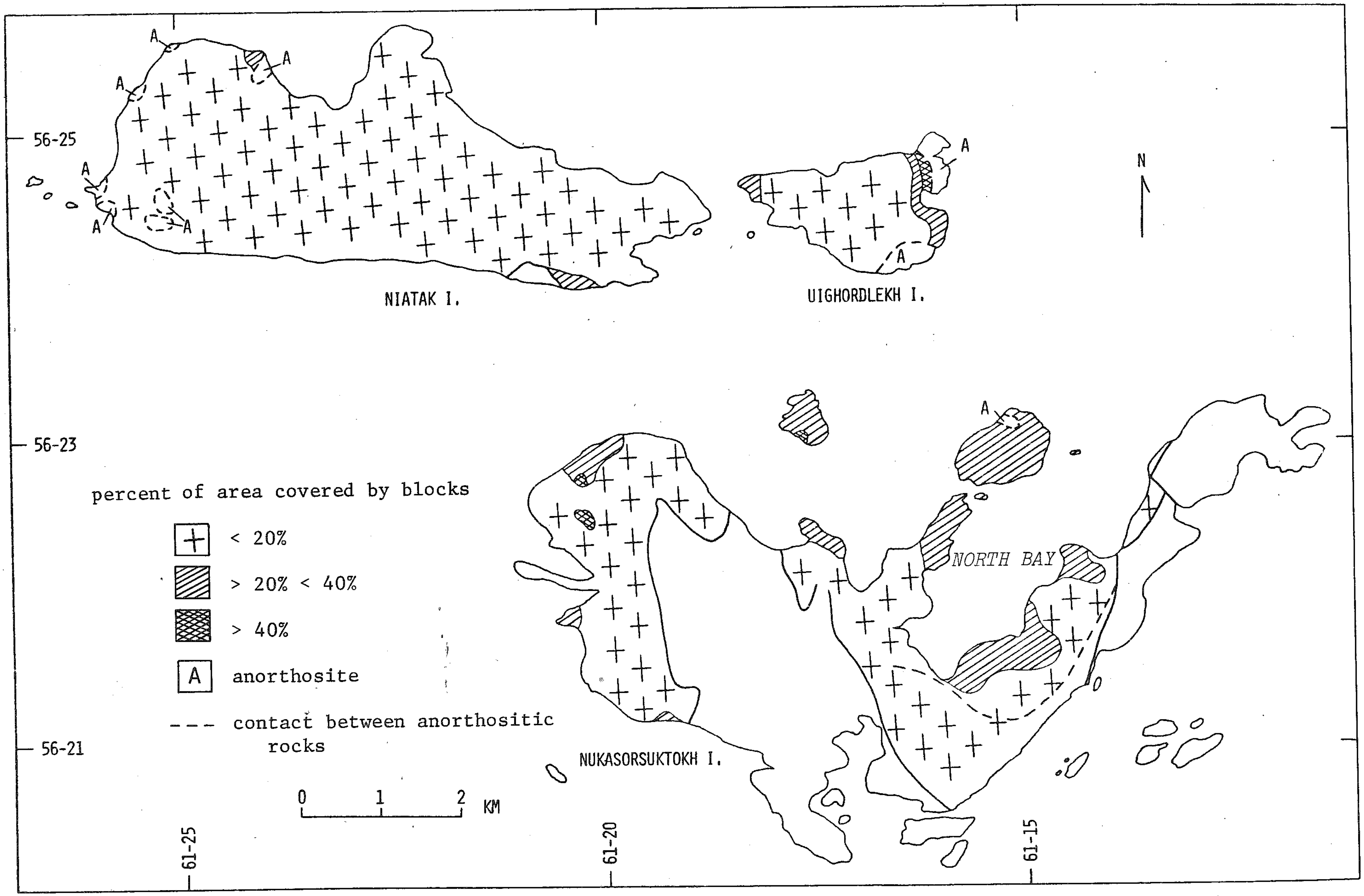

Fig. 20. Map of block abundances as determined in the field.

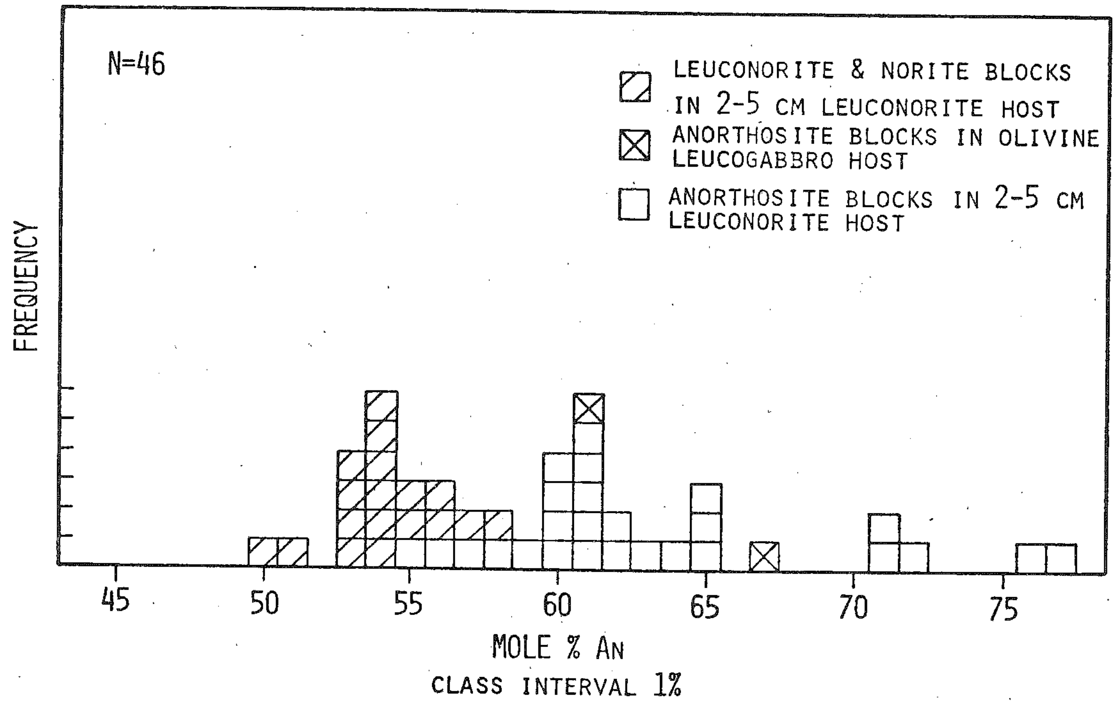

Fig. 21. Plagioclase composition histogram of blocks. Data compiled from Morse (FR 1972, p. 105), Runkle & Saunders (1973), and Davies.

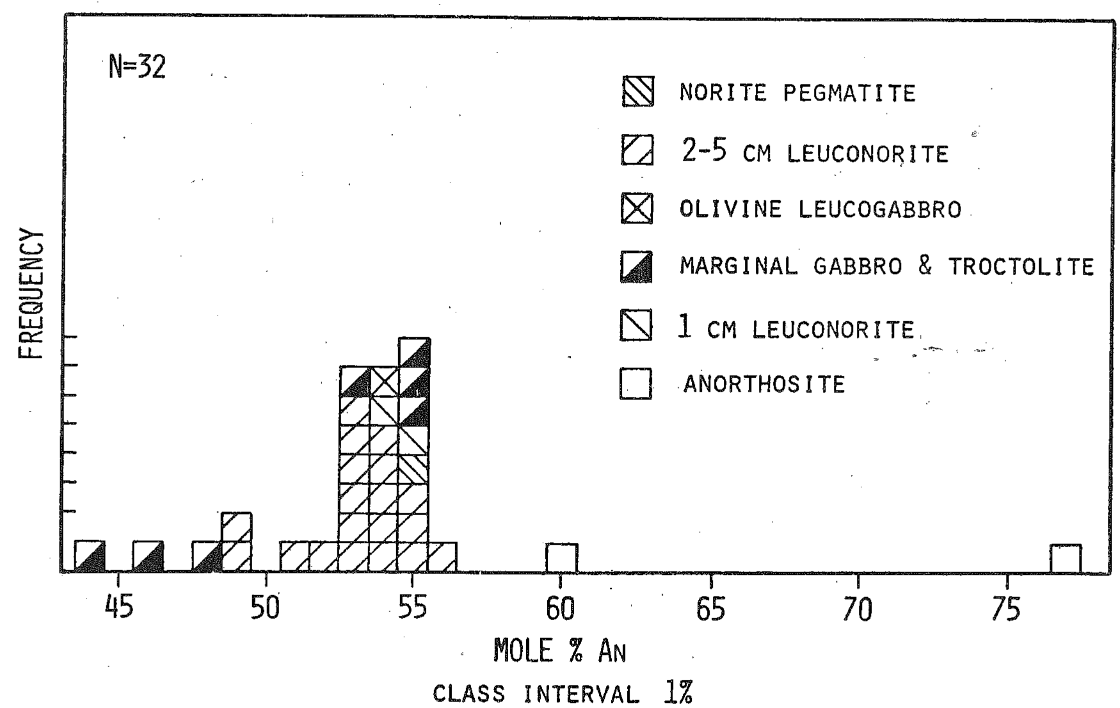

Fig. 22. Plagioclase composition histogram of host rocks. Data compiled from Runkle & Saunders (1973) and Davies.

Fig. 20. Map of block abundances as determined in the field.

Conclusions

Because contacts between different anorthositic rocks are usually difficult to define, complete comagmatic intrusions have not yet been mapped in this part of the Nain complex. Consequently the igneous history of the area is subject to at least two working hypotheses.

A. The sequence discussed above may represent one continuous igneous event which originated from one magma. Mineralogical evidence for one magma includes the nearly continuous range of plagioclase compositions in the blocks (Fig. 18), which appear to be representative samplings of the anorthosite complex in the study area. The bimodal distribution of plagioclase compositions in the blocks may be related to the bimodal mafic content of the blocks. The highly calcic blocks are anorthosites and probably represent adcumulates, whereas the less calcic blocks have higher mafic contents and are orthocumulates which contained more trapped liquid. The anorthosite may have been an adcumulate roof accumulation which became sufficiently solidified to produce sharp angular blocks in younger facies of anorthositic rocks. Structural evidence on northeast Uighordlekh Island suggests a shallow-dipping anorthosite roof pendant.

B. The sequence may also be the result of several igneous events where older anorthosite units were engulfed by younger magmas. Mafic rinds surrounding the blocks and the angular nature of the blocks support the conclusion that the blocks were cool and solid during emplacement of the host rock. This suggests a considerable time interval between emplacement and solidification of one unit and the emplacement of the succeeding unit. Both of the above hypotheses require careful evaluation.

ANORTHOSITE INTRUSION IN ANORTHOSITE

Dirk de Waard and Susan Hancock

Syracuse University[1]

During the investigation of the contact zone between anorthosite and country rock in the eastern part of Paul Island in 1971, samples were collected of anorthosite to determine possible systematic variations in the rock from the contact westward (de Waard, FR 1971, p. 14-26). The mineral compositions of the 12 samples, taken about 2.5 km apart, showed differences, but data were too few to reveal order in the distribution of mineral compositions and anorthosite varieties (de Waard, FR 1973, p. 101-105). This year a larger area was sampled and a closer grid used in a further attempt to detect and evaluate systematic variations in anorthositic rocks.

During sampling a dike-shaped body was discovered of anorthosite intruded in anorthosite (Fig. 23). The mapped portion is about 4 km long, and dips 45° to 80° to the south. The east end narrows, goes to sea in Higher Bight, and was not found on the south side of the Bight. Its extent toward the west, where the body appears to widen, has not yet been explored.

The dike consists of dark-colored poikilitic anorthosite, and the intruded rock is a lighter colored poikilitic anorthosite. The intrusive relationship is based upon the decreasing grain size and increasing mafic mineral content of the rock of the body towards the contact, thus resembling a chill zone. The contact zone would not have been very apparent in the weathered and lichen-covered outcrop were it not for the rusty, orange color which is most intense in the contact zone, and noticeable everywhere on rocks of the body. The color is caused by lichen on olivine.

In the field the contact zone is easily followed by means of this color difference with the surrounding rock. The chill zone seems to be absent in the southwestern part of the body (dashed contact in Fig. 23). Here the rock of the body appeared to be alternating with anorthositic rocks similar to those outside the body, and there seems to be a transition rather than a sharply defined chilled margin.

Layering is common in the body, and well-developed, density-stratified layering parallel to the contacts occurs in the western part of the body. The layering indicates bottom accumulation of mafic minerals and plagioclase.

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

Preliminary analyses done aboard R/V *Pitsiulak* indicate that the plagioclase of the dike is somewhat more calcic (An_{63}) than that of the surrounding anorthosite (An_{57}), but there seems to be little difference in the composition of the orthopyroxene (En_{70}). The main difference between the two rock types, based upon four samples, seems to be that the anorthositic rock of the dike consists of plagioclase, orthopyroxene, olivine, and biotite, whereas the surrounding anorthositic rock contains plagioclase, orthopyroxene, and clinopyroxene.

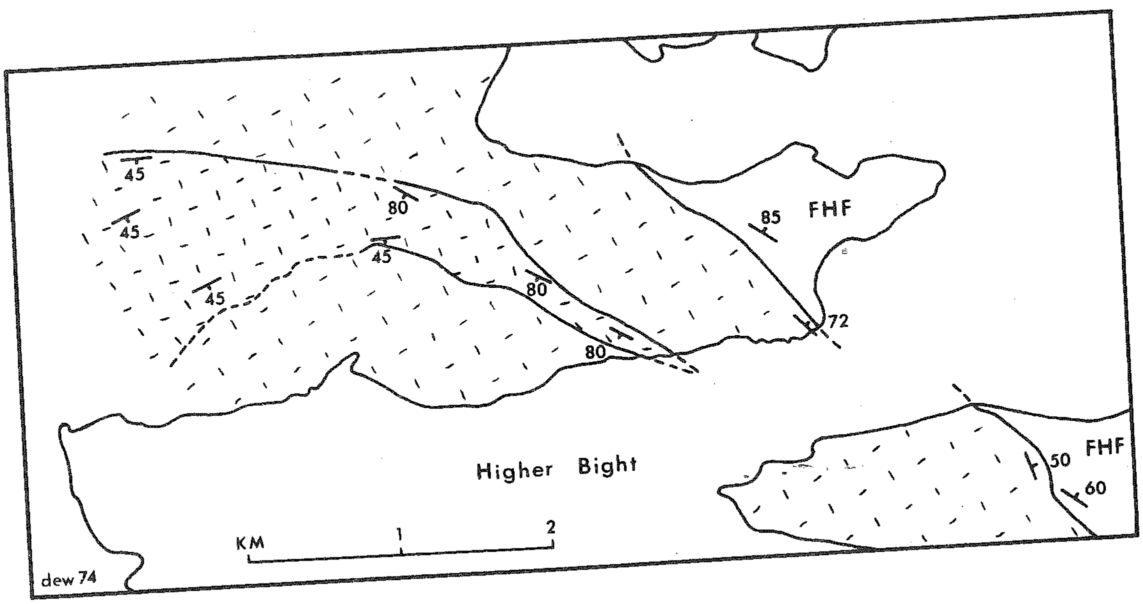

Fig. 23. Sketch map showing the layered intrusion of dark-colored, olivine-bearing anorthosite in lighter colored, olivine-free anorthosite in the eastern part of Paul Island. Where a chill zone was observed the contact is shown by a full-drawn line. Strike and dip symbols indicate the orientation of contacts and layering in the body. FHF refers to the Ford Harbour Formation, which is here the country rock of the anorthosite massif.

ABSTRACTS AND BIBLIOGRAPHY

ABSTRACTS OF THESES AND FORTHCOMING PAPERS

THESES

APATITE AND VOLATILES IN THE KIGLAPAIT LAYERED INTRUSION, LABRADOR

Hope M. Davies

Electron microprobe analyses show that Kiglapait Upper Zone apatites are fluorine-rich and contain minor chlorine. Apatite from the Outer Border Zone has a higher Cl content. Infrared absorption analysis results show no detectable water in Kiglapait apatites. About 13% of the monovalent anion site is unaccounted for by probe analyses and there appears to be excess Ca in the structure. These crystal-chemical anomalies may be explained by either O substitution for F, or domains of tetracalcium phosphate.

The refractive indices of Upper Zone apatites have the following ranges: ω=1.6345-1.6379, ε=1.6326-1.6352, and B=0.0020-0.0028. The birefringence is low for apatites with these refractive indices. Some Outer Border Zone and Upper Border Zone apatites have higher indices of refraction and normal birefringence.

Fractional crystallization of the basaltic Kiglapait magma produced apatite beginning at the 94% solidified level when P_2O_5 reached saturation in the liquid. The percentages of P_2O_5 and modal apatite decrease gradually from the 94% to the 99.99% solidified level as P_2O_5 is used from the liquid. F and Cl appear to be equally partitioned between the liquid and apatite because no fractionation trends are noted between the two halogens.

The volatile chemistry of the Kiglapait intrusion is calculated from apatite and biotite chemistry. The intrusion contains an estimated 900 ppm P_2O_5, 169 ppm F, 11 ppm Cl, and 10^{-3} ppm H_2O. It is proposed that the anhydrous basaltic Kiglapait magma was a second partial melt of amphibole-bearing mantle rock.

--M.S. Thesis, U. Mass., 1974

THE GEOLOGY OF THE BARTH ISLAND LAYERED INTRUSION, LABRADOR

W. T. Levendosky

The Barth Island layered intrusion is located on the coast of Labrador, Newfoundland, Canada, 6 km northwest of Nain. It intrudes Precambrian anorthosite. The intrusion is nearly ovoid in map view, and is probably a lopolithic structure in cross section. The intrusion exhibits some "whispy" rhythmic layering as well as pronounced phase and cryptic layering. Orientations of the layering have been measured in the field. Strikes are tangent to the outer contact of the body and dips are inward ranging approximately 60° to 30° in the outer parts to irregular at the center.

Three distinct zones are recognized: (1) the "Collar rocks" consisting of adamellite and fine-grained norite between the troctolite rocks and the anorthosite series, (2) a lower sequence consisting of rocks which grade from troctolite to olivine gabbro toward the center of the intrusion, (3) an upper sequence consisting of rocks which grade from gabbro to jotunite centerward.

Modal analysis of thin sections and mineral compositions, determined optically, support a comagmatic origin for the rocks of this body and those of the rest of the Nain complex. Mineral compositions support a down-temperature crystallization trend toward the center of the intrusion. Plagioclase becomes more sodic as the anorthite content decreases from An_{73} to An_{25}. The mafic minerals become more iron-rich (Fenner trend). Enstatite percentages of orthopyroxene decrease from En_{76} to En_{24} and forsterite percentages of olivine decrease from Fo_{73} to Fo_{58}. An olivine hiatus is observed by the disappearance of olivine at Fo_{58} and its reappearance near the center as fayalite (Fo_{7-17}). Opaque ore compositions suggest fractionation under intermediate oxygen fugacities. Trend analysis of mineral compositions and mineral variation curves display the systematic variations in the intrusion.

--M.S. Thesis, Syracuse Univ., 1975

PETROGRAPHY AND STRUCTURE OF THE NORTHERN MARGIN OF THE BARTH LAYERED STRUCTURE, LABRADOR

Kathleen Mulhern

The Barth layered structure, Labrador, is a well-exposed near-circular body, measuring about 6 x 9 kilometers and containing a troctolite-opdalite suite of rocks. The margins of the structure are made up of concentric septa of jotunitic and adamellitic rocks, which lie between the troctolite and the anorthositic country rocks. Wherever any orientation is visible in the rocks, it is parallel to the septa, strikes are tangent to contacts and dips are toward the center.

The anorthositic rocks grade over a few meters from undeformed coarse-grained plagioclase-pyroxene rocks with round poikilitic pyroxenes to medium-grained plagioclase-pyroxene rocks with stretched and flattened pyroxenes. The jotunitic rocks of the outer zone are medium-grained plagioclase-pyroxene rocks with good density-graded layering. The adamellitic rocks, recognized by their large ovoidal feldspars and their lack of layering, are plagioclase-K feldspar-(quartz)-pyroxene-olivine rocks. The jotunitic rocks of the inner zone are fine-grained plagioclase-pyroxene rocks, with orientation shown by alternation of coarser and finer layers. The troctolitic rocks are coarse- to fine-grained plagioclase-olivine-pyroxene rocks with poorly developed density-graded layering. Contacts are gradational except between the adamellitic rocks and the jotunitic rocks of the inner zone.

Phase and cryptic layering are both well demonstrated. Orthopyroxene is present in all except the adamellitic rocks. High magnesian olivine (Fo 68-60) is found in the troctolitic rocks. Olivine is absent from the jotunitic rocks, and occurs as fayalite in the adamellitic rocks. Anorthite and enstatite percentages vary systematically from the margin to the center. High values (An 55, En 64) are found in the anorthositic rocks. They decrease consistently through the jotunitic rocks of the outer zone, to lows in the adamellitic rocks (An 22, En 33). There is a steady increase across the jotunitic rocks of the inner zone, to a maximum (An 63, En 76) in the troctolitic rocks.

The Barth layered structure is considered to be the result of diapiric deformation of already existing layers of crystal mush. The original rock sequence, from bottom to top, was: troctolite, jotunite, adamellite, jotunite, and anorthosite. The troctolite and lower jotunite are considered to be bottom cumulates, whereas the upper jotunite and anorthosite are considered roof cumulates. The presence of the lighter acidic residuum under the anorthositic crystal mush was unstable. The residual liquid pierced upward through the roof cumulates, dragging the layers with it. The result is granulation, thinning and displacement of layers on the flanks of the structure and thickening in the center.

The Barth layered structure is seen as an integral part of the evolving Nain anorthosite complex, rather than a later intrusive feature. This is in contrast with the Kiglapait intrusion: an upright, undeformed lopolithic structure, whose last differentiates are syenites.

--M.S. Thesis, Syracuse Univ., 1974

STRUCTURAL, STRATIGRAPHIC AND PETROLOGIC RELATIONS OF ROCKS SOUTH OF THE BARTH LAYERED INTRUSION, LABRADOR

C. C. Rubins

South of the Barth Island layered intrusion, Labrador, is a well-exposed contact area between rocks associated with the Nain anorthosite massif. The troctolitic and related rocks of the saucer-shaped layered intrusion are bordered, in order, by an adamellitic intrusion, a fine- to medium-grained, cryptically layered noritic zone, and anorthositic and noritic rocks of the massif. A short distance into the anorthositic rocks and surrounded by them are two zones of granulitic rocks; one extends north-south and the other east-west. Although they are not connected with each other in map view or contiguous with the margin of Nain massif, similar rock types and structural relations show them to be granulite facies country rock older than anorthosite and correlative with granulites of the eastern margin of the massif. At the margins of the north-south granulitic zone is a partial sheath of layered and locally granulated rocks. These may have been produced by rapid deposition from anorthositic liquids and subsequent granulation during the foundering of the country rock fragment from the chamber wall into crystallizing anorthosite. The southern termination of the north-south granulitic zone coincides with a sharp contact between two varieties of anorthosite: a pale facies in which both zones are imbedded, and the seemingly younger dark facies anorthosite.

cess of 30 meters and in length from a few tens of meters to several kilometers, these dikes may be divided five groups on the basis of their strike directions. Four of these, with strike directions of 050°, 090°, 110° and 135°, are fairly evenly distributed throughout the area. One group, however, with north-south strikes is found only south of Okhakh (Okak) Island. Nearly all the dikes show effects of deuteric alteration. Whole-rock chemical analyses indicate, however, that they originally ranged in composition from quartz normative to alkaline diorites and gabbros. They display, for the most part, tholeiitic affinities, have low potassium contents and have undergone extreme iron and titanium enrichment.

--Submitted to Can. J. Earth Sciences

AGE AND GEOCHEMICAL STUDIES OF THE SNYDER BRECCIA, COASTAL LABRADOR

Jackson M. Barton Jr. and Erika S. Barton

The Snyder breccia is composed of angular to subrounded xenoliths of migmatite and amphibolite in a very fine-grained matrix. It is apparently intrusive into the metasediment and rocks of the Snyder Group exposed at Snyder Bay, Labrador. The Snyder Group unconformably overlies a migmatitic and amphibolitic basement complex and is intruded by the Kiglapait layered intrusion. K-Ar ages indicate that the basement complex is Archaean in age (> 2600 m.y. old) and that the Kiglapait layered intrusion was emplaced prior to 1280 m.y. ago. Major and trace element analyses of the matrix of the Snyder breccia indicate that while it was originally of tonalitic composition, later it locally underwent alteration characterized by loss of sodium and strontium and gain of potassium, rubidium and barium. Rb-Sr isotopic analyses show that this alteration occurred about 1842 m.y. ago, most probably contemporaneously with emplacement of the breccia. The Snyder Group thus was deposited sometime between 2600 and 1842 m.y. ago and may be correlative with other Aphebian successions preserved on the North Atlantic Archaean craton.

--Submitted to Can. J. Earth Sciences

OSUMILITE OF DEEP-SEATED ORIGIN IN THE CONTACT AUREOLE OF THE ANORTHOSITIC NAIN COMPLEX, LABRADOR

Jonathan H. Berg and E. P. Wheeler

Pink osumilite occurs with quartz, hypersthene, orthoclase, cordierite, plagioclase, graphite, and pyrrhotite in a granulite in the contact aureole of the Precambrian Nain complex. It occurs as a discrete phase as well as with quartz and hypersthene in symplectites. The osumilite is uniaxial positive (locally anomalously biaxial), $\varepsilon = 1.5473 \pm 0.0002$, $\omega = 1.5406 \pm 0.0002$, $\underline{a} = 10.117(2)$ Å, $\underline{c} = 14.255(6)$ Å, and density is 2.62-2.64 g/cm^3. Its composition, determined by electron probe analyses, is $\square\,^{IX}(K_{0.88}\,Na_{0.07}\,Ba_{0.02}\,Ca_{0.01})^{XII}$

$(Mg_{1.46}\ Fe_{0.55}\ Mn_{0.01})^{VI}(Al_{2.59}\ Mg_{0.39}\ Ti_{0.02})^{IV}(Si_{10.35}\ Al_{1.65})^{IV}\ O_{30}$. When its composition is compared with other osumilites and related minerals, the following prominent substitutions are apparent: $Al^{3+} \rightleftarrows Fe^{3+}$, $Mg^{2+} \rightleftarrows Fe^{2+}$, $Na^{+} \rightleftarrows K^{+}$, $Si^{4+} + (Mg, Fe)^{2+} \rightleftarrows 2(Al, Fe)^{3+}$, and $(Na, K)^{+} + (Al, Fe)^{3+} \rightleftarrows \square + Si^{4+}$.

Prior experimental and natural evidence has indicated that osumilite is formed only at very low pressures and probably metastably. However, in the Nain specimen, textural and chemical data suggest osumilite was a stable phase, and based on $\underline{P}$ - $\underline{T}$ data for the metamorphic aureole of the Nain complex, the osumilite formed at $\underline{P}_{Total} \sim 5$ kbar and $\underline{T} = 700° - 900°\underline{C}$, but $\underline{P}_{H_2O} \ll \underline{P}_{Total}$. We conclude that osumilite is stable at moderate pressure under anhydrous conditions.

--Submitted to American Mineralogist

PLAGIOCLASE LAMELLAE IN HYPERSTHENE, TIKKOATOKHAKH BAY, LABRADOR

S. A. Morse

Abundant lamellae of plagioclase are present in the (100) planes of hypersthene megacrysts in andesine anorthosite along Tikkoatokhakh Bay, northwest of Nain, Labrador. Spongy intergrowths of plagioclase in hypersthene also occur. Plagioclase lamellae have mean compositions ranging from An_{43} to An_{92}, with extreme compositions from An_{39} to An_{97}; the calcic compositions are the more abundant. Such lamellae are always accompanied in the hypersthene by grains or lamellar segments of magnetite, and rarely by lamellae of olivine, augite, magnetite, or ilmenite. Some calcic plagioclase lamellae contain antiperthitic spindles of orthoclase. The host rocks of the hypersthene megacrysts are layered leuconorites and anorthosites with mean plagioclase compositions ranging from An_{41} to An_{55}. The plagioclase lamellae in hypersthene are characteristically much more calcic than the host rock plagioclase. There is little doubt that the lamellae exsolved from a pyroxene host, dominantly by a coupled redox reaction which generated magnetite, thereby releasing silica to combine with the Ca-Tschermak's and jadeite components of the precursor pyroxene.

--Submitted to Earth and Planet. Sci. Letters

SULFIDES AND SULFUR CONTENT OF THE KIGLAPAIT LAYERED INTRUSION, LABRADOR

Steven B. Shirey

Sulfides in the Kiglapait intrusion occur as composite grains and display textures compatible with an origin as immiscible liquid droplets. Sulfides are primarily pyrrhotite with lesser amounts of chalcopyrite. Secondary marcasite replaces pyrrhotite at the highest levels of the intrusion. Cobalt-pentlandite, covellite, and cubanite are sporadically present. A jump occurs in modal abundance of sulfide in Kiglapait rocks, from .008% at the 80% solidified level to 0.5% at the 90% solidified level. This jump presumably reflects saturation of the liquid in S. In the same interval, the texture of sulfides changes from intercumulus to cumulus. Early cumulus composite grains are the most Cu-rich, indicated by highest abundances of chalcopyrite. Calculated curves for weight % S in the liquid show S saturation at 2900 $\pm$ 900 ppm. The inferred S content of the initial magma is 280 $\pm$ 70 ppm. Below the 80% solidified level, pyrrhotite is homogeneous and has electron probe-determined compositions corresponding to hexagonal pyrrhotite (63.1 $\pm$ .4% Fe). Above the 80% solidified level, it consists of a sigmoidally lamellar two-phase intergrowth with lamellae compositions of troilite (63.5 $\pm$ .5% Fe) and Fe-deficient hexagonal pyrrhotite (61.2 $\pm$ .4% Fe). The bulk composition of the two-phase intergrowth is more S-rich than the homogeneous pyrrhotite. Knowledge of fO_2, temperature, weight % S, and weight % of all major-element oxides allows calculation of apparent fS_2 using the data of Haughton et al. (1974). Thus, apparent fS_2 rose during crystallization from $10^{-1.4}$ atm for the initial magma to $10^{0.1}$ atm for the last liquid.

--Submitted to G.A.C. - M.A.C., Waterloo, 1975.

STRUCTURES IN THE NAIN COMPLEX, LABRADOR, AND THEIR BEARING ON THE ORIGIN OF ANORTHOSITE

D. de Waard

Structures in rocks of the Nain anorthosite complex indicate that movements occurred in the complex after the formation of anorthosite, and before the consolidation of associated rock types. The structures include zones of shear between blocks of anorthosite, the separation of anorthosite blocks forming dikes of jotunitic, gabbroic, and troctolitic rocks, the tilting of blocks of layered anorthosite, and the deformation of anorthosite layering caused by diapirism of adamellitic magma.

The observed structures, and the age and spatial relationships between rock types of the Nain complex fit a model in which anorthosite is formed by floatation of plagioclase and growth at the roof by the adcumulus process. Bottom accumulation followed, forming a troctolitic crystal mush, and leaving a layer of adamellitic residuum. Due to the gradually decreasing density of the fractionating magma a density inversion developed between the residuum and the overlying plagioclase cumulate, and a period of roof collapses followed. Blocks of anorthosite subsided, and residual magma and crystal mush intruded between and above anorthosite blocks. Depending on the local cooling history and the local strength of the roof, density overturn occurred at different times in different places, resulting in intrusions which differ in composition from place to place.

--Proc. Kon. Ned. Akad. v. Weteasch., 1974

ANORTHOSITES AND THEIR ENVIRONMENT

D. de Waard, J. C. Duchesne, and J. Michot

This joint paper, written in honor of Professor Paul Michot, explores differences in interpretation of some well-studied anorthositic terrains which are geologically similar in many respects.

The Adirondack anorthosites and the Nain complex in Labrador are considered anorogenic plutons with long fractionation histories, giving rise to a great variety of associated rock types. It is concluded that anorthosite massifs are essentially anorogenic, and related in space and time to each other and to the Rapakivi plutons of Fennoscandia (D. de W.).

The Rogaland complex of southern Norway, at the other hand, is considered a synorogenic pluton, differentiated from a parental magma to some degree hybridized by crustal material. Here the conclusion is that anorthosites are emplaced at different times in the tectomagmatic cycle, and at various levels in the Earth's crust (J. C. D. and J. M.).

A joint conclusion is that the parental magma must have had a monzogabbroic to granodioritic or quartz monzonoritic composition.

--Soc. Géol. Belg., Michot volume.

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HYDROGRAPHIC REPORT

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University of Massachusetts[1]

INTRODUCTION

Despite a season curtailed by ice in the first half of July, the research and support missions of R/V *Pitsiulak* allowed the addition of 135 miles of sounding track, bringing the total for four seasons to 581 nautical miles. The index maps (Figs. 24 to 26) show the locations of new tracks, which are summarized also in Table 1. Edited field sheets and fathometer records are being submitted concurrently with this report to the Dominion Hydrographer. Most of this report is devoted to notes on the tracks, given in a section below.

The dilettante hydrographer in Labrador is a lucky fellow: he is spared the tedium of day-long, week-long sounding, but has the satisfaction of recording new runs for the first time, of noting new shelters and dangers to navigation, and musing about the larger implications of the ocean bottom which he explores. Perhaps it is fitting to take brief notice here of some of the satisfactions brought by the 1974 work. The "rattle" which empties Tikkoatokak[2] Bay was examined again, and the giant ripple marks noted last year (p. 153) were verified to have a local relief of nearly 6 meters. A rapid calculation suggests that if the mean current velocity through the rattle reaches 2.5 kt (probably a realistic figure for the ebb tide at springs), the discharge could reach some 3000 m^3/sec, which is a very large figure, about half that observed at the mouth of the Churchill River in spring freshets, for example. One is struck by the thought that this may represent a potential tidal hydroelectric power source easily sufficient to satisfy the needs of Nain, thereby eliminating the expensive and dangerous fossil-fuel plant which nearly destroyed the town in a holocaust this summer. On a more mundane note, further examination of the bar which lies outside the rattle revealed depths of 6-8 fm near the northern shore, allowing for safer passage in rough weather than the center of the bar with its

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

[2] 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.

occasionally large standing waves. The bar across the mouth of Avakutak Bay, west of the Kiglapait Mountains, also has standing waves, due to the discharges from Tessiujak Bay and the Avakutak River, which collectively are constrained by the baymouth bar to the central third of this wide bay. A profile across the bar is shown in Fig. 26; this suggests a possible morainic origin for the bar, which resembles the sills found at the mouths of many fiords.

New harbors are always a delight, and three which suit the needs of small vessels come especially to mind from this season's work. The cove at Itikaut on Kikkertavak Island (track 80) is completely landlocked and very cosy. The same is almost true of a two-fathom cove off the southeast end of Perrett Tickle, on Tunungayualok Island (track 77), and the long, northeast-facing inlet on the same island (track 74a) also provides good shelter.

Finally, we have for the first time achieved a workable track along Tom Gears Run, the main inland waterway from Davis Inlet to Nain. Much remains to be done to find the best route along the south side of Tunungayualok Island, but at least we have a track, plotted in part on 1:25,000 sheets kindly furnished by the Hydrographic Service on short notice. (Ironically enough, even these sheets fail to close the gap in base mapping entirely.)

I am guilty of a reportorial error in a bit of oral history quoted in last year's report (p. 148). My informant advises me that a "roaring" Commander Wyatt is a product of literary license; the comment, somewhat differently phrased, is described as acid, which conveys a very different, if no less forthright, personality.

DANGERS TO NAVIGATION

Refer to Table 1 and the track notes for details.

Track or Note	Brief Description
66	Mary-Myrtle Island group to main shore, many shoals not adequately examined.
67	Avakutak baymouth bar - very shoal and bouldery for long distances off both shores.
67 (note)	Iluvektalik Island, SW end encumbered with rocks and shoals.
70	Amushavik Island area, rocks not completely shown on chart.
72 (note)	Nukasusutok Island, offshore rock not shown on chart.
77	Shoal off entrance of "Two-Fathom Cove".
77	SW corner of Akpiktok Island is shoal.
79	A 4-fm shoal, encountered on a previous run when not running a track, could not be relocated.
80	Itikaut, harbor entrance, rock on south side.

82 Tom Gears Run - inadequately examined shoals north of Pigeon Island and north of ledges along Tunungayualok south shore.

Danger removed:

69 Rock shown on topographic sheet is really a schooner at anchor in airphoto. Good anchorage is reaffirmed.

NOTES ON 1974 TRACKS

Track

66 The tickle west of Mary Island, between the narrow islet and mainland, has abundant rocks and shoals (visible on airphoto). Two rocks lie approximately in the plotted position of an earlier track, which should lie about 1/2 cable to the east here. The water SSW of Myrtle Island to the above-mentioned narrow islet is foul. A large shoal occurs about 1.5 cables off the mainland shore west of the north end of Myrtle Island (see airphoto). Track 66 commences just north of this shoal. The run along the mainland shore for 1.5 miles south of the sounded track is not well surveyed and should be attempted only when visibility is good. The sounded track west of Sandy Island appears clear of dangers.

67 The northern part of the track is clear of apparent dangers. The southern terminus of the track occurs at the Avakutak baymouth bar, which is very shoal and dangerous to at least 1 mile from the western shore and probably for a similar distance from the eastern shore. Large boulders occur on near-shore parts of the bar. Strong currents set in and out of the bay across the bar. Safe water, with depths of 4 fm or more, is apparently obtained anywhere in the central one-mile part of the bay mouth, between the 1972 sounding tracks. A longitudinal profile of the bay from Tessiujak Bay entrance to the Orne Islands group is furnished as a supplement to Track 68. This profile shows deep water behind a sill with an extensive outer rampart, which, combined with the large fresh-water discharge entering Avakutak Bay from Tessiujak Bay, can be expected to generate a very complex oceanographic mixing system.

Note to tracks 67 and 33 (1972 report): The SW end of Iluvektalik Island (57-16N, 61-43.5W) is encumbered with many rocks and shoals not shown on sheet 14F/5. These can be seen on airphotos LAB-43-170, 175. Track 33 evidently misses the worst shoals, but should not be relied upon in this area. Further examination is required.

68 The short track from the inner part of Avakutak Bay across the mouth of Korokuluk Bay shows depths from 14 to 26 fm and appears clear of dangers.

69 Black Island Harbour furnishes anchorage in 5 to 12 fm, and there is no rock off the houses as shown in sheet 14 c/14. This track runs through the southern entrance tickle to Black Harbour, where a least depth of 3 fm was found just at the entrance to the Harbour. Elsewhere the shores are steep-to and depths near 10 fm are found to the west end of Lopear Island, where 6 fm is encountered about 1 1/2 cables from the island. The remainder of the track to the east end of Moskie Island appears clear of dangers.

70 The track begins on sounds of Chart 4748, off the eastern extremity of Paul Island. The islets and shoals ESE of Amushavik Island include two rocks not shown on Chart 4748, but visible on airphoto LAB-46-17. Southward of the Nukasusutok Island group, the track crosses at least three deep valleys (78, 62, and 95 fm) also found on earlier tracks to the west, and an 8 fm shoal or ridge about 1.5 miles ESE of Nuasurnak Island. A least depth of 6 fm was obtained on the track about 1.5 cables off the west end of Iglusuaktalialuk Island. The track stops in a small ESE-facing cove on North Tunungayukulluk Island, where there is a passable anchorage in 4 fm, mud, close to the north shore.

71 This is a short track in the outer part of a long, northeasterly bay, "Goodnews Inlet", on Tunungayualok Island. Depths of 10 to 40 fm were encountered.

72 The track runs from the west end of Iglusuaktalialuk Island to soundings on Chart 4748 SW of Nukasusutok Island. The track appears to cross the same three deep valleys encountered on Track 70 with depths of 98, 79 and 137 fm. There is a 24 fm ridge between the latter two valleys, and the least depth on the track is 17 fm, about 7 cables NE of the east end of Nochalik Island.

Note: A rock or islet occurs about 1.2 cables off the northeast-facing shore of western Nukasusutok Island, at 56°-22.9'N, 61°-18.9'W relative to Chart 4248, at the outer edge of the shoal marked 4.5 fm on that chart. The rock is not shown on the chart, but appears in airphotos and on Sheet 14 C/6.

73 A short track starting at 56 fm, crossing a 142 fm trench, and ending at 41 fm. Least depth 31 fm.

74 The track runs along the south side of Iglusuaktalialuk Island toward the left tangent of Spracklins Islands, thence southeasterly to the NE - facing bay on Tunungayualok Island, thence part way into the bay. Least depth 8 fm (south of a suspected 4 fm shoal) south of the easternmost low-lying part of Iglusuaktalialuk Island.

75 Short segment begins in aforementioned NE - facing bay to meet the end of track 74, then resumes at small island 1.5 miles from Tunungayualok Island, and continues to the start of track 74. Least depths 10 fm on inner segment and 13 fm on outer segment.

76 This track crosses the east end of the Tikkoatokak Rattle bar, where the best depths occur. A series of previous transits of the bar yielded depths of 6 and 8 fm at locations shoreward from the 1973 track (4 fm) and it is apparent from our recent experience that the near-shore route avoids much of the turmoil which may occur over shallower parts of the bar to the west. The rest of the track runs toward the Harmony Run end of Outer Tikkoatokak Bay.

77 Track runs northward through Perrett Tickle to the north side of Akpiktok Island. The origin is at a small cove, ESE of the east end of Perrett Tickle, and south of the mouth of Kayutak Bay. This cove was examined in some detail; it has a 3 fm spot at the center, and depths of 2 fm everywhere to within about 100 ft of shore. The bottom is mud with small rocks. This cove is a secure anchorage for small vessels, well protected from any wind except north, and possibly adequate even in northerly winds. We have used the informal name "Two-Fathom Cove", pending further investigation of a local name. A shoal with drying rocks lies off the entrance to the cove, and an unexamined extension of this shoal runs ENE-ward to cover the mouth of the cove (airphoto interpretation). The west entrance point to the cove is shoal. The east entrance land is unencumbered, as verified upon entering and leaving.

Perrett Tickle has good water, as the track verifies. West of Akpiktok Island, the shoal off the southern point is now more clearly delineated, and the 6 fm spot farther north on the earlier track (25 Aug 72) can now be verified as either an isolated or westwardconnecting shoal, as track 77 encountered depths of 34 fm eastward of the shoal. Consequently, the sailing directions for Akpiktok Island should advise keeping well clear of the SW corner of the island, but thereafter favoring the island shore after reaching the center of the west-facing bay (see track 82).

78 The track from Akpiktok Island to Nochalik Island via the west end of Nuasarnak Island is clear of dangers. It passes over an exceedingly complex system of E-W trenches. These have received comment before in connection with tracks 1, 2, 70 and 72. Track 78 suggests the presence of four trench systems with depths of about 87, 62, 82 and 62 fathoms, each having a medial ridge of depths 49, 43, 53 and 51 fathoms. There is as yet no simple way of matching individual trenches to those encountered on other tracks, or to adjacent landforms. The geological implications of these trenches are not yet clear.

79 Short track in search of a suspected 4 fm shoal on the south side of Iglusuaktalialuk Island. Shoal not found.

80 Itikaut Bay (Pilot, p. 237, line 26) is a long inlet extending well into Kikkertavak Island from its eastern end. The greater part of the bay lies inside a shallow constriction which is foul and subject to strong currents. This constriction, passable by motorboats at high water, separates the inner part of the bay from the outer part which contains an excellent anchorage for small vessels in a small 2 fm cove just SE of the constriction. The outer part of the bay is only incompletely shown on Chart 4748. A rock which dries lies about one cable off the southern entrance point of the bay. On entering the bay, one sees two rocky islets labelled 8 and 6 feet on Chart 4748; there is good water near the southernmost islet and past it to the low island which lies in the entrance to the anchorage cove.

Directions. A vessel should enter at the middle of Itikaut Bay entrance to avoid the rock and shoal about 1 cable off the southern entrance point, and should steer for the southernmost rocky islet of the pair which lies about 4 cables west of the entrance. When within 2 cables of this islet, a vessel may make for the southern shore and stay along it, passing between that shore and the low cove island, to anchor in 2 fm in a small cove. The water WSW of the cove island and off the NW point of the cove is shoal. Larger vessels may anchor in 6 fm about 2 cables NE of the cove islet, off the shallow passage which leads to the inner bay. It should be noted, however, that strong currents set in and out of the inner bay through the rattle. The small 2 fm cove affords good holding ground and excellent protection in any wind.

81 Track runs from the west end of Nochalik Island to the passage between Kiuvik and Sungilik Islands, thence to the north shore of Akpiktok Island. A least depth of 7 fm was encountered off the east end of Kikkertavak Island, and this shoal has not been examined.

82 Tom Gears Run is the main inside track from Davis Inlet to the Nain area. Data are still insufficient to write a completely adequate sailing direction, but the following will perhaps serve as an interim note, to replace those of Forbes (1938) and the Pilot.

From the new site of Davis Inlet, situated just north of Porcupine Rattle near the eastern end of Iluikoyak Island, a vessel should steer northward toward Kasungatak Island, then about 305° T to pass between Kasungatak Island and the northeastern extremity of Iluikoyak Island, and thence through the passage between Uyagaksuak Island and the island to the northeast. A group of islets lies about 3 cables off the eastern end of Uyagaksuak Island. Depths in the range 10-35 fm occur along this general route. From the aforementioned islets, a course of about 308°T will lead close along the SW shores of the larger and smaller islands north of Uyagaksuak Island, where depths in the range 10-35 fm occur within 2 cables of the shore. This course should be maintained to within 2.5 or 3 cables of the south shore of Tunungayualok Island (15 fm). A course of 290° T will then lead along this shore, toward the middle of the passage between Pigeon Island and Tunungayualok Island. A mile-long group of inconspicuous low islets and shoals lies 3 to 5 cables south of this track, and extensive shoals reach outward from each of the two wooded indentations along the Tunungayualok shore. A 3 fm shoal occurs 3 cables off the mouth of the brook in the first such indentation, and a shoal of unknown depth extends 3 cables out from the next indentation. Depths along the track range from 42 fm just after the cited 3 fm shoal to 8 fm, northeast of Pigeon Island. An extensive shoal patch lies 6 - 10 cables due north of Pigeon Island. The course 290° T should be maintained for 1/2 mile beyond the east end of Pigeon Island at which point a vessel should steer 338° T to pass along the narrower parts of Tom Gears Run, and thence by the land into Perrett Tickle. Depths of 3-4 fm can be expected 8-10 cables north of Pigeon Island, at which point the shore of Tunungayualok Island should be no closer than 5 cables, as a dangerous shoal lies 3 cables from that shore about 1 mile north of Pigeon Island at the NE corner of the extensive shoal patch. All of the track along the southwest shore of Tunungayualok Island from the low inconspicuous islets to the shoal 1 mile north of Pigeon Island requires special care, but the remainder of Tom Gears Run is deep and straightforward. Shores are bold on both hands. After passing by the entrance to Shoal Tickle a vessel should swing sharply to the east toward the entrance to Nuverdluktok Bay, thence north, and northwesterly through Perrett Tickle. A vessel may pass to either side of the small island about two-thirds of the way through Perrett Tickle, but greater depths (20 fm) are found on the more northerly track. Akpiktok Island lies two miles north of the western entrance of Perrett Tickle. The southwest corner of the island can be skirted at a distance of 5 cables to avoid inshore shoals of 3-4 fm, and thereafter a vessel should seek the eastern half of the passage between Akpiktok Island and the island 1 mile to the west, to avoid a 6-7 fm patch which extends eastward across the western half of the passage. Smooth bottom with depths of 40-50 fm occurs off the NW corner of Akpiktok Island.

ERRORS IN NAMES

The long island northeast of Akpiktok Island (sheet 14 c/3, 56°-14'N, 61°-08'W) is misspelled "Iglosiatik". The correct spelling, consistent with that on sheet 14F for the large island of the same name south of Okak Island, is Iglusuaktalialuk.

The peninsula at 57°-21'N, 61°-50'W, named "Ublik" on sheet 14 F/5 and "Ubilik" on sheet 14F, should be spelled Udlik (see Wheeler, 1953, p. 92). The same spelling should apply to the bay just south of the peninsula.

Table 1. 1974 Sounding Tracks, Listed in Chronological Order.

Note: Spellings are those of published hydrographic charts[3]. Sheets designated 14 -- are Canada Topographic Series 1:50,000. LAB refers to an airphoto. All others are Canadian hydrographic charts. For track numbers 1-65, see 1972 and 1973 reports.

Track Description	Date (1974)	Sheet	DR Roll	Mileage
66. Myrtle I. To Ringbolt I.	22 Jul	14 c/11, c/14	1	12.3
67. Udlik(Ublik) to Avakutak B. Photo interp: Iluvektalik I.	23 Jul	14 F/5, F/4	1	7.5
68. Avakutak B. to Korokulak B. Supplement: Profile of Bar; delete island	24 Jul	14 F/4	1	3.0
69. Black I. Hr. to Moskie I. Note re harbour	25 Jul	14 c/14, c/11	1	6.0
70. Paul I. to N. Tunungayukulluk I.	28 Jul	14 c/6, c/3	1	19.3
71. Tunungayualok I., "Goodnews Inlet"	29 Jul	14 c/3	1	2.4
72. "Iglosiatik" I. to Nukasusutok I.	29 Jul	14 c/3, c/6	1	7.2
73. Wyatt Hr. to Satok I.	9 Aug	14 c/6	1	1.9
74. "Iglosiatik" I. to "Goodnews Inlet"	9 Aug	14 c/3	1	7.7
74a Inner "Goodnews Inlet"	9 Aug	14 c/3	1	2.1
75. Outer "Goodnews" to "Iglosiatik"	11 Aug	14 c/3	1	6.8
76. Tikkoatokak Rattle to Barth I.	13 Aug	14 c/12	1	3.8
77. Tunungayualok-Perrett-Akpiktok	17 Aug	14 c/3	1	10.4
78. Akpiktok I. to Nochalik I.	17 Aug	14 c/3, c/6	1	7.3
79. S. side "Iglosiatik"	16 Aug	14 c/3	1	2.2
80. Itikaut outer bay and cove	17 Aug	14 c/6	1	2.0
81. Nochalik I. - Sungilik - Akpiktok	22 Aug	14 c/6, c/3	2	10.5
82. Tom Gears Run	24 Aug	14 c/3, LAB 46-29, Hydro 17,18	2	22.2
	TOTAL, 1974			134.6
	TOTAL, 1971 - 1974			580.9

[3]"Ublik" and "Iglosiatik" are considered to be misspellings of Udlik and Iglusuaktalialuk. See note after track descriptions.

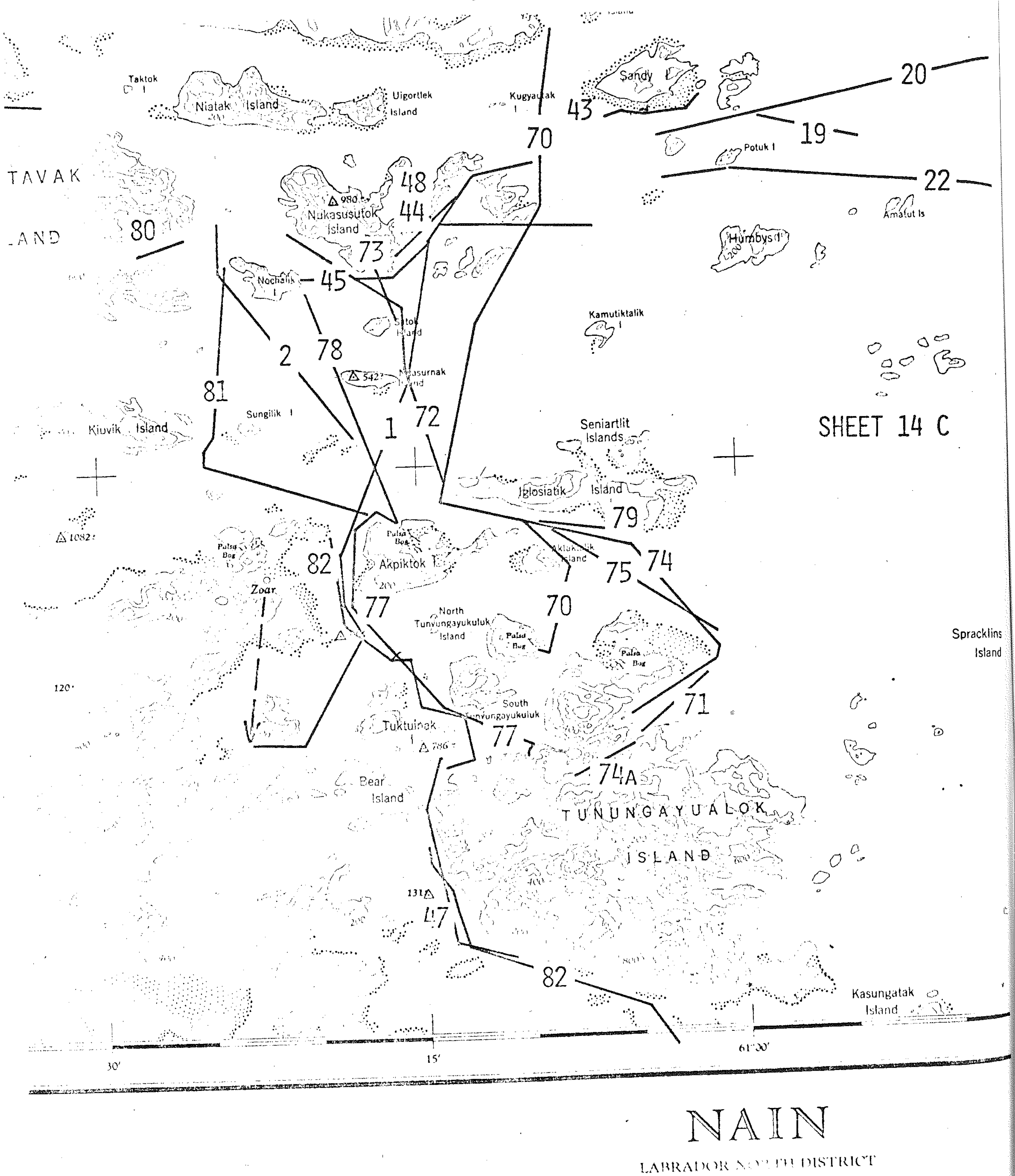

Fig. 24. Recent sounding tracks southeast of Nain.

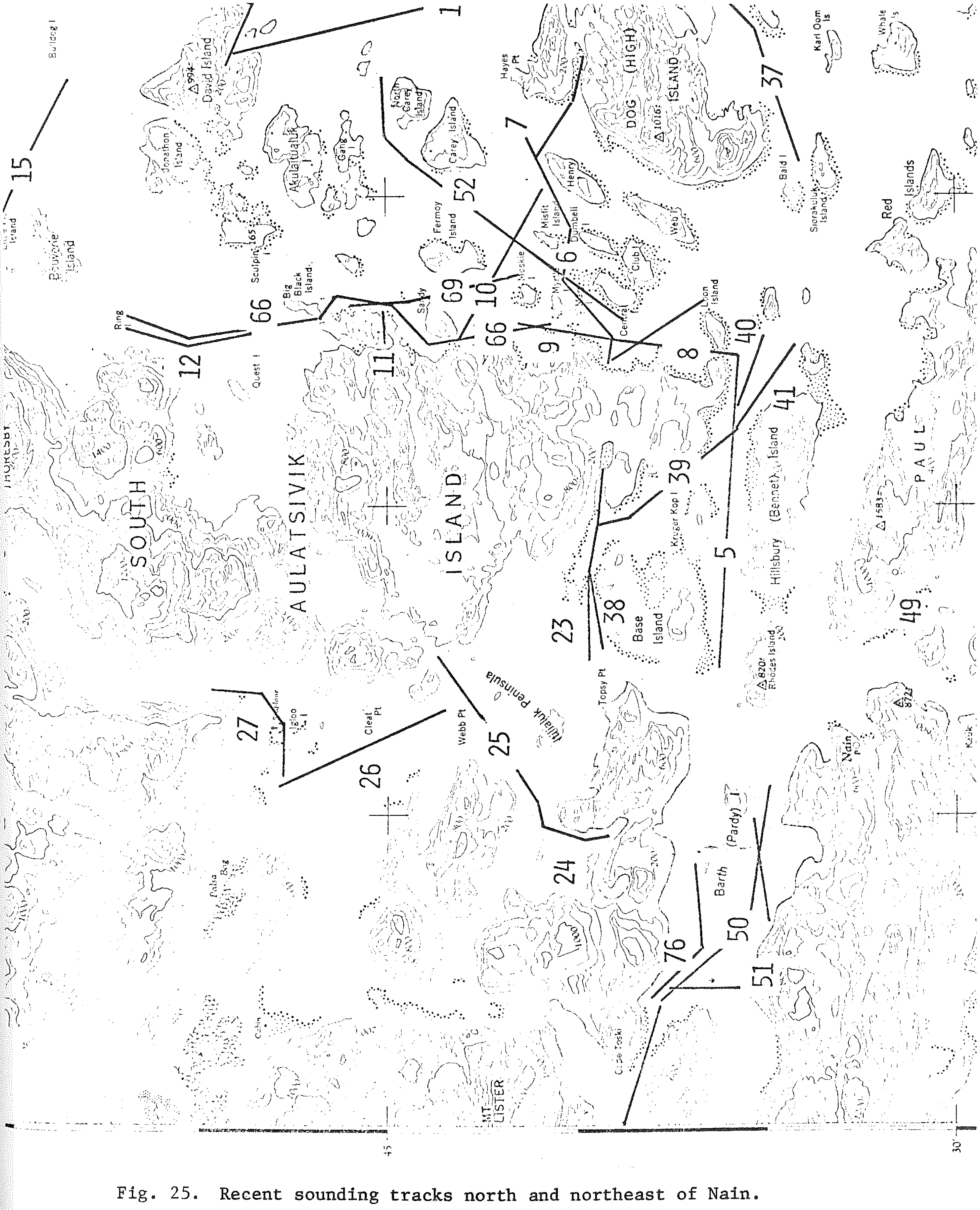

Fig. 25. Recent sounding tracks north and northeast of Nain.

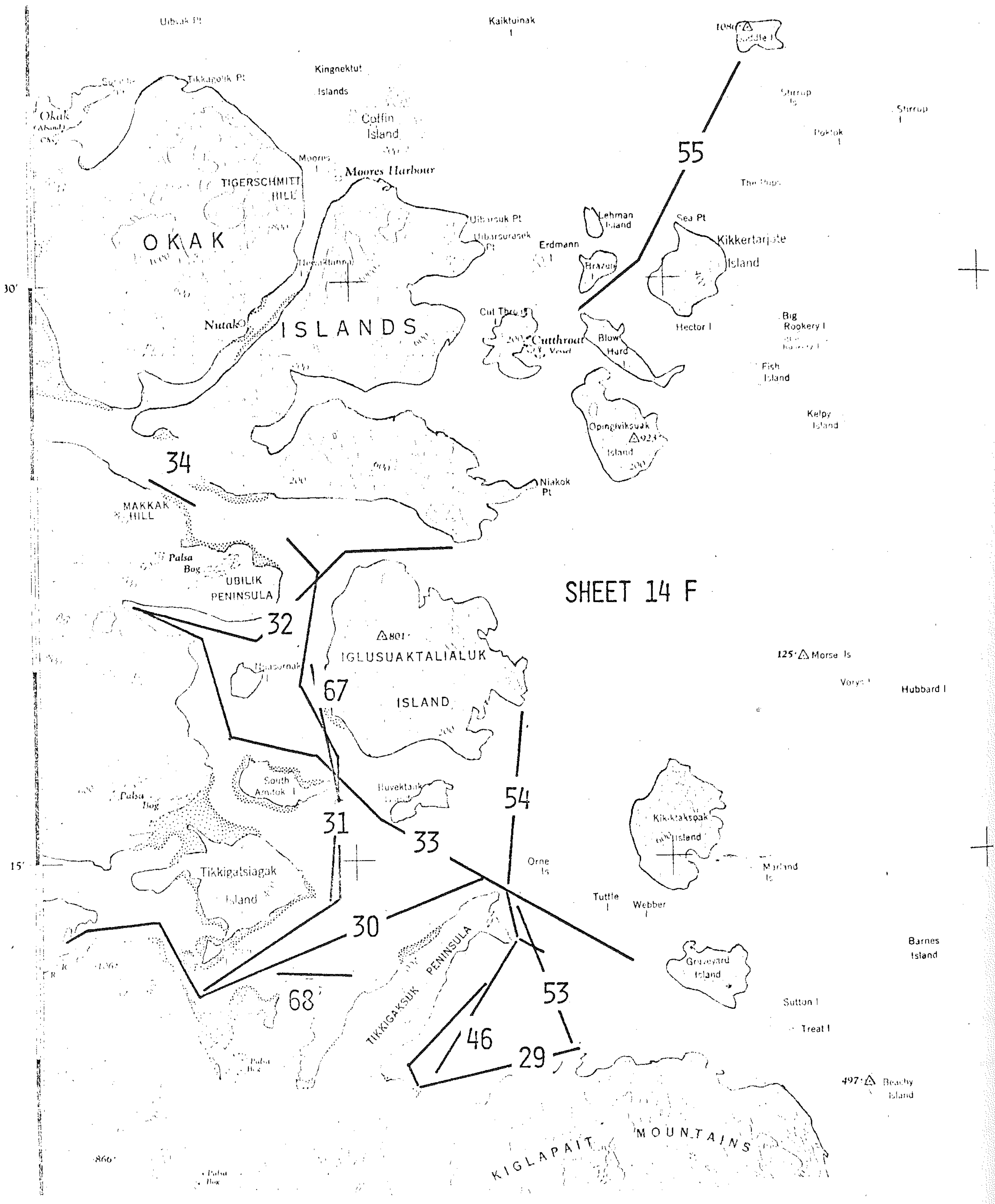

Fig. 26. Recent sounding tracks north of the Kiglapait Mountains.

AVAKUTAKH BAYMOUTH BAR - 24 July 74

Profile run from Tessiuyakh Bay entrance toward
southern Orne Island group. Supplement to Track 68.
Vertical exaggeration 23X (speed 8.7 kt., chart 8 mm/min.)

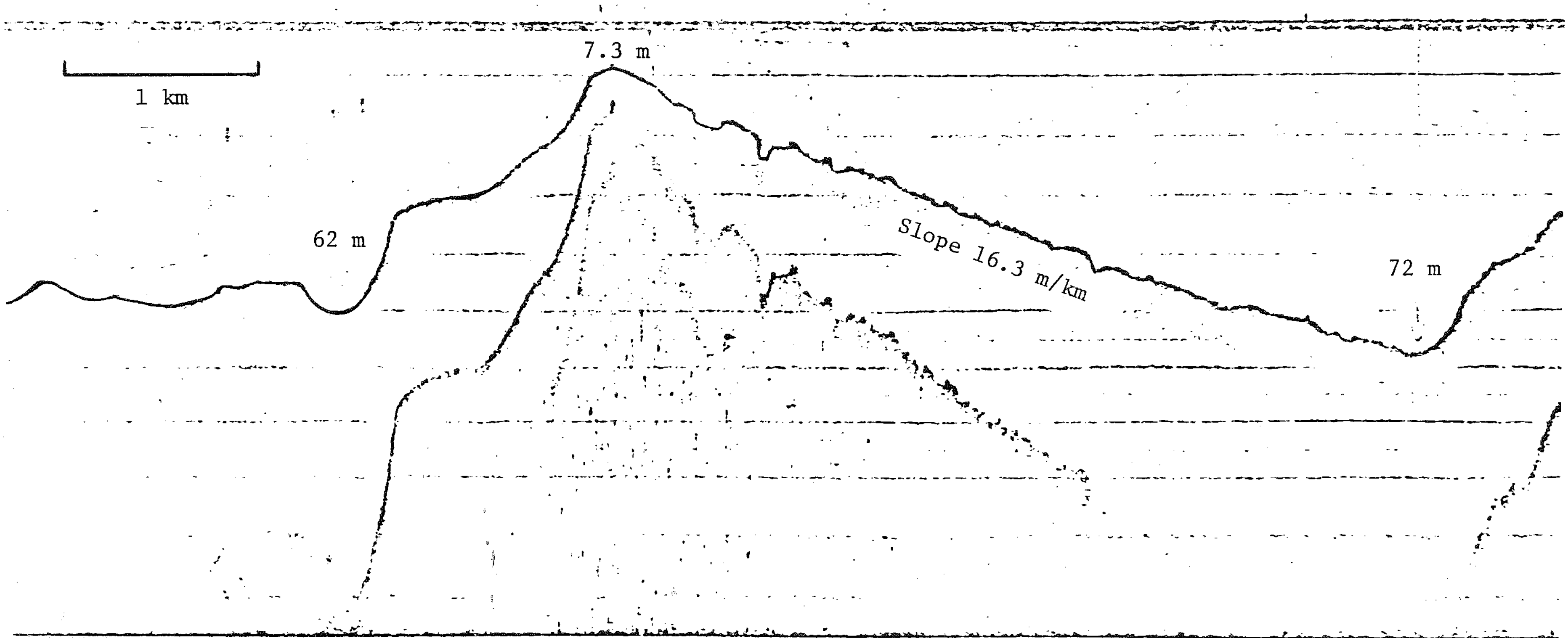

Fig. 27. Fathometer profile across Avakutak baymouth bar.

OPERATIONS

S. A. Morse

NARRATIVE REPORT

Every field season has a characteristic signature, and 1974 will be vividly remembered as the year it took two weeks to launch the vessel by hand-hauling, during which time a sizeable piece of Nain went up in flames and the open water which had been left by a seasonable breakup gradually became closed with northern pack ice. Fiasco and disaster followed closely upon one another, reminding us that while it is true about the best-laid plans often going awry, in Labrador they seldom do otherwise. To cap the season's follies, the staff of R/V *Pitsiulak* had the dubious privilege of relaying to the outside world the news of a 500,000-gallon diesel oil spill in Saeglekh Bay, witnessed by our colleagues Collerson and Bridgwater of the Memorial University - Geological Survey field party and reported through their courtesy by Mr. Newbold Smith of the Philadelphia sloop *Reindeer*.

It all began when somebody neglected to leave a tractor in Nain for the winter. The advance guard of the Project, composed of Williamson and Cincotta, arrived in Nain betimes on 15 June and began the dreary process of hand-hauling the vessel down the slipway by means of triply-connected six-part blocks and tackles, aided by a six-ton chain hoist and numerous townspeople. The chain hoist jammed, cables and anchor chains snapped, and offshore purchase boulders shifted, all with an orchestrated regularity until the vessel could be tugged clear of her cradle on 1 July. By that time, the main field crews had arrived and been dispersed by motorboat to permanent or temporary locations among the islands off Nain. The crew which arrived on 29 June was greeted by the sight of the Nain fire, which consumed the centrally-located power plant, fuel depot, and five dwellings in a towering inferno enlivened by the explosions of oil drums and the energetic orbits of empty propane bottles. Mercifully, there was no wind. The incoming Otter aircraft proved to be unserviceable on arrival. Telephones and radios went out with the power plant, except for our portable radios, and upon stringing up an antenna to the flagpole it developed that the ionosphere was not cooperating; no transmissions were successful. Meanwhile, three of *Pitsiulak's* crew members who happened to be highly trained firefighters assisted at the pumps and hoses, and the organist fetched the hymnals and litanies from the church, which appeared threatened. Families fled to the outer ends of the town, except for several who threw kettles, guns, nets and a few provisions into the motorboats and left for nicer places.

Nobody was hurt, and the weather remained fine. The news got out the next day by a search plane sent to find the inactive Otter, and emergency equipment was brought in by air and by boat. By 4 July, when *Pitsiulak* became serviceable, a steady east wind had brought the pack ice in to fill North Bay on Nukasorsuktokh I., where several field crews were camped. These were evacuated across and amongst the ice by hand-hauled canoe, and re-established in preferred locations. The ice continued to advance until on 11 July Nain Harbour was filled and boats had to be hauled ashore. *Pitsiulak* retreated to Port Manvers Run, west of the main ice pack, and remained there for eight days, making four unsuccessful attempts to find a route around Cape Kiglapait through the tight ice to establish the three camps north of the Kiglapait Mountains. On each of these trips she found heavy going in the fast-moving pack ice of the "rattles" (narrow passages with tidal currents), and amply proved her sound construction and power by pushing ice and maneuvering nimbly in the openings. A fifth attempt finally succeeded on 17 July; two crews were put ashore in Snyder Bay in the evening, and favorable conditions permitted a night run to Okhakh Harbour through the ice-free inside passage.

At the same time, the Smithsonian archeology group under Dr. William Fitzhugh reached Nain in the *Tunuyak*, the first boat to arrive from southern Labrador. There the CNR freighters were ice-bound for weeks, and one eventually holed, before the pressures of the east wind relented and allowed the ice to move offshore. The first freighter reached Nain on 20 July, when *Pitsiulak* had been active for more than two weeks, even though not very effectively. It was clear that the advantage of wintering in Nain had been realized again, in part, but that deteriorating local conditions (including vandalism) had made the advantage marginal at best. Had the vessel been fully operational in mid-June, at breakup, all crews could have been placed by 20 June instead of 17 July, and although they would have been inaccessible for some time, they could have continued to work effectively. Alternative plans for wintering were now to be entertained seriously.

The impact of ice on the transducer housing for the depth sounder had aggravated an old injury sustained in the fall of 1972, and now the sounder ceased to work altogether. A new transducer was flown in, accompanied by a welcome bottle of warm beer and a genial service engineer, and on 21 July the vessel was dried out at the wharf on the falling tide and the damaged part replaced. Sounding for charting purposes, hitherto prevented by ice conditions anyway, was now possible again. Upon the arrival of a new supply of diesel fuel, which needless to say had become scarce on 29 June, the vessel immediately returned north on 22/23 July to hold field conferences and move the Okhakh crew to Tessiuyakh, taking in tow for the trip north the Harvard archeology group under Steven Cox. The move to Tessiuyakh was rewarded with the discovery of important outcrops of "tiger-striped-gneiss", the trademark rock of the ancient anorthosite, and cursed by a still, sweltering, sleepless night at anchor in the company of a voracious horde of mosquitos.

The succeeding days were taken up largely with operational services to field crews, including increasing amounts of laboratory work. On 31 July, E.C. Simmons arrived to begin geochemical sampling, and on 3 August Prof. H.E. Wright arrived with a baggage-bereft group to begin a reconnaissance of the pollen stratigraphy associated with forest fires, in collaboration with the Smithsonian group. There ensued two weeks of intensive laboratory and field work with Simmons, followed by further operational work until all crews had left the field area, on 24 August. By this time it had been determined that none of the research or fisheries vessels would winter in Nain, and agreed that *Pitsiulak* would go to Makkovik, about 150 miles to the south. This she did on 24/25 August, being laid up for the fall at two anchors on 26 August. She was hauled out for the winter in October, on two tides with a D-8 tractor, and laid up for the winter during a snowstorm.

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The message from *Reindeer* on 4 August ran as follows.

> "As we rounded Cape Uivak to Saeglekh Harbor yesterday we ran into an oil spill caused by an inexcusable mistake by personnel operating the radar base. The Canadian tanker *Joseph Simard* was pumping diesel oil to the base but the ITT personnel ashore were not watching and allowed the tanks to overflow for 24 hours, spilling 700,000 gallons of diesel which is now running into Saeglekh Bay. We think this should be reported . . . because none of the people here seem likely to notify authorities."

The message was received at 0715 and passed on to North West River at 0820-0830; the authorities and the news media were duly notified and the oil spill became a matter of major concern to all Canadians. The figure carried later by the news media was 500,000 gallons. It was reported that an unattended valve on the storage tank was left open for a long time while oil was being pumped in from the tanker. The capacity of man to foul his nest was never greater.

TOPICAL SUMMARIES

Ice

Breakup occurred at about the same time in 1974 as in 1973, and flying was possible by 14 June. The ice moved out of the bays and remained slack until late June, when it crowded in with the daily easterly winds. It continued to deter shipping until late July. The filling of Nain Harbour in July was an uncommon event. All in all, this was probably the worst season for ice since 1957, especially as far as shipping was concerned.

Weather

Like 1973, this was a better season than average for weather. There were four major rainy periods, which lasted up to four days, and a few brief gales early in the season and westerly winds later. There were no great storms, however, and two very long periods of fine weather occurred, both of 17 days length. The first of these, from 12 to 28 July, was largely fair except for showers in an afternoon or evening. A similar period from 8 to 24 August contained only a few showery periods, although there were some brisk westerly winds. The average barometric pressure was comparable to last year's, which will be remembered as the best of all working seasons; the barometer was higher in 1974 for exactly half of the 42 days of record which overlapped with 1973.

Vessel Maintenance

It will be recalled that the 1973 season ended with a badly-needed refit in St. Anthony, Nfld. We were fortunate to capitalize on this running start throughout the 1974 season by virtue of having a seasoned engineer and a self-trained boatswain in the persons of Williamson and Deuring.

Cincotta, who carried the main burden of cooking, also brought to bear valuable sea experience and training in electronics. The result was that for the first time the state of the vessel improved continually during the season, and shows every prospect of doing so in the future. The new maintenance procedures owe much to a successful change in personnel policy, embodied in the decision to retain a dedicated professional who could make a long-term contribution to the Project. The executive officer now assumes all the functions of pilot and engineer, as well as sharing in operations. A new set of heavy-duty (468 amp-hour) batteries and a repaired battery charger made a great difference in the vessel's electrical reliability. There continue to be some problems with the shaft alignment, necessitating frequent readjustment. These are now thought to be due to having excessive weight on the vessel's keel during past winters, and this has been cured by doing away with the short cradle and jacking the vessel up to relieve the keel on the slipway.

Communication

Auroral blackouts occurred with some frequency in 1974, and a few mechanical problems were encountered, but the network of field radios worked satisfactorily, for the most part. A new communications facility, including a television capacity, is now scheduled for Nain.

Flying

Conditions for flying with chartered and scheduled aircraft were largely good. Nain saw an unprecedented amount of air traffic this summer, often with several planes a day for many days in a row. A small handful of dedicated master pilots continue to make reliable air service to Nain possible; unfortunately the state of airworthiness of the aircraft has not been of comparable excellence, and two major repairs were made in Nain during the season. For the first time, it was found necessary to lodge a formal complaint against an inexperienced pilot who failed to take effective (and obvious) measures to remain airborne.

Laboratory

Sample reduction and mineral determination procedures were inaugurated on 7 July with the determination of seven plagioclase compositions;

this was only three days after the vessel herself became fully operational. A record number of mineral composition determinations (168) was made during the season, almost entirely by D.E. Deuring. Associated mineral identifications and modal analyses were made in addition for the benefit of field investigators. Sample shipment procedures were improved by the adoption of 5-gallon steel drums and machine-cut stencils for addresses; 41 drums were shipped, totalling about 800 kg of samples, mostly petrographic.

Subsistence

As before, heavy reliance was placed on a rotating supply of freeze-dried foods, supplemented when possible by frozen meat or fresh fish. The cod fishery again failed utterly, but rock cod were in plentiful supply for chowder and fillets. Arctic char, available at the Nain fish plant, again provided an economical and substantial share of the protein intake. An experimental fishing program conducted for the fish plant yielded welcome samplings of scallop, flounder, and turbot. One camp went on short rations after appeasing a brazen black bear, forgetting the dictum that the concept of "enough" is foreign to the ursine mentality.

Health

A back injury which proved to be a muscle strain caused one field crew some loss of time, but improved satisfactorily thanks in part to a quick hospital visit and suitable medication. A skin ailment previously thought to be of solar origin was successfully treated as an allergy. No other notable health problems arose.

Wintering

Pitsiulak was hauled out on her bilge on 18/19 October in Makkovik, and jacked upright by 22 October. The Makkovik slipway is closely supervised by Provincial personnel, and in 1973 it launched two vessels on a single tide. An early launching and refit are anticipated for 1975. The new location carries with it some uncertainty about reaching Nain soon after breakup, but there is only one major cape to round, and past experience has shown that with good management a small vessel can find a route through the bays and passages inside the ice.

Cooperative Investigations

A major study of the ancient rocks of Saeglekh Bay was undertaken by a joint team from Memorial University (K.D. Collerson), the Geological Survey of Canada (D. Bridgwater, on loan from Grønlands Geologiske Undersøgelse), and the University of California at Los Angelos (R.W. Hurst). The work of our Project did not extend that far north this year, so our cooperation was limited mainly to radio communications. Closer interaction was possible with the two archeological teams from Harvard and the Smithsonian Institution, who have moved their operations northward from the Groswater Bay area where they enjoyed major discoveries and productivity over the past several seasons. Like everybody else, these teams were hampered by ice and by logistical problems, and the small favors we were able to exchange could provide only small, but welcome, relief. The excellent geochemical facilities of SUNY - Stony Brook were brought to bear on the Project through the visit of Mr. E.C. Simmons, who carefully selected a suite of well-documented specimens for geochemical and isotopic analysis.

SUMMARY OF OPERATIONS

The 1974 working season lasted 61 days, although the effective working period was at most 55 days for the luckiest crews and far less than that for most, due to ice delays. de Waard's party again provided much of its own transporation by 20 ft canoe, being able to take good advantage of small openings in the ice pack, but also finally becoming icebound as the pack tightened from shore to shore in places. Field camps were established in Snyder Bay and Okhakh on 17/18 July, and at Post Lake only after still further delay. Brief field seminars were conducted on Nukasorsuktokh Island before the ice reached its peak density. Other field conferences were held from time to time in smaller groups, usually in connection with resupply and sampling operations. The shipboard laboratory furnished 168 mineral determinations and processed 41 drums of samples. Hydrographic surveys totalled 135 miles of reconaissance track, including a number of harbor investigations. The calendar below summarizes the main events.

CALENDAR

May 7-11	Early maintenance trip to Nain.
June 14	Flying resumed at Nain on floats.
15	Advance personnel to Nain to start launching vessel.
25	First two research crews to Nain and Khaukh Hr.
26/27	Crews to North Bay and Paul Island

28	Vessel moved 5, 6, and 16 feet last 3 days.
29	Nain fuel fire. Third research crew to Nain and Khaukh.
30	Vessel and cradle floating but not separated.
July 1	Cradle tied down, vessel yanked free and towed to wharf.
4	Trial run to Khaukh Hr., vessel operational.
6	Wiebe established in field area. Fueled at Davis Inlet.
7	Evacuation of North Bay over ice. Only two crews in place.
8-16	Attempts to go north; dodging ice. *Tunuyak* to Nain 16th.
17	Vessel to Snyder Bay and Okhakh. Six crews in place.
18-31	Conferences and resupply operations.
August 1	First termination of field season (Berg).
3-14	Geological work and sampling operations.
8	Second termination of field season (de Waard).
14	Third termination of field season (Brand, Simmons).
15/16	Northern resupply trip.
16/17	Southern resupply trip.
21	Northern camps terminated, returned to Khaukh Hr.
22	Southern camps terminated. Seminar-review at Khaukh Hr.
23/24	Secured operations.
24/25	All research personnel out; vessel to Makkovik.
25	Arrived Makkovik, running time 18 hr.
26	Secured vessel at anchor.
October 18/19	Hauled vessel out on Government slip, Makkovik.
23	Vessel secured for winter.

PERSONNEL

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Henry Webb, Nain	Expediter
S.A. Morse, Amherst, Mass.	Master

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