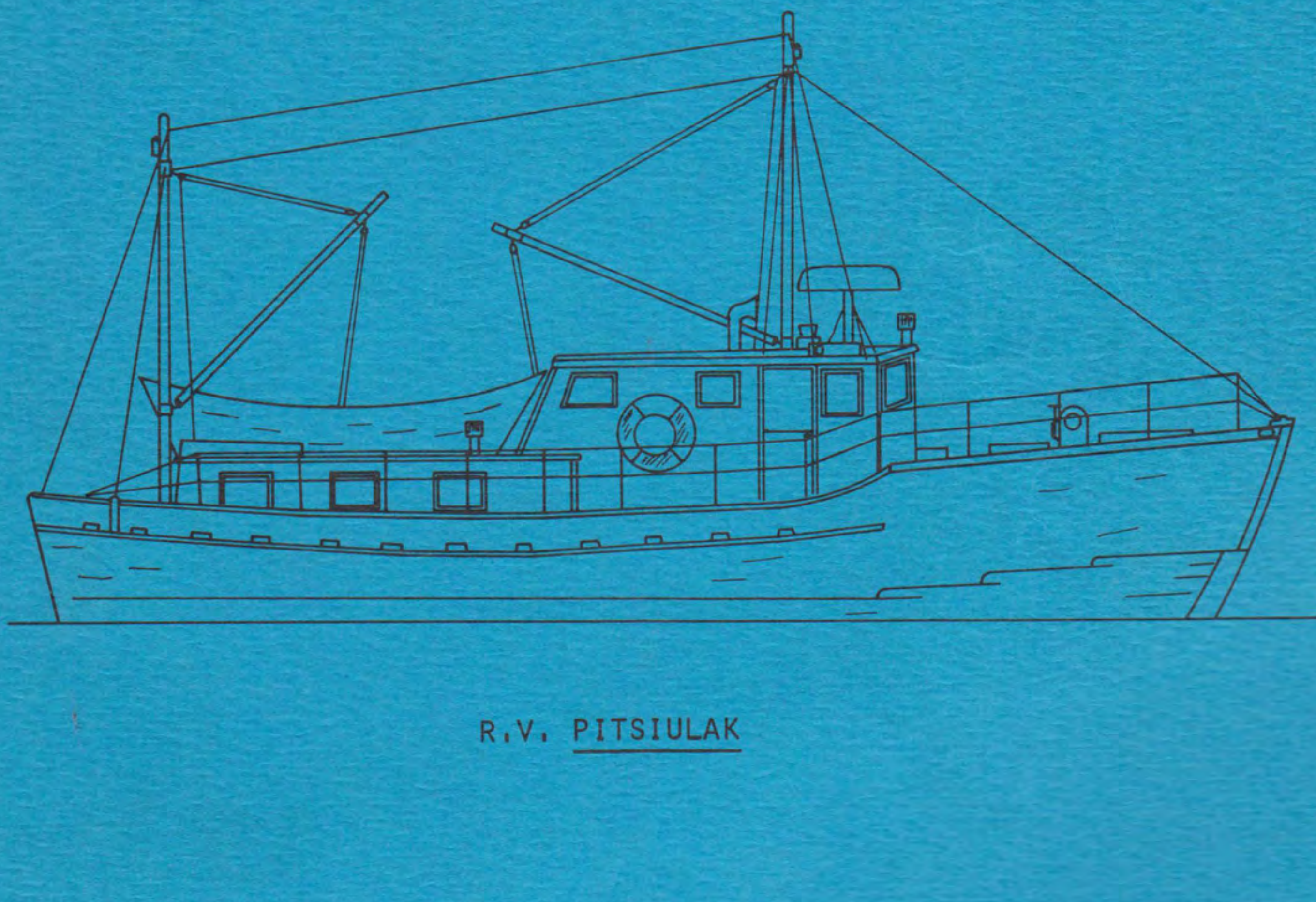
THE NAIN ANORTHOSITE PROJECT, LABRADOR: FIELD REPORT 1972

S. A. MORSE, EDITOR



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FIELD REPORT 1972

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Interim Report under NSF Grant GA-32134:
"Evolution of anorthosite and related
crustal rocks in coastal Labrador."

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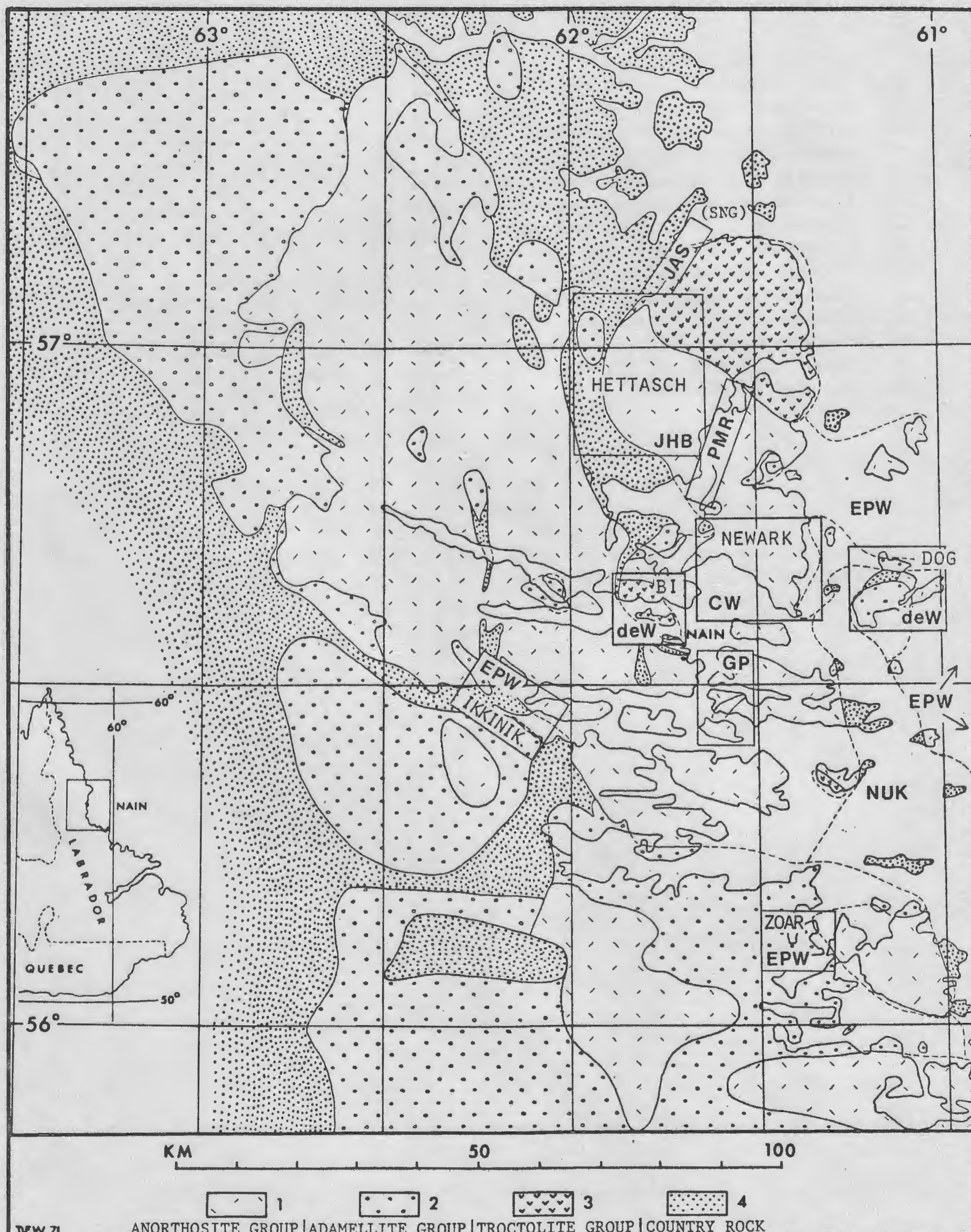

Fig. 1. Regional geology of the Nain area, after Wheeler (1968), showing locations of field areas. FIELD AREAS, from north to south: JAS, Speer (Snyder Group); JHB, Berg (Hettasch intrusion); PMR, Port Manvers Run; EPW, Wheeler (outer islands); CW, Woodward (Newark I.); deW, de Waard (Dog Island, BI, Barth Island); GP, Planansky (Bridges area); IKKINIK., Wheeler (Ikkinikulluit drainage basin); NUK, Nukasorsuktokh I.; Zoar, Wheeler.

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> A dominant disposition to find out what is, should precede and crowd aside the question, commendable at a later stage, "How came this so?" First full facts, then interpretations.
>
> --Thomas Crowder Chamberlin, 1890

INTRODUCTION AND REVIEW

The beginning of a new research effort inevitably springs from a conviction that a paucity of facts stands in the way of understanding. The origin of anorthosite has remained one of the great unsolved problems of geology not for lack of creative imagination, nor very likely from insufficiency of theory, so much as for lack of a warp and weft of fact upon which to build and against which to test hypotheses. The most inspired of creative insights, of which the study of anorthosites has seen a goodly share, are like arrows shot through a cloud when the target of fact is obscured and the archer knows not whether he hits or misses. The Nain Anorthosite Project, now reporting its second season of investigation, celebrates Chamberlin's dictum with increased conviction that the unmetamorphosed, nearly undisturbed rocks of the Nain area hold many new and critical facts pertaining to anorthosite genesis.

A general statement of the anorthosite problem in the Nain area was offered in last year's Field Report (designated hereinafter as FR 1971), and will not be repeated here. The basic pattern of research continued, in 1972, to center around geologic mapping and sampling of selected areas by shore-based field parties. A major difference in operational effectiveness resulted from having the first full season's use of R.V. Pitsiulak. This permitted investigations in the outer islands among the most persistent and pervasive pack ice known for many years, and greatly facilitated the logistic and laboratory support of field parties and of guest investigators.

A significant role for geophysics was seen in the earliest planning stages of this project. Geophysical research has been started along several lines, and preliminary results of a paleomagnetic study are reported herein by Dymek and Hargraves. The plagioclase of anorthosite commonly shows exceptional magnetic stability, yielding closely defined paleomagnetic vectors. For reasons not yet clear, the Nain samples show much scatter, and cannot yet be compared with confidence to other North American anorthosites or to the Precambrian polar wander curve.

The shape of anorthosites at depth is essential to an understanding of their origin, and gravity studies will be of great importance in setting limits on the deep geometry of the Nain anorthositic rocks. Such studies have an added value in the Nain area, where sharp contacts with country rock and the lack of metamorphism and deformation (other than fracture) imply that the anorthositic rocks have not been dislocated from their original site of emplacement. A preliminary, helicopter-supported gravity traverse over part of the Nain-Kiglapait area was made in 1972 by J. G. Tanner of the Earth Physics Branch, Ottawa. An extension of this work is planned for the future, with collaboration from field investigators who can furnish rock densities on a routine basis.

The problems of anorthosite are inextricably bound up with geologic and stratigraphic setting. In last year's report, the possibility was raised that the history of crustal evolution on the Labrador Coast might be very long indeed if counterparts of the ancient rocks of West Greenland were present. Collections were made in 1972 by two groups of geochronologists interested in the timing and geochemistry of crustal evolution. Using samples collected in both seasons, Barton is able to report K-Ar closure ages for several rock systems, most notably the Snyder Group and the diabase dikes which form two oriented swarms in the Nain area. A surprising result from the dikes is that they appear to record three widely separated pulses of emplacement before, during, and after the inferred anorthosite emplacement period. Farhat and Hurst describe a comprehensive sampling program designed to test for the presence of very ancient ($>3.5 \times 10^9$ yr.) crustal segments in Labrador. This program was curtailed in geographic range by severe ice conditions in 1972, and clearly deserves continuation.

Perhaps no lithic unit in this part of Labrador is more fortunately or more spectacularly preserved than the Proterozoic supracrustal Snyder Group. Although of small size, this scrap of dominantly clastic metasedimentary rocks at the northwest contact of the Kiglapait intrusion bears witness to a post-Archaean depositional event which may have preceded closely the emplacement of anorthosite. In the first detailed study of this group, Speer has established and mapped five stratigraphic units, including a marble unit; has clarified the structure; and has provisionally outlined an Abukuma-type metamorphism from the greenschist facies to the sillimanite + orthoclase zone. Speer's evidence suggests that the moderate deformation of the Snyder Group was completed before the peak of metamorphism, and that the latter is most probably related to the emplacement of the Kiglapait intrusion. Metamorphic pressures no higher than 3-5 kbar are indicated, implying that Kiglapait and probably anorthosite emplacement occurred at depths of only 10-17 km in the crust. The Snyder Group seems certain to be the most important single key to understanding the tectonic, metamorphic, and intrusive history of the Nain anorthosite and its crustal environs.

The Nain area is turning out to be a veritable garden of layered intrusions, comparable to the prolific occurrences in West Greenland. A new example, probably dioritic, and with abundant large xenoliths of anorthosite, was found by Wheeler on The Castle, a small outer island difficult of access except by a sheathed vessel such as ours. This brings the total of known layered bodies in the Nain area to 10; these are listed later in the report. The layered intrusions provide the best sort of insight into the types of magma associated with the anorthosite massif, and it is already possible to say that these span a considerable range of basaltic and perhaps andesitic varieties. All the basic magma types are probably characterized by high alumina. At one extreme is the ultrabasic (An_{80}, En_{80}) Bridges layered group studied by Planansky. The Kiglapait intrusion (Morse, 1969) represents critically undersaturated low-K olivine tholeiite (0.2 % K_2O; unpublished data). Berg's Hettasch intrusion appears similar, but slightly higher in silica saturation, leading to a noritic anorthosite differentiate. The Barth Island layered body of de Waard and Mulhern is apparently a Skaergaard-type olivine tholeiite which shows extreme fractionation to granodiorite, complete with an olivine hiatus in the intermediate stratigraphic levels. These four intrusions alone serve to suggest that high-alumina olivine tholeiite magmas with varying degrees of silica saturation (and probably K content) were emplaced in the Nain area, and produced at least some of the anorthosite.

The Barth Island layered body is of particular interest for tectonic, structural, and petrologic reasons. Reconstruction of the body along two faults yields a total left-lateral displacement of 5 km associated with two of the most profound east-west linears of the Nain area. The structural arrangement of thin, nearly continuous septa of gabbro, troctolite, and adamellitic rocks in the margins of this intrusion is truly remarkable, and has led de Waard and Mulhern, in keeping with Chamberlin's method of multiple working hypotheses, to offer a working hypothesis involving diapiric uprise of a partly crystallized body through overlying anorthosite.

Berg has delineated part of a major synclinal layered intrusion--the Hettasch intrusion--with asymmetric stratigraphy and an impressive variety of layering and crystal growth features. Among the latter is a spectacular "snowflake troctolite" with 5-cm plagioclase tablets arranged radially in spherical clusters. Similar features on a smaller scale were found by Wheeler in the outer islands. Although the full meaning of these clusters is not yet clear, they do undoubtedly bear on the growth of big plagioclase crystals in basic magmas. One limb of the Hettasch intrusion is rich in noritic anorthosite, and the intrusion appears to demonstrate an origin of anorthosite from olivine tholeiite magma, a sample of which is well-preserved in the chilled margin of the intrusion. This fine-grained rock is the first essentially uncontaminated basic chilled margin to be found in the non-dike rocks of the Nain area.

The monoclinal layered intrusion at The Bridges is now shown by Planansky to be essentially ultrabasic, having bytownite, bronzite, very magnesian augite and olivine near the base, and labradorite (An_{64}) near the top. In this respect, The Bridges layered group resembles the Stillwater complex of Montana. The intrusion, suggested last year to be allocthonous (FR 1971, p. 57), may have been floored at the time of origin by pale anorthosite, and its upper levels invaded later by dark anorthosite and gabbro.

Woodward has further delineated a layered intrusion on Newark I., finding evidence to suggest the form of a closed basin, with lithologies ranging from troctolite at the base to norite and mangerite at the top.

Outcrop-sized xenoliths of country rock in anorthosite are not abundant in the Nain area, but they do occur. Wheeler, in recording a paragranulite xenolith in buff-weathering anorthosite (p. 68), was prompted to search earlier field notes for similar occurrences, and he found 10. Xenoliths of anorthosite within anorthosite (block structure) are much more common, especially near contact zones, and an example of the plagioclase composition distribution in such xenoliths is given in an article by Morse, where a histogram of recently determined plagioclase compositions in rocks of the complex is also given. The limits found to date in anorthositic to gabbroic rocks of the Nain area are An_{84} and An_{39}--a far wider range than commonly supposed to occur in the Nain anorthosite, and one which extends and perhaps complicates the classification by Anderson and Morin (1968) of anorthosite into labradorite and andesine types.

Plagioclase studies and a continuing study of giant pyroxenes by Wheeler demonstrate that most megacrystic segregations in anorthosite are more basic than their host rocks, and hence are phenocrysts or xenocrysts rather than late-stage anorthositic pegmatites. Although this might argue for plagioclase accumulation by flotation, the bottom accumulation of feldspar in layered intrusions, if correctly interpreted, implies that feldspar simply refuses to float when it ought to. This paradox is discussed (but not resolved) in an article by Morse. Mechanisms of accumulation aside, however, Wheeler's giant pyroxenes tend to demonstrate that pyroxene and plagioclase crystallized together at high temperatures, and that the plagioclase-richness of anorthosite must therefore result from feldspar accumulation. Orthopyroxene compositions in the entire complex are also reviewed by Wheeler in a histogram showing a range from En_{80} to En_{20}.

Readers more familiar with modern magma types than with the rocks associated with anorthosite complexes may have difficulty in identifying the latter in terms of the former. In this respect, Berg has done a service by referring to a tholeiitic (= subalkaline) group and a calc-alkaline group in the Nain area, corresponding to the troctolitic group and adamellitic group, respectively, shown in Fig. 1. This correlation is probably correct, and it may be instructive for those who wish to contemplate the possible similarities between the Nain plutonic magma types and those of island arcs, or who may wish to contemplate models for anorthosite related to subduction zones. (For example, one might ask if the anorthositic kindred could be generated where subduction is sub-continental rather than sub-oceanic, i.e. at moderate depth in an Andean situation.) Reference to a calc-alkaline magma series may be felicitous, because many rocks mapped by us under the designation "adamellitic" are diorites, granodiorites, and monzodiorites (see de Waard, this report, pages 39 and 79). Application of a new terminology does not, of course, settle the matter of which magma type is the chief parent of anorthosite, or whether there is a continuum between the magma types (see de Waard, this report, p. 73 , for review).

Rocks of calc-alkaline affinity are described herein by de Waard at Dog I. and by Wheeler at Ikkinikulluit Brook and at Zoar. Transitional contacts with norite and anorthosite are recorded at Dog I., in contrast with the usual expectation of sharply cross-cutting relationships, as indeed found in Wheeler's 1972 areas.

Our report on the anorthosite complex is organized by geographic region, and it may help the reader to have the following listing of articles by lithologic group as a guide to selective reading.

Tholeiitic group

Woodward (Newark)
Berg (Hettasch)
de Waard and Mulhern (Barth)
Planansky (Bridges)

Anorthosite only

Wheeler (giant pyroxenes)
Morse (plagioclase)

Calc-alkaline group

de Waard (Dog)
Wheeler (Ikkinikulluit)
Wheeler (Zoar)

ON THE NOMENCLATURE OF ROCKS OF THE NAIN REGION, LABRADOR

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The following are excerpts of proposals made for the Granulite Working Group and the Working Group on Charnockitic Rocks of the I.U.G.S. on the nomenclature and classification of felsic and mafic rocks. The excerpts are presented here in the hope that it may facilitate giving names to the various rock types of the Nain anorthosite complex and its country rock. Since these are proposals I will welcome suggestions for improving the system.

Rocks are classified either as an igneous or as a metamorphic rock, even though in nature rocks are not always easily identified as belonging to one of the two groups. The distinction should be based upon textural and structural characteristics of the rock.

Since 1942 the igneous rocks of the Nain area have been classified by E. P. Wheeler II according to Johannsen's (1939) system. As long as there is no international agreement on rock classification, it seems wise to continue this tradition. Felsic and mafic rocks are classified according to their modal quartz-K feldspar-plagioclase ratios. The diagram shows the division and the names (underlined) for rocks plotting in those pigeonholes. Different names, as shown in the diagram, are given to rocks of similar composition, but containing orthopyroxene (or its substitutes, fayalite and quartz) in addition to, or instead of other ferromagnesian minerals[1]).

The exception to this rule is the lower right-hand pigeonhole which is marked "diorite" if hornblende is the predominant ferromagnesian mineral, and "gabbroic rocks" if anhydrous ferromagnesian minerals prevail[2]). The

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[1]Since most of these rocks contain perthitic feldspars, the amounts of the exsolved components should be estimated and treated as K feldspar and plagioclase in plotting the rock in the diagram.

[2]This departs from Johannsen's system (but follows his field classification).

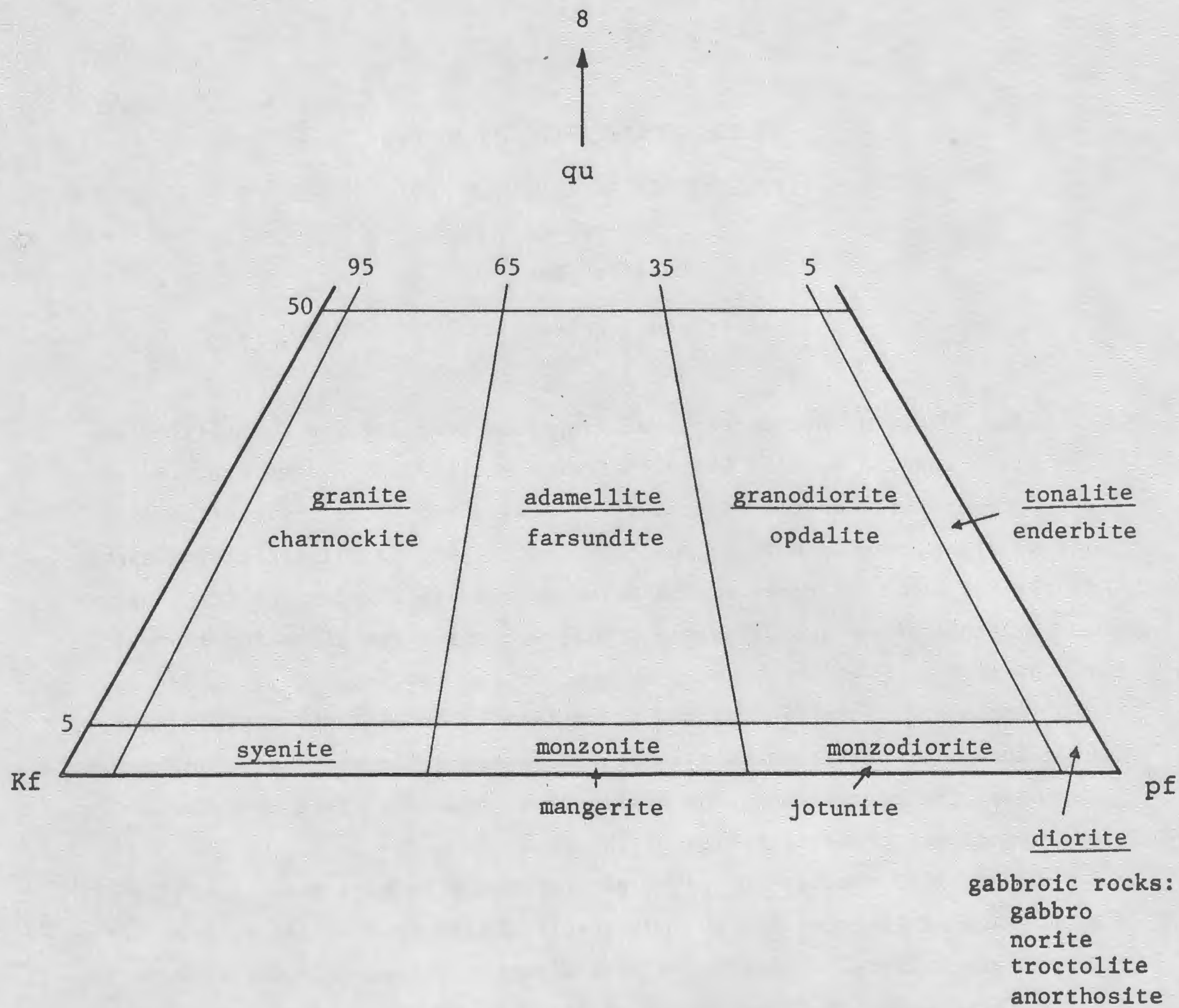

Fig. 2. Subdivision of the modal quartz - K feldspar - plagioclase field according to Johannsen, showing nomenclature and classification of common plutonic igneous rocks (underlined) and of charnockitic rocks. Note 1: The IUGS Subcommission on the Systematics of Igneous Rocks recommends a 90-65-35-10 division of the base of the triangle, and a 5-60 division horizontally. Also: Kf would include albite An_{0-5}. Note 2: 'Monzodiorite' is more commonly used (and recommended by the Subcommission) than Johannsen's term 'syenodiorite'.

gabbroic rocks are subdivided according to the dominant ferromagnesian mineral: in gabbro it is clinopyroxene, in norite orthopyroxene, and in troctolite olivine. The prefix leuco (or anorthositic) may be added to these terms to denote a plagioclase content between 65% and 95%. With more than 95% plagioclase the rock is an anorthosite. The prefix ferro may be used for rocks with a high Fe/Mg ratio, such as the fayalite-bearing rocks.

Metamorphic rocks of the catazone are divided into felsic and mafic rocks by means of a 30% boundary of ferromagnesian mineral content. Each group is subdivided according to whether the ferromagnesian minerals are predominantly hydrous (hornblende, biotite) or anhydrous (pyroxenes, garnet, cordierite). Thus, the following catazonal metamorphic rock types are defined:

Granulite: fine to medium-grained felsic rock in which the ferromagnesian minerals are predominantly anhydrous.

Granofels: medium to coarse-grained felsic rock in which the ferromagnesian minerals are predominantly anhydrous.

Pyriclasite: mafic rock in which the ferromagnesian minerals are predominantly anhydrous.

Gneiss: felsic rock in which the ferromagnesian minerals are predominantly hydrous.

Biotite schist: mafic rock in which biotite is the dominant ferromagnesian mineral.

Amphibolite: mafic rock in which hornblende is the dominant ferromagnesian mineral.

Further subdivision of these types is done by using mineral names as a prefix (in increasing order of abundance), or by using an igneous rock term (ending with "ic") as a prefix to indicate similarity in mineral composition, e.g.: granitic gneiss, charnockitic granulite, enderbitic granofels, noritic pyriclasite, and so on.

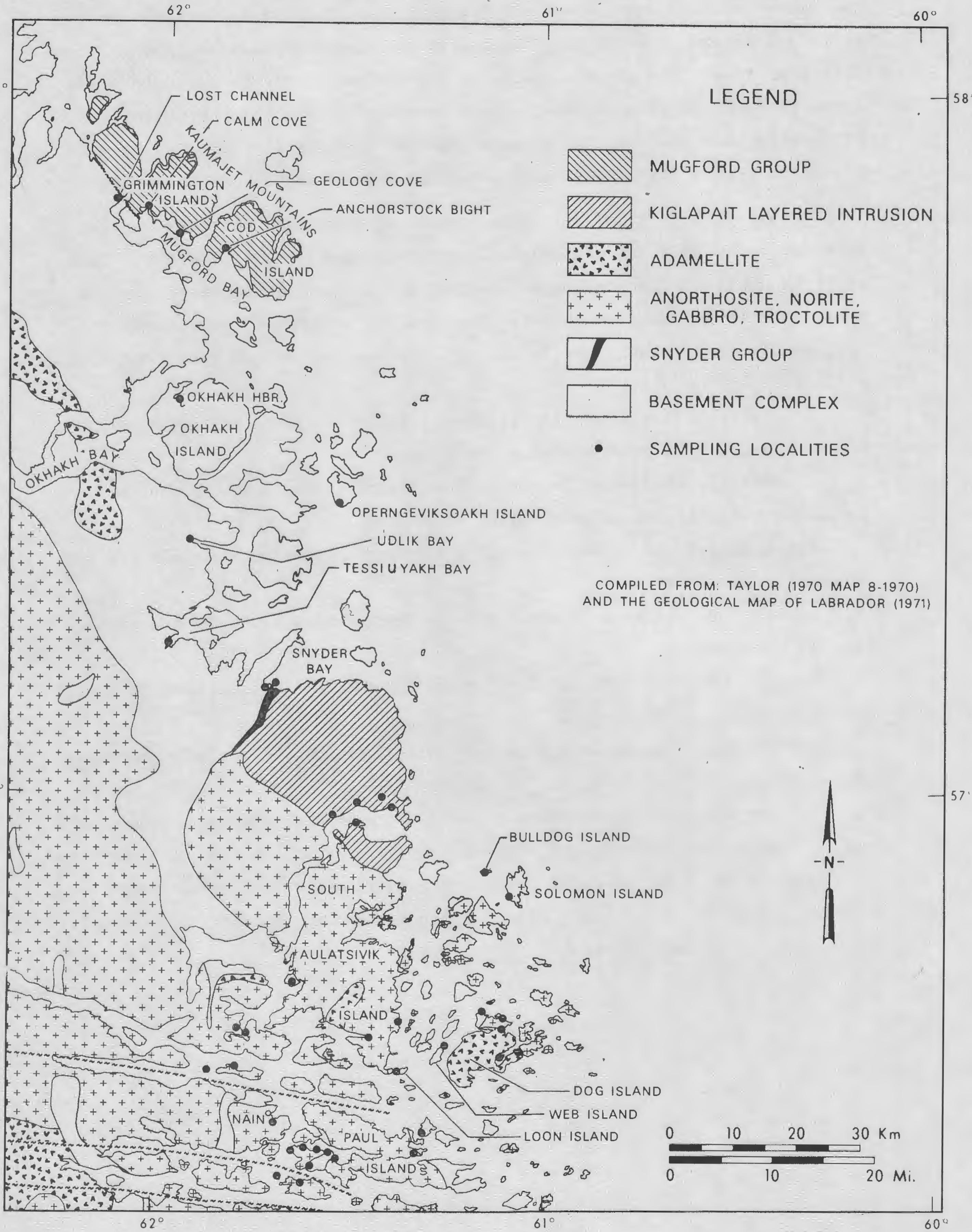

Fig. 3. Geologic sketch map of the Labrador Coast from Nain to the Mugford area, showing sampling sites for isotopic studies.

GEOLOGIC SETTING

SAMPLING FOR Rb-Sr and K-Ar ISOTOPIC STUDIES IN THE REGION OF THE LABRADOR COAST FROM PAUL ISLAND TO THE KHAUMAYÄT MOUNTAINS: 1971 AND 1972 SEASONS

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Introduction

During the 1971 and the 1972 field seasons of the Nain Anorthosite Project, a total of 259 samples were collected for Rb-Sr and K-Ar isotopic analyses at U. de Montréal. These samples are from an area extending from Paul Island in the south to the Khaumayät Mountains in the north (Fig. 3). They represent every known major time-stratigraphic unit in the area from the basement complex to the younger rocks of the Snyder Group, the Nain anorthosite complex, the Kiglapait layered intrusion and the Mugford Group, as well as pegmatite bodies and diabase dikes and sills. The following report is an outline of the specific investigations that are currently being undertaken by the author with these samples.

The Basement Complex

The basement complex underlying most of this region is a sequence of migmatites, amphibolites, granitic gneisses and granites of possible Archean age (Taylor, 1970). They include the unit described by de Waard (Field Report 1971) as the Ford Harbour Formation. The migmatites that were examined consist of a complexly folded quartzofeldspathic mobilizate and an amphibole-rich restite. The migmatites occur as xenoliths with amphibole-rich reaction rims in both the granitic gneisses and the granites. The granitic gneisses appear to engulf the blocks of migmatites as well as blocks of amphibolite which may be recrystallized diabase dikes and sills. The fabric of the granitic gneisses is only slightly folded. Other undeformed granite bodies are often found engulfing xenoliths of migmatites, amphibolites and granitic gneisses.

These relationships suggest the following history for the basement complex in this area:

(A) The precursors of the migmatites were deposited on an unknown crust.

(B) These rocks were migmatized.

(C) The migmatites were intruded by dikes and sills of diabase.

(D) The migmatites and the diabase dikes and sills were intruded by granites.

(E) These granites were metamorphosed into granitic gneisses.

(F) The granitic gneisses were intruded by other granites.

One hundred and five samples of the various rock types comprising the basement complex were collected at the following localities:

(A) Hayes Point on Dog Island

(B) Web Island

(C) Loon Island

(D) Snyder Bay

(E) Tessiuyakh Bay

(F) Lost Channel of Mugford Bay

(G) Calm Cove on Grimmington Island

(H) Geology Cove on Grimmington Island

(I) Anchorstock Bight on Cod Island

(J) Operngeviksoakh Island

(K) Udlik Bay

(L) Okhakh Harbour on Okhakh Island

(M) Bulldog Island

(N) Challenger Cove on Aulatsivik (Newark) Island

Rb-Sr and K-Ar isotopic studies are currently underway to determine:

(A) the absolute chronology of the events affecting the basement complex,

(B) the initial $^{87}Sr/^{86}Sr$ isotopic ratios of the rock units comprising the basement complex,

(C) the correlation of these rocks and their histories to those in western Greenland, and

(D) the effect of the emplacement of the Nain anorthosite complex and the Kiglapait layered intrusion on the strontium isotopic ratios within the basement complex.

Geochemical studies are planned to investigate:

(A) the original nature of the precursors of the migmatites, and

(B) the possible correlation of the compositions of the granitic gneisses and granites with age.

The Snyder Group

Unconformably overlying the basement complex and preserved along the northwestern margin of the Kiglapait layered intrusion is the Snyder Group, described by Speer elsewhere in this report. It consists of an interlayered sequence of metasedimentary rocks intruded by dikes and sills of gray breccia apparently of igneous origin. The metamorphism and deformation of the Snyder Group appear to have occurred as part of a single event (emplacement of the Kiglapait intrusion), suggesting that the Group was deposited after the basement complex had been migmatized and intruded by granites (see Speer, this report). K-Ar ages on these rocks are regarded as cooling ages which may be related to uplift past the 250 ± 50°C isotherm, and hence may be appreciably younger than primary crystallization ages.

Preliminary K-Ar analyses of hornblende from the gray gneissic dikes and sills, and of biotite from the paragneisses of the Snyder Group itself, demonstrate that the K-Ar ages become older away from the Kiglapait layered intrusion. This is consistent with the field interpretation that the Snyder Group is in the contact metamorphic aureole of the Kiglapait intrusion and it implies that the Kiglapait intrusion had cooled by about 1245 m.y. ago.

Ten samples of the gray breccia dikes and sills were collected on the edge of Snyder Bay and on Snyder Island. Rb-Sr analyses of these samples should define the time of intrusion of the dikes and sills. This time will be a minimum age for the deposition of the Snyder Group and by comparing it with the ages of deformation of the basement complex, it should be possible to establish an interval of time within which the Snyder Group was deposited. It will then be possible to compare the time of deposition of the Snyder Group with those of other metasedimentary sequences, such as the Aillik, Ramah, and Seal Lake Groups in Labrador, and the Gardar Group in Greenland.

The Nain Anorthosite Complex

Intruding the basement complex and probably the Snyder Group is the Nain anorthosite complex. Seventy-one samples were collected from this complex (mostly on Paul Island and on Dog Island) representing all of the rock-types present from troctolite, gabbro, diorite, norite and anorthosite to adamellite and granophyre. From these samples, it is hoped it will be possible to determine:

(A) a catalogue of the initial $^{87}Sr/^{86}Sr$ ratios of all of the rock types in the complex,

(B) the age or ages of crystallization of the complex for purposes of time-stratigraphic correlation,

(C) a series of constraints with which to evaluate the interrelationships of these rock types,

(D) the variation of initial $^{87}Sr/^{86}Sr$ ratios in plagioclase with anorthite content,

(E) the variation of initial $^{87}Sr/^{86}Sr$ ratios in orthopyroxene as a function of enstatite content, and

(F) the variation of initial $^{87}Sr/^{86}Sr$ ratios in plagioclase with the iron oxide/titanium oxide content of the inclusions within the plagioclase.

Ultimately, it is hoped it will be possible to evaluate the possibility that deformed and partly recrystallized anorthosite complexes such as the Morin may be remobilized equivalents of undeformed complexes such as the Nain.

The Kiglapait Layered Intrusion

Intruded along the northern boundary of the Nain anorthosite complex and intruding the Snyder Group is the Kiglapait layered intrusion. Fifteen samples have been collected from this body, representing all the divisions of it from the Outer Border Zone to the Upper Border Zone (Morse, 1969). From these samples, it should be possible to evaluate:

(A) the genetic relationship between the Kiglapait intrusion and the Nain anorthosite complex,

(B) the degree of contamination (if any) experienced by the Kiglapait intrusion during crystallization, and

(C) the age of the intrusion.

Diabase Dikes and Sills

Intruding this region are numerous undeformed diabase dikes and sills, some of which contain megacrysts of feldspar up to 10 cm in length. These bodies as a first approximation form two sets, one striking approximately north-south and the other striking approximately east-west (see Upton, FR 1971, p. 66). Finely crystalline samples were collected from 28 of these bodies for K-Ar and Rb-Sr analyses. Preliminary results suggest:

(A) that a majority of the dikes and sills were emplaced about 1200 m.y. ago,

(B) that some dikes and sills were emplaced about 1380 m.y. ago and still others about 1615 m.y. ago, and

(C) that some dikes and sills of each of these ages were emplaced with north-south strikes while others were intruded with east-west strikes.

The dikes and sills emplaced about 1200 m.y. ago intrude the Nain anorthosite complex and may have resulted from regional relaxation following the emplacement of this complex. At this point, however, no correlation has been established between the 1380 and 1615 m.y. bodies and specific tectonic events.

No dikes or sills have been recognized that can easily be correlated with the postulated rifting resulting in the separation of Greenland from Labrador, but the search for these is continuing.

Manvers Granite

The Mugford Group is a series of flood basalts intercalated with sedimentary rocks and exposed in the Kaumajet Mountains (e.g. Kranck, 1939; Christie, 1952). It rests unconformably on a basement complex of supposed Archean age. A single K-Ar age measured on a whole-rock sample from a lava flow indicates that the Mugford Group was formed about 948 ± 90 m.y. ago (Wanless et al., 1966, Sample: G.S.C. 64-163). Sixteen samples were collected from four lava flows within the Mugford Group, and three samples were collected from dikes that intrude the basement complex and that apparently fed the flows. It is hoped that Rb-Sr and K-Ar analyses of these rocks will yield:

(A) a clearer definition of the age of the lavas, and

(B) an initial $^{87}Sr/^{86}Sr$ ratio for them.

Geochemical analyses of these samples are underway to determine whether there is any chemical variation in the compositions of the lavas from the bottom of the sequence toward the top or from the bottom to the top of an individual flow. Major and minor element chemistry may also serve to characterize these lavas in terms of modern ridge or arc-trench affinities.

SEARCH FOR ANCIENT ROCKS IN COASTAL LABRADOR

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Introduction

As a consequence of the great increase in our understanding of the early history of the solar system resulting from the study of meteorites and of the moon, together with the new insights into terrestrial processes resulting from plate tectonics, it is now appropriate to direct attention to geological processes occurring in the earliest phases of earth history, and to attempt to relate these to recent tectonic processes.

Black et al. (1971) reported ages of 3900 m.y. for gneisses in the Godthaab area of Greenland. This suggested the possibility that similar high ages may be found on the coast of Labrador. The study of rocks with such high ages is important in understanding the early thermal history of the earth, as it is now evident that the moon underwent a major period of igneous differentiation within the first 100 m.y. of its formation. It is difficult to construct a planetological model in which the early thermal history of the earth involved temperatures lower than that of the moon.

Our plan is to carry out detailed geochronological studies on the gneisses north of Nain. The work will consist of Rb-Sr measurements on whole rocks and mineral separates, U-Th-Pb measurements on zircons and other uranium-bearing minerals such as sphene and apatite, and isotope dilution analyses of potassium, together with necessary petrographic examination. Isotope dilution work on Ba and the rare earth elements may be done if time permits. Such studies as these will help to clarify the very poorly known stratigraphy and metamorphic history of the Archaean belt of coastal Labrador, and they will provide a geochemical signature for the evolution of continental crust in this area. The possibility of finding very ancient rocks warrants a sustained and systematic program of investigation.

Sampling Program

Because of uncertainties in the exact correlation of Greenland and

Labrador Archaean rocks, our intention was to collect Archaean rocks from as many coastal sites as possible. The use of R.V. Pitsiulak as a base rather than camping on shore made the problem of being stranded on shore if a sudden storm appeared (not uncommon in Labrador) less disastrous to the mission, as well as making sampling more efficient. Sampling was done in cooperation with J. M. Barton, whose map (Fig. 3) in this report will serve as reference for the locations mentioned below.

The Archaean rocks along the coast of Labrador are primarily granites and amphibolite facies gneisses with mafic inclusions. K-Ar ages in the Archaean rocks have yielded ages from 2 to 2.7 Gy* (summarized in Taylor, 1970). It is possible that these are metamorphic ages, not primary crystallization ages, and that the rocks are older than the 2.6-2.7 Gy Superior Province of the Precambrian shield of Canada, exposed west of the Labrador Trough.

In the Tessiuyakh Bay area we collected 45 kg. from six locations. A K-Ar age of 2.36 Gy has been reported from this area. The basement rocks were typical of the Archaean in this part of Labrador, i.e. granites, gneisses, and occasional mafic inclusions, as well as ultramafic lenses.

Similar basement outcrops were sampled in Lost Channel, Grimmington Island, and Anchorstock Bight. In addition to basement rocks, dike samples were taken in order to study post-basement events in the area. Over 200 kg of samples were taken from 10 sites.

Calm Cove provided shelter while a three day storm passed through the area. When we were able to go ashore, we made field observations of the Proterozoic Mugford Group, a series of lava flows, locally vesicular, with numerous chert clasts. The Mugford Group is in fault contact with the basement. Ten kg of rocks were collected from one site in the basement.

Thirty kg of rocks were taken from three localities on Okhakh Island. The basement on Okhakh Island is more complex than in other areas since younger granitic rocks and mafic dikes intrude the basement. Granitic intrusions (as opposed to migmatite component) are not present in the other areas sampled.

The last collecting site was Operngeviksoakh (Lady Bight) Island. The island is composed of a pink granite which is surrounded by a granodioritic rock. Fragments of basement gneisses are found in the pink granite. Samples of both rock types were collected. Twenty-five kg of samples were taken from four sites.

*Gy = Gigayear = 10^9 yr.

Our group was unable to sample farther north than the Lost Channel area due to pack ice which blocked the northern passage through Mugford Tickle. Hence the intended sampling at the more northern sites of Saglekh Fjord, Rifle Bay, and Reddick Bight had to be excluded from this trip.

Acknowledgement

This field work has been supported in part by NSF Grant GA-12701 to G. W. Wetherill.

STRATIGRAPHY, STRUCTURE, AND METAMORPHISM OF THE SNYDER GROUP

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Contents

Introduction

Wheeler (1942) first reported a group of metasedimentary rocks adjacent to the anorthositic rocks (Kiglapait intrusion) at the west end of the Kiglapait Mountains. Because of the well-preserved nature of the sedimentary features, the open folding of the group, and the lack of intruded igneous rocks, Wheeler suggested that these rocks were distinctly younger than the other gneisses of the region (Tikkegharsuk migmatites and the Ford Harbour Fm.). These metasediments were termed the Kiglapait Group by Morse (1961) but were subsequently renamed the Snyder Group (Morse, 1969).

A field study of the Snyder Group was undertaken in order to examine mineral assemblages and changes of chemical composition of minerals with progressive metamorphism. This part of the investigation involves the lithology, structure, and grade of metamorphism of the Snyder Group, and

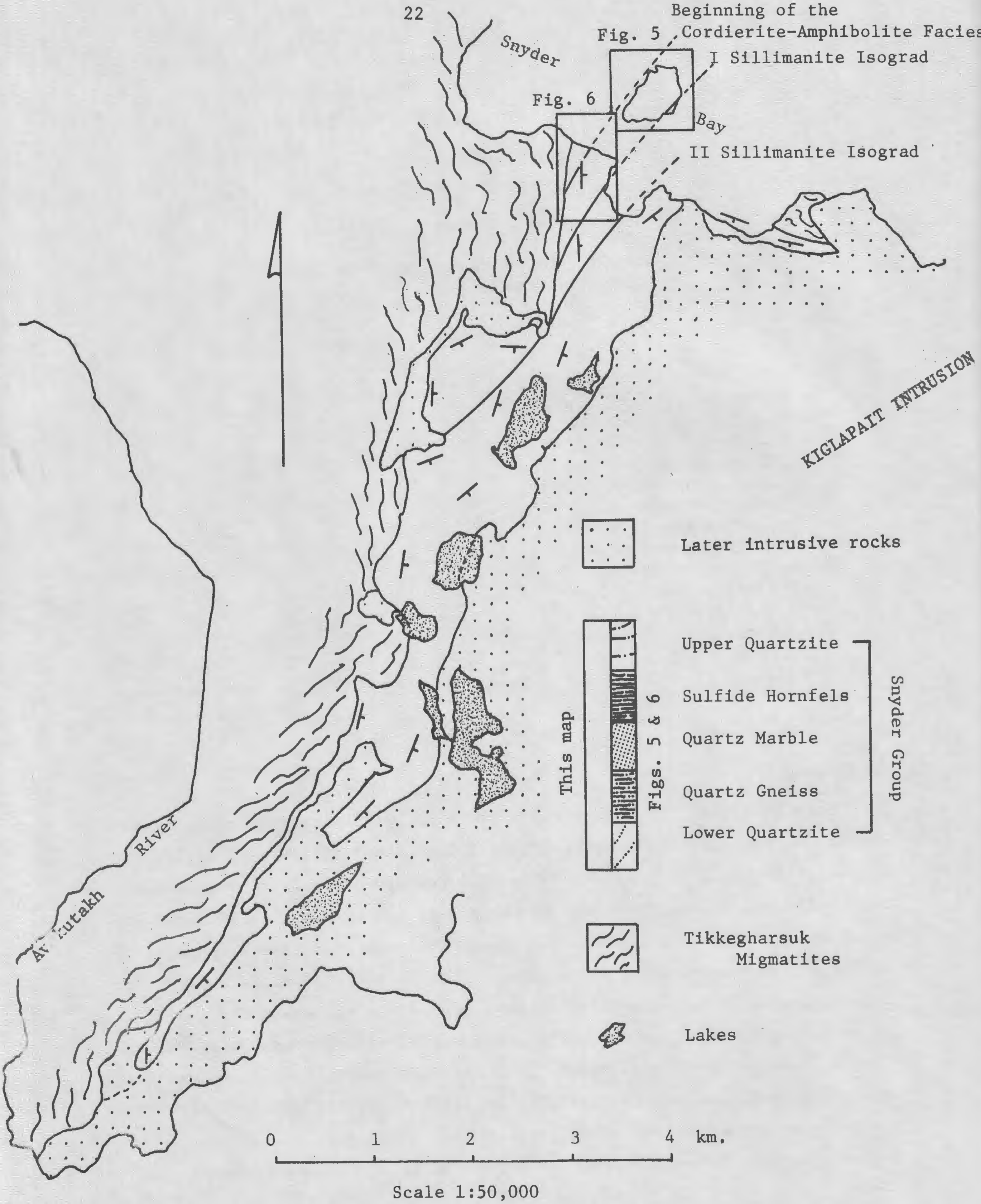

Figure 4. Generalized geology of the area underlain by the Snyder Group between Snyder Bay and the Avakutakh River.

the effect of later intrusives as far as they could be determined in the field. Systematic sampling of the Snyder Group and later intrusive rocks was carried out for laboratory study. The general geology of the area is shown in Fig. 4. Geologic sketch maps of the more accessible areas underlain by the Snyder Group are shown in Figs. 5 and 6 for the convenience of later visitors.

Country Rocks

The country rocks adjacent to the Snyder Group generally consist of biotite and amphibole gneisses of granitic to tonalitic composition with minor amounts of amphibolite and alpine ultramafics. Termed Tikkegharsuk migmatites by Morse (1969) they may be equivalent to the Ford Harbour Formation described by de Waard (FR 1971). The pre-Snyder Group history of the country rocks consisted of deformational and metamorphic events leading to the development of granitic rocks of anatectic origin. They were uplifted and eroded to form an erosional surface on which the Snyder Group was deposited. Subsequently they were subjected to the same deformation and metamorphism as the Snyder Group in the vicinity of the Kiglapait intrusion.

Stratigraphy

Morse (1961, 1969) reported four lithologic units and various mineral assemblages which he assigned to the hornblende hornfels and pyroxene hornfels facies. During the past field season, five units within the Snyder Group have been recognized, as described below.

Lower Quartzite unit. The oldest unit of the Snyder Group consists of interbedded quartzites, conglomerates, and aluminous gneisses with a thin bed of conglomerate overlying the angular unconformity at the top of the Tikkegharsuk migmatites. The lower contact has previously been described by Morse (1969; FR 1971, p. 67). The basal conglomerate is relatively thin (1-3 cm), consisting of quartz pebbles up to 15 cm long in a dark matrix of quartz, biotite and/or chlorite. The quartzites range from a white orthoquartzite to a feldspathic quartzite commonly spotted by 1-cm diameter concentrations of andalusite, micas, chlorite, and/or cordierite. Green quartzites occur, colored by chlorite or amphibole. Where andalusite is unstable, clusters of sillimanite occur. Locally, bands or veins of the stable aluminum silicate polymorph occur. Grain size varies from that of

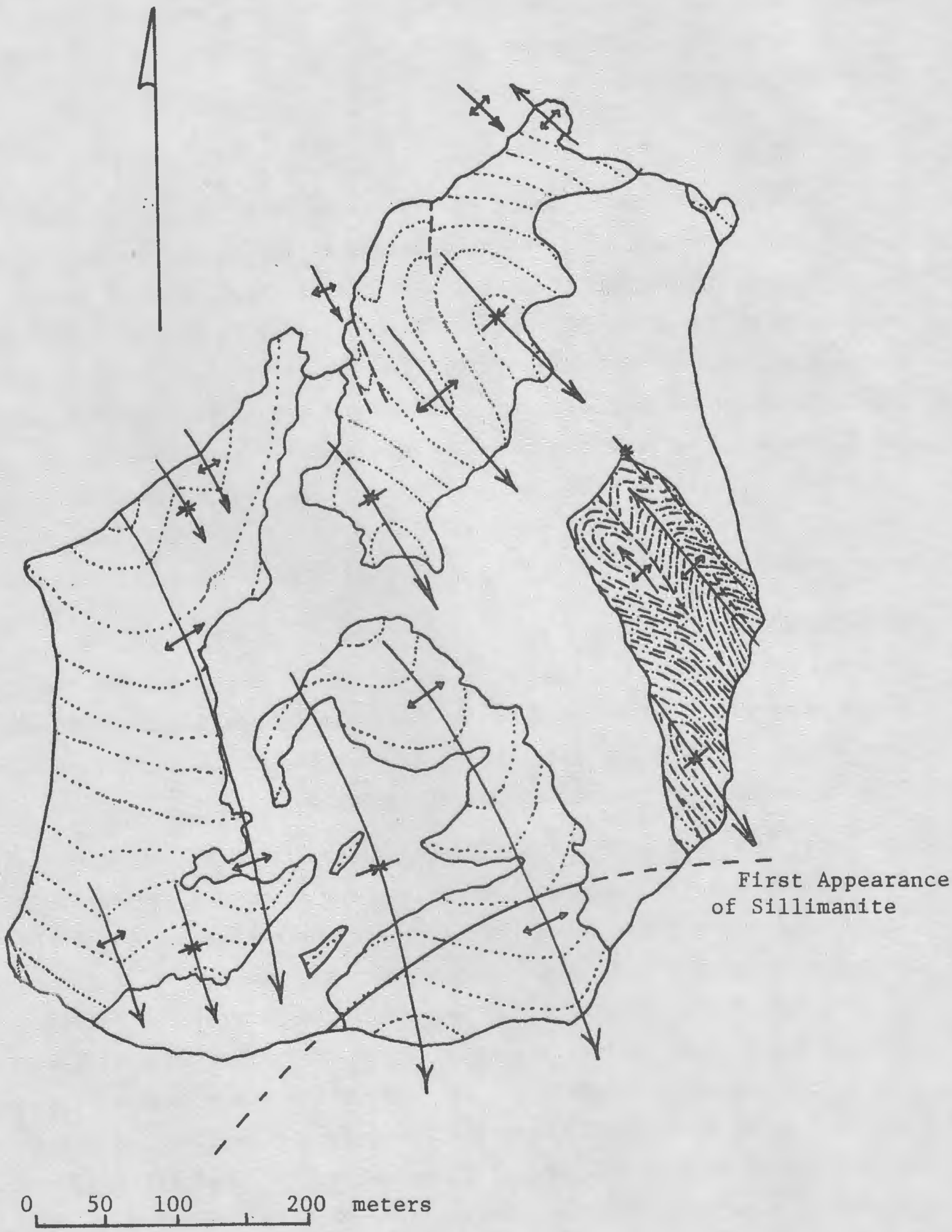

Figure 5. Geologic sketch map of Snyder Island. The rock unit symbols are the same as in Figure 4.

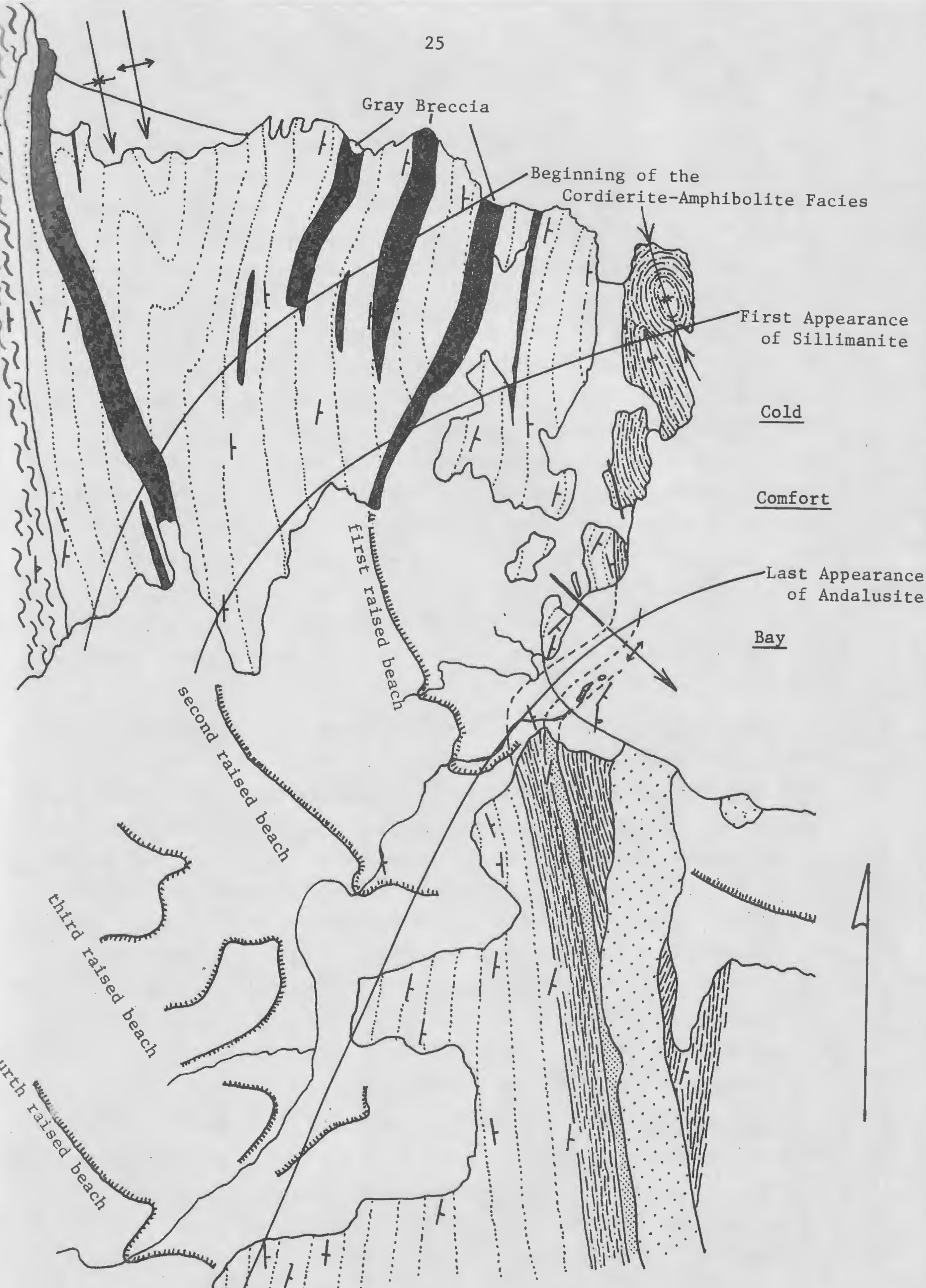

Figure 6. Geologic sketch map of the mainland adjacent to Snyder Island. The rock units and scale are the same as those in Figure 5.

coarse- to fine-grained sand. Well-defined sedimentary structures such as festoon crossbedding, graded bedding, and ripple marks are common. Near fault zones, the quartzites are recrystallized into massive white quartz with the concomitant disappearance of other minerals and the loss of structural features. Besides forming the basal unit, conglomerates also occur at stratigraphically higher levels in the Lower Quartzite unit. The conglomerates are of two types: quartz pebbles with a finer matrix of originally coarse sand, and quartz pebbles in a dark matrix of quartz + micas + chlorite + Al_2SiO_5 polymorph ± garnet. Graded bedding is common and shows tops toward the east on the mainland and southeast on Snyder Island. Modal variation in the quartzites gives rise to the aluminous gneisses, rich in Al_2SiO_5 polymorphs, K-feldspar, micas, and/or cordierite. They are distinguished in the field by their pink to gray color, prominent slaty cleavage, and ease of weathering. They commonly contain fine-grained, cross-bedded quartzite lenses. Rocks of the Lower Quartzite unit are the most prevalent of the Snyder Group outcrop area. They represent a thickness of about 110 meters cropping out from the Avakutakh River to Cold Comfort Bay and on the greater part of Snyder Island.

Quartz Gneiss unit. The Quartz Gneiss unit is a distinctive 10-meter thick, brown unit lying stratigraphically on top of the Lower Quartzite unit. It is thinly bedded (5-15 cm), consisting of alternating quartz, quartz-amphibole-garnet, quartz-cordierite, and quartz-hypersthene layers. Convincing examples of soft-sediment deformation are present both on Snyder Island and on the mainland; if misconstrued as metamorphic deformation structures these features would give an impression of metamorphic deformation inconsistent with that seen in surrounding rocks. Outcrops of Quartz Gneiss near the border of the Kiglapait intrusion (west of Wendy Bay) show tectonic deformational effects in the form of rotated boudins. Some thicker quartzite beds within the unit have been recognized, along with amphibole-garnet pods and lime-rich layers toward the top of the unit.

Quartz Marble unit. The next youngest unit consists of quartzites interbedded with marble and calc-silicate rocks. Laterally the unit may range from beds of marble up to one meter thick with thin layers of quartzite to nearly pure quartzite with pods of marble or calc-silicate minerals. It is characterized in the field by the much lower resistance of the marble and calc-silicate minerals, leaving a quartzite outcrop with large irregular cavities. The unit is estimated to be 8 meters thick on the measured section although it appears to vary laterally.

Sulfide Hornfels unit. Within the last 2 meters of the Quartz Marble unit are interbedded lenses of a graphite-bearing hornfels which grade upward into a massive sulfide-bearing unit designated as the Sulfide Hornfels unit. This is apparently identical with the graphite-bearing beds mentioned by Wheeler (1942). Numerous quartzite layers (2-3 cm thick) occur within the unit and define bedding. Sillimanite and cordierite porphyroblasts occur wherever the appropriate bulk rock composition is present. The Sulfide Hornfels unit attains its greatest thickness (about 12 meters) on the hill south of Cold Comfort Bay; however, its actual thickness is obscured by the presence of large dikes in that area. This unit and the next younger Upper Quartzite unit both develop thin gossans where weathering permits.

Upper Quartzite unit. This little-understood unit occurs above the Sulfide Hornfels unit and ends at the margin of the Kiglapait intrusion. Its areal extent is limited to the hill east of Cold Comfort Bay where it is heavily intruded by later dikes. Consisting mainly of quartzites with some beds of hornfels, it is extensively mineralized, chiefly with pyrite, pyrrhotite, and minor chalcopyrite. The mineralization is apparently associated with one of the later intrusive bodies.

Later Intrusive Rocks

Numerous post-depositional intrusive rocks are recognized and are classified as either pre-deformational or post-deformational intrusive rocks.

Pre-deformational Intrusive Rocks. The problematical gray breccia of Morse (1969) appears to represent sill-like injections into a sedimentary pile. It was noted that the gray breccia: 1) intrudes and crosscuts both the Tikkegharsuk migmatites and the Snyder Group, 2) contains numerous rounded xenoliths of the Tikkegharsuk migmatites but no Snyder Group xenoliths, 3) participated in the deformation, showing development of a gneissic fabric toward the south, 4) participated in the metamorphism with the apparent attainment of stable metamorphic assemblages, and 5) is limited in extent to Snyder Island and the adjacent mainland. Outcrops of gray breccia have been found on the mainland shore northwest of Snyder Island (not shown in Fig. 4) as well as on the shore to the south of the island (Fig. 6).

Other pre-deformational intrusive rocks include highly deformed diabase dikes and sheared garnet-bearing dikes on Snyder Island. These sheared dikes contain veinlets of wollastonite + diopside ± quartz ± calcite ± garnet ± sphene.

Post-deformational Intrusive Rocks. Included here are the Kiglapait intrusion and associated dikes and sills of its Outer Border Zone. Numerous minor intrusive rocks, such as the Wendy Bay granodiorite, occur at the margin of the Kiglapait intrusion from Cold Comfort Bay southward for a distance of 4 km. Spatially associated with these marginal granitic intrusive rocks is a mineralization affecting the various units of the Snyder Group. Other post-deformational intrusive rocks are a group of NW-SE trending diabase dikes and several andalusite or andalusite-cordierite bearing granitic dikes, which crop out on Snyder Island.

Metamorphism

While a detailed statement on metamorphic mineral assemblages awaits a laboratory study, the following succession of mineral assemblages could be distinguished in the quartzites and aluminous gneisses:

andalusite-chlorite-muscovite-biotite-K feldspar-quartz
andalusite-cordierite-muscovite-garnet-biotite-K feldspar-quartz
sillimanite-cordierite-muscovite-garnet-biotite-K feldspar-quartz
sillimanite-cordierite-K feldspar-garnet-biotite-quartz

This sequence represents a facies series of a deep-seated "contact" metamorphism which possesses a mineralogical identity with the Abukuma type of regional metamorphism (Miyashiro, 1961, and Winkler, 1967). A greenschist and cordierite-amphibolite facies are recognized, the boundary being marked by the disappearance of chlorite + quartz and the appearance of cordierite. Characteristic of Abukuma type metamorphism is the sequence andalusite-sillimanite. This suggests that the operative pressure must have been lower than 5 kb (Richardson *et al.*, 1969). The coexistence of garnet with cordierite suggests a possible higher grade of metamorphism within the cordierite-amphibolite facies and the possibility of establishing the pressure range more accurately.

The heat source for the metamorphism of the Snyder Group is thought to be the Kiglapait intrusion. The possibility of the Wendy Bay granodiorite as a heat source is less favorable because of its limited extent and its proposed origin as an anatectic melt "generated by the heat of the crystallizing Kiglapait intrusion" (Morse, 1969). Tentative isograds are drawn in the accompanying figures and are compatible with metamorphic zoning around the Kiglapait intrusion. It is expected that detailed examination of the mineral assemblages will confirm these isograds, establish the existence of an additional high-temperature regime characterized by the presence of an orthopyroxene, permit a more accurate determination of P, T and fluid conditions, and allow a better characterization of the original sediments.

Structure

In general, the Snyder Group is a border fragment around part of the Kiglapait intrusion in the form of a syncline plunging to the southeast with its core occupied by the intrusion. The western limb of the fold is elongate, with the entire Snyder Group section eventually being cut off by the Kiglapait intrusion in the vicinity of the Avakutakh River. The eastern limb of the fold is short due to faulting against the basement and crosscutting by the Wendy Bay granodiorite. Small, upright, open folds within the syncline plunge gently parallel to the major fold axis. These small folds cause irregularities in the syncline, especially on Snyder Island. Except for the faults cutting the eastern limb of the fold, all faults observed in the Snyder Group have negligible displacements, being merely breaking of the competent quartzite beds.

Summary

The Snyder Group represents a thin, clastic sedimentary sequence which has undergone deformation and metamorphism as the result of the emplacement of the Kiglapait intrusion. There is only one cycle of deformation evident, which was complete before the final establishment of the thermal gradient. Observed mineral assemblages suggest a high-temperature, low-pressure environment similar to that of Abukuma type metamorphism. The distribution of isograds parallel to the Kiglapait intrusion suggest the latter as the heat source. The Snyder Group affords a glimpse of the Proterozoic history of the area and permits interpretation of conditions in the country rock during the emplacement of the Nain anorthosite-Kiglapait intrusion sequence.

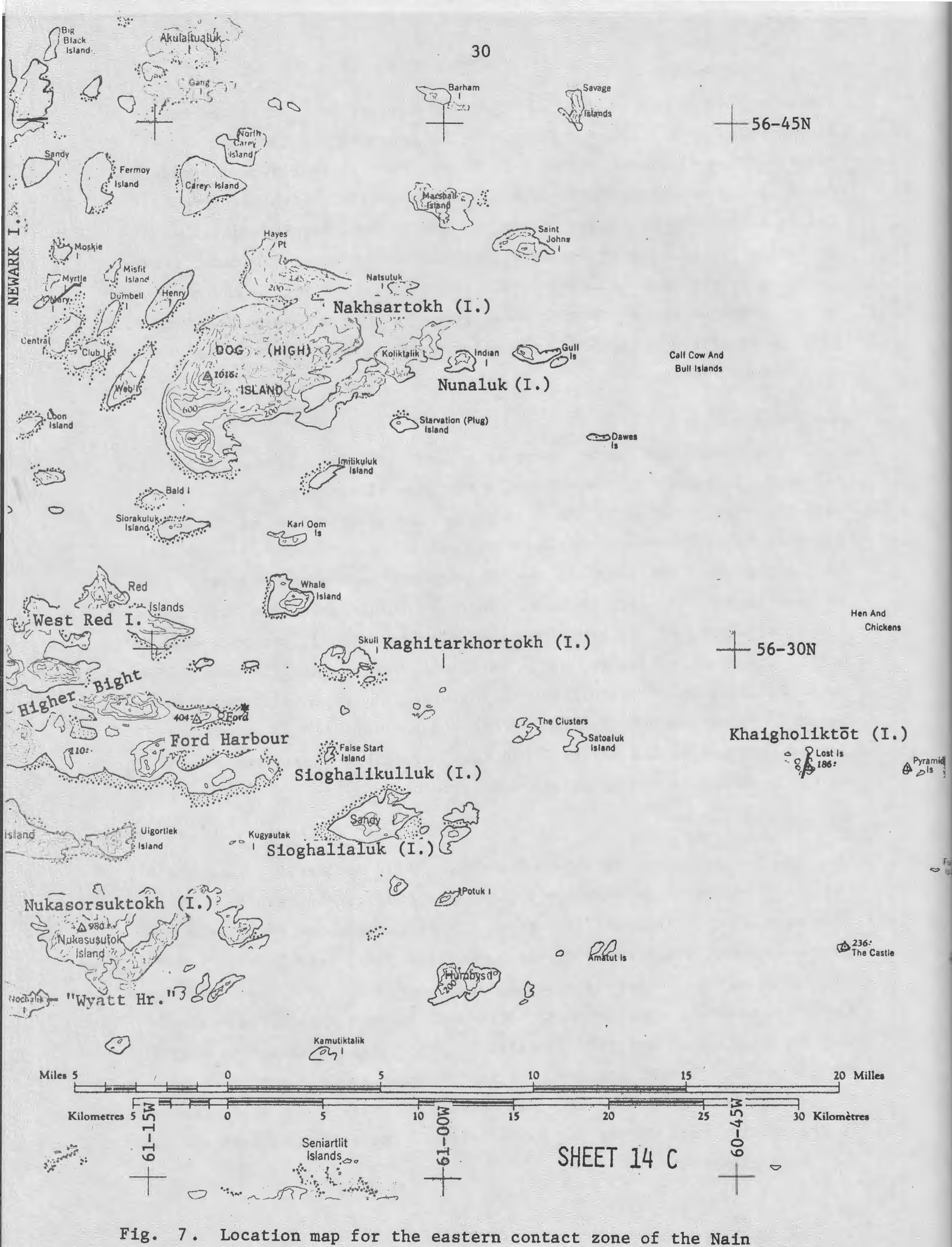

Fig. 7. Location map for the eastern contact zone of the Nain Anorthosite. Black I. is in the upper left corner, and The Castle is in the lower right. Typed names follow the spelling of Wheeler (1953).

EASTERN CONTACT ZONE

ANORTHOSITE FIELD RELATIONS IN THE OUTER ISLANDS

E. P. Wheeler, 2nd

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Introduction

The mobility of R.V. Pitsiulak facilitated undertaking a number of small operations in widely scattered areas where the general geologic mapping was particularly weak. This report and the two which follow (p. 65 and 81) concern the results of the new mapping. A generous amount of time was allocated to visiting the outer islands early in the season while pack ice kept the surf at a minimum, and to visiting more sheltered islands later in the season.

A short plane charter gave access to the country inside Annakhtalak Bay (56-26 N, 62-19 W), and help from the vessel eased portaging back to the bay. Logistical support allowed the mapping to be extended around the bay head (see p. 65).

Special late-summer trips to Zoar Peninsula (56-08 N, 61-22 W) permitted work on the anorthosite-adamellite boundary there (see p. 81).

In many of these areas, material was collected to continue last year's study of giant pyroxenes in anorthosite (FR 1971, p. 66; this report p. 91).

Island Zone

Previous work among the outer islands in the Nain region (Fig. 7) was limited by difficulty of access and difficult living conditions on them. This season's more detailed work indicates the need to change earlier assumptions, as might be expected, and reveals a number of particularly interesting features. In summary, the areas of anorthositic rocks and of basement complex have been increased with a corresponding decrease in the area of adamellitic rocks, as may be seen by comparing Fig. 8 of this report with Fig. 1 of last year's Field Report (1971, p. 8).

Southeastern Section. Anorthosite occurs as far east as pack ice permitted us to go (Pyramid I., 56-27 N, 60-36 W). Here and 9 km farther south the anorthosite is dark-facies. Westward, at Lost Islands (56-26 N, CAPTION

Fig. 8. General geologic sketch map of the Newark Island - Dog Island region of the Nain Anorthosite Complex. Legend: 1. Basement Complex, Ford Harbour Formation; 2. Anorthositic rocks; 3. Adamellitic and granitic rocks; 4. Gabbroic, noritic and troctolitic rocks. Dashed lines indicate approximate boundaries between rock groups; dash-dot lines represent prominent linears.

Solomon I.
David I.
KM
5
10
N
Black I.
NEWARK I.
Sioghalialuk I.
56°
45'
St. Johns I.
Chronicle I.
DOG I.
Ermngittokh I.
61° 30'
61° 00'

60-41 W), contorted basement granulite[1] with transgressive granitic material was encountered. West of that (56-26 N, 60-49 W), pale-facies anorthosite appears, and continues through most of the nearby islands.

On The Castle (56-22 N, 60-40 W), what may be a small basin of dioritic layered rock occurs. A complex agmatite of dark anorthosite blocks in layered rock forms the west shore of the island. Some blocks contain brown plagioclase, possibly signifying partial oxidation of opaque rod inclusions to hematite. Layering appears to dip gently towards the center of the island east and west of the summit, and the summit may be mafic basement granulite. This structure should repay a day or so of detailed mapping and collecting. However, the island is largely inhospitable bare rock that has been swept clean by higher the ocean. A shore party would have to supply their own fuel and water.

Northwest Section. In the Black Islands area (56-46 N, 61-21 W) the rock is dark enough to be classed as dark-facies anorthosite, but is generally too fine grained and high mafic to be readily acceptable as anorthosite. It contains olivine in many places, and may be troctolite locally. On the islet 3.8 km east of the houses at Black Islands and the first major island east of south from that, inclusions of pale anorthosite occur in this olivine-bearing rock, and a contact between pale anorthosite and the younger gabbro-troctolite crosses the southwest end of the islet.

On the islet close southwest of the contact islet, snowflake texture is so striking when brought out by hydrothermal bleaching that it deserves special mention, though its significance has yet to be determined. The unaltered rock is a snowflake troctolite containing abundant 2-cm laths of plagioclase, many of which form 2-4 cm orbicules of radiating laths with interstitial olivine. The texture is a smaller scale and more strongly orbicular variety of the snowflake texture described by Berg elsewhere in this report.

On Newark Island east shore headlands, 2.8 km and 4.8 km southward from the Black Islands houses, the anorthositic gabbro-troctolite becomes finer grained as the contact with basement granulite is approached, and the texture changes from subophitic to equant-granular. In the contact

[1]Presumably equivalent to the Ford Harbour Formation of de Waard; the non-interpretive epithet "basement granulite" is preferred here in view of the isolated occurrences under discussion.

zone on both headlands there is a well-developed agmatite of basement fragments in the marginal gabbro-troctolite. At the southern headland, cordierite is well-developed in the basement rock, indicating derivation from aluminous sediments. Farther from the contact, the basement rock is much more granitic, and layering becomes less distinct. At this headland, the view from shore indicates the basement rock is only a skin on the face of the shore hill.

On Sioghalialuk Island, close southeast of the contact zone just described, much of the basement rock is so granitic and lacking in layering that it was mistaken for adamellite in the past. However, a traverse across the island reveals local layering which grades from obscure to prominent in some places, and at least one major amphibolite zone.

Ermngittokh Island off the southeast tip of Newark Island (56-36 N, 61-22 W) is also a granite complex, but here a well-developed agmatite of sharp, blocky basement-complex fragments occurs in the granite.

Discussion

Finding anorthosite on the most easterly islands visited suggests that it may extend to the edge of the continental shelf in the Nain area. This would be in keeping with the hypothesis that Greenland and Scandinavia, regions where anorthosite occurs in western coastal areas, have been separated from Labrador by continental drift. Further investigations among the outer islands should be carried out with this hypothesis in mind.

Gabbroic rocks of the Black Islands area may belong to a separate intrusion unrelated to dark anorthosite, which they resemble. The following argument is offered in support of this conclusion. The separation of the dark and pale facies of anorthosite by basement granulite, as west of Pyramid Island, is so common that it is the expected relationship. Thus when granulite is found separating a lobe of the dark anorthositic gabbro-troctolite body east of Black Islands instead of lying along the nearby contact between the gabbro and pale anorthosite, correlation of the gabbro with dark anorthosite becomes suspect. Such definite intrusive relations between dark and pale anorthosite as appear to occur east of Black Islands are not known elsewhere in the Nain anorthosite complex, though this evidence loses some significance because block structure and other evidences of autointrusion are so prevalent in anorthosite. In general, anorthosite and adjacent basement rocks have conformable structures, suggesting that the anorthosite has reached its present site by processes involving plastic deformation. Hence the agmatite zones where the gabbro invades granulite southward from Black Islands is the strongest single piece of evidence justifying treatment of the gabbro as a separate intrusive rock unit, though the other features support this conclusion.

The granites of Sioghalialuk and Ermngittokh Islands are not the same, to judge from their relationship to the basement complex. Gradations between basement material and granite on Sioghalialuk justify provisional mapping of that granite with the basement complex. Perhaps it is a pre-anorthosite intrusion to be correlated with other granitic and pegmatitic portions of the basement. The sharp, angular blocks of basement material in the agmatite of the Ermngittokh granite indicates that this granite is younger, perhaps contemporaneous with the adamellite group, though not a typical member of the group. It is provisionally mapped with this group in Fig. 8 to avoid introducing a new rock unit of very limited extent.

CONTACT RELATIONSHIPS OF ADAMELLITIC INTRUSIONS ON DOG ISLAND

Dirk de Waard

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Introduction

Wheeler's (1968) general geologic map of the Nain region shows the presence of large adamellitic masses on Dog Island, about 30 km ENE of Nain, in contact with granulitic, anorthositic and dioritic country rock. Such relationships seemed well-suited for a research project on the contact relations and compositional variations of adamellitic bodies occurring in the Nain anorthosite complex.

Preliminary investigations show the presence of a small adamellite body in the northern part of the island, intruding anorthositic and granulitic country rock. The intrusion will be called here the Alagaiai[1] adamellite, after the high peak in its center. There is a much larger adamellite mass in the central and southern part of Dog Island, which is named here the Iviksuak[2] adamellite, after the southern peninsula of the island. General field relations are shown in Fig. 9.

The Iviksuak Adamellite

Only the northern contact of the Iviksuak body has so far been investigated. Contrary to our expectations there is no sharp contact between the adamellite and the anorthositic country rock. Instead there is a transitional zone where the adamellite grades via porphyry, fine-grained norite and medium-grained leuconorite into anorthosite. The adamellite is a green, fayalite-bearing rock with large, mesoperthitic, ovoidal feldspars in a medium-grained matrix. In the contact zone the ovoidal feld-

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[1] "The place of looking about", (Wheeler, 1953).

[2] "The very big beach grass", (Wheeler, 1953).

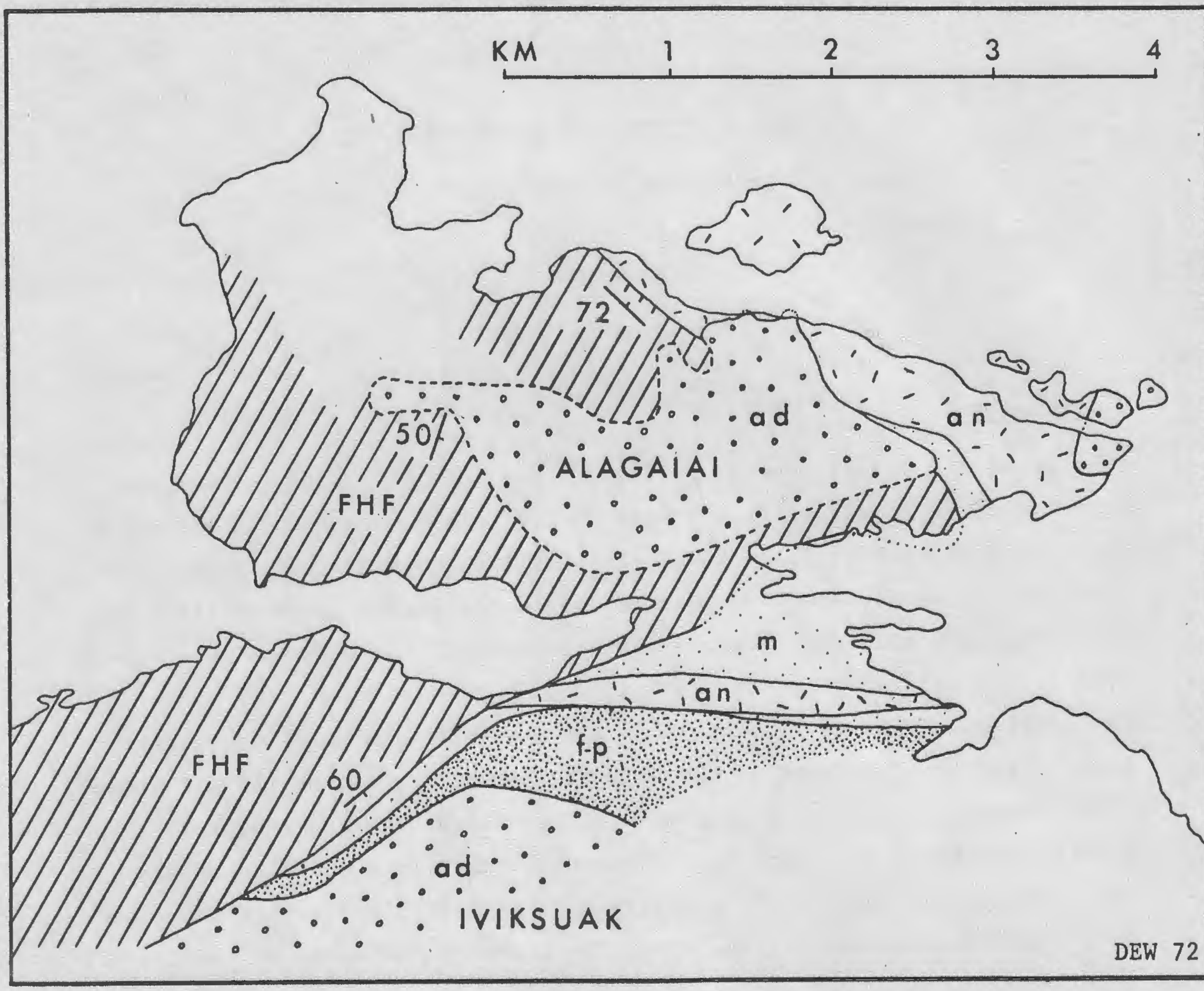

Fig. 9. Geologic sketch map of the northern part of Dog Island, showing the locations of the Alagaiai and Iviksuak adamellitic bodies. A third mass occurs on the northeastern peninsula. Legend: an, anorthosite; m, medium-grained leuconorite; f-p, fine-grained noritic and porphyritic rocks; ad, adamellitic rocks; FHF, country rock of layered enderbitic granulites and enderbitic gneisses of the Ford Harbour Formation.

spars are still there, but the groundmass has become finer. Further outward, the phenocrysts also diminish in size, and the rock is a porphyry with a granodioritic composition. Still further, the phenocrysts disappear, and the rock is a fine-grained norite which grades into medium-grained leuconorite and finally into anorthosite. There is a similarity in texture among these rocks: all show cumulus textures with euhedral plagioclase and interstitial quartz and both interstitial and exsolved K feldspar. They differ in the proportion between the cumulus and interstitial phases. The possible exception is the fine-grained norite which has a granular texture.

Except for the local development of veins of porphyritic rock in the fine-grained norite there is a general absence of intrusive relationships. There are no dikes or inclusions indicating a ductile versus rigid behavior among rock types; instead the adamellite and its country rock show almost equal structural mobility. The observations seem to indicate that the country rock was a crystal mush at the time that the adamellite was largely in a magmatic state.

There is nothing in the rocks of this transitional contact to indicate the orientation of the contact plane. The nearest oriented rock is the Ford Harbour Formation, the country rock of the anorthosite to the northwest, which dips 55° to 75° towards the anorthosite-adamellite sequence.

A tentative interpretation is that the sequence: anorthosite, medium to fine-grained norite, porphyry, adamellite, is part of a stratification which developed during crystallization-differentiation of the Nain anorthosite complex. Adamellitic magma was formed at the bottom of this sequence, and having the highest structural mobility and lowest density of all units, tended to invert the sequence. The adamellite appears here to have emerged with respect to the porphyry-norite-anorthosite series, which now forms a lateral contact zone. The Ford Harbour Formation, once overlying the sequence, became overturned in the process.

<u>The Alagaiai Adamellite</u>

The Alagaiai adamellite forms a small body which is in contact with anorthosite and rocks of the Ford Harbour Formation. As in the Iviksuak contact zone, there is a transition zone between the adamellite and anorthosite composed of finer grained and porphyritic rocks, but here this zone is considerably narrower and appears to be absent in places. Locally, there are also dikes and veins of adamellitic material occurring in the anorthosite, forming an agmatitic or reticulate structure. In other words, the transition zone, wherever present, reacted predominantly in a ductile manner to magmatically induced stresses, while the anorthosite, at least locally, reacted rigidly, and was fragmented and intruded.

The contact between the adamellite and the layered granulitic rocks of the Ford Harbour Formation is everywhere transgressive. The contact is sharply defined; there are abundant dikes of adamellite in the granulite, and numerous inclusions in all sizes of rocks of the Ford Harbour Formation in the adamellite. The Ford Harbour Formation was obviously the most rigid of all rock units in the area, as the adamellite was the most mobile.

Preliminary Conclusions

Observations on contact relations seem to indicate that the emerging Alagaiai mass reached a cooler environment and presumably a higher structural level in the Nain anorthosite complex than the Iviksuak adamellite. The Iviksuak mass was surrounded by a ductile transition zone which, at the higher levels of intrusion of the Alagaiai body, had thinned or was left behind. At the structural level of the Iviksuak mass the anorthosite was not intruded, but at higher levels the anorthosite apparently had consolidated sufficiently to react rigidly to stress in some places. The Alagaiai body also transgressed the bounds of the Nain anorthosite complex and penetrated the overlying country rock of the Ford Harbour Formation.

If the Alagaiai and Iviksuak adamellite sections represent two different levels of intrusion, a third and deeper section may be represented by the layered structure of Barth Island (q.v.). There, adamellitic rocks occur stretched and sheared in a narrow zone which is overlain (superseded outward) by medium-grained gabbroic and noritic rocks grading into anorthosite, i.e., a sequence which is similar to that at the contact of the Iviksuak adamellite. The adamellitic zone of the Barth structure is considered to represent the tail end of a residual magmatic mass which was formed at this level, but which was squeezed out and pierced through overlying units, possibly because of its lower density and high structural mobility. The higher levels of this mass may have resembled the Iviksuak and Alagaiai adamellite intrusions.

Appendix: Adamellitic Rocks of Dog Island

	qu	kf	pf	bi	hb	cp	op	&c	Johannsen:
Di-50-J	16.1	14.4	51.5	0.4	9.5	1.9	2.0	4.2	granodiorite
DI-68	34.3	17.7	43.3	0.2	3.7	-	-	0.8	granodiorite
DI-47-C	21.7	3.6	43.6	-	2.4	6.9	13.9	7.9	granodiorite

Table showing compositions of rocks from the 'adamellitic' bodies of Dog Island. Sample DI-68 is a gray rock from the center of the Alagaiai intrusion. DI-47-C is a dark-green rock from near the contact of the adamellite body on the eastern tip of the northern part of the island. DI-50-J is also dark green and comes from near the northern contact of the Iviksuak intrusion. All three appear to have a too low K-feldspar content to be called adamellite in Johannsen's system. The possible variation in rock composition within each of the bodies will be studied next summer.

NEWARK ISLAND LAYERED IGNEOUS COMPLEX

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Introduction

The southern end of Newark Island is underlain in the west by a mass of anorthosite-leuconorite and in the east by a layered group of rocks. Country rock is exposed on the east side of the island and on offshore islands in contact with both the anorthosite and the layered series rocks.

The layered group is of particular interest in that it consists of rocks varying from troctolite, interlayered with oxide-rich wehrlite in the eastern (basal) portion of the field area, to layered gabbro, norite, and mangerite, locally containing ovoidal feldspars and mesoperthite, in the western (upper) portion of the series, adjacent to the anorthosite-leuconorite mass.

Field mapping in the 1972 season extended the field area to the hills in the north, the eastern offshore islands, and as far west as Challenger Cove (Fig 10). Investigations indicate that the layered body is of great size. A discussion of the layered body follows a review of the lithologies found in the field area.

Basement Complex

The basement complex underlying the eastern portion of the field area is composed of granulite and migmatite. The granulites range from ultramafics to rocks of granitic and tonalitic composition. Locally one finds quartzite, rocks bearing garnet, and ultramafic pyroxene granulites containing pods of wollastonite and calcite. The variety of lithologies present suggests a metasedimentary or metavolcanic origin for the basement complex, which is believed to be the Ford Harbour Formation.

Near the contacts of the igneous body, the granulites are isoclinally folded on the scale of several meters, but are surprisingly unaffected by the intrusion of igneous material, locally concordant with the layering of the granulites. At a distance of several meters to 1/2 km from the contact, the rocks become increasingly contorted and migmatized. Granitic and tonalitic material is commonly found crosscutting older mafic granulites, and locally forms agmatite. The leucocratic, mobilized portion of the agmatite may locally be traced to granulite layers of this composition within the basement complex. Basement complex is also found in the form of tabular to blocky inclusions within the layered group, which increase in abundance toward the bottom of the layered group.

Pale Facies Anorthosite

The pale facies anorthosite unit consists of very coarse 15-20 cm plagioclase, with interstitial hypersthene in the north, 2- to 5-cm plagioclase in the middle area and 1-cm plagioclase, locally layered, in the southwestern part of the field area. Pale facies rocks of actual leuconoritic composition, which are patchy and gradational with the true anorthosite, are included in the anorthosite unit. Both the true anorthosite and the leuconorite are easily identified by the pale gray-blue weathering. The anorthosite is overlain structurally on the north and east by rocks of the layered group, beneath which it dips, and has a clean, vertical contact with the Ford Harbour Fm. The eastern contact of the anorthosite mass with the layered group is marked by a pronounced change in weathering, from the hard gray of anorthosite to the crumbly brown of the layered group. This weathering change may be due to the first appearance of augite to the east. In crossing the contact from west to east, one observes a regular decrease in anorthite content, from greater than An_{50} on the anorthosite side to somewhat less than An_{50} on the layered group side (four samples), as well as rapid increase in the percent of orthopyroxene present, and the appearance of augite. This contact may be transitional. The N-S portion of the contact is approximately vertical in the north, and may dip 50 to 70° east at the southern end, where it disappears in a shear zone. In the Needles Knoll area, the anorthosite makes a sharp, intrusive contact with the basement complex. without the presence of the layered group on the eastern side. Inclusions of anorthosite are recognized in younger layered group rocks, and inclusions of basement complex are recognized in the younger anorthosite. The anorthosite is cut locally by dikes of noritic material (An_{52}+Opx, two samples), which are probably related to the eastern layered group.

Fig. 10. Preliminary reconnaissance field map of the southern part of Newark I.

Newark Island Map Key

1. Ford Harbour Formation; pyroxene granulites and enderbites.
2. Anorthosite; λ = pale facies; δ = dark facies.
3. Troctolite; locally interlayered with oxide-rich wehrlite.
4. Gabbroic rocks; Cpx > Opx; olivine may be present. Locally plagioclase may be less than An_{50}.
5. Noritic rocks; Opx > Cpx; olivine scarce. Locally plagioclase is less than An_{50}.
6. Mangeritic to jotunitic rocks, locally containing ovoidal concentrations of mesoperthite. Locally cut by dikes and plugs of adamellitic rock.
7. Adamellitic rocks, commonly containing ovoidal feldspars.
8. Gneisses of uncertain origin. May represent sheared contact rocks.

Layered Group

Much of the northern and eastern part of the map area (Fig. 10) was previously mapped as diorite (Wheeler, 1968 and ms. maps). It now appears that the area in question is underlain by a layered igneous complex ranging in lithology from troctolitic to mangeritic rocks. This complex may be divided into two blocks separated by a probable E-W fault in the north-central part of the map area. The northern block shows a map pattern consistent with a basin structure showing a bilateral symmetry. The southern block shows most of the same rock types, but with less symmetry. Conspicuous igneous layering appears to be limited to the eastern part of the southern block (see Fig. 5, FR 1971), so the structural relationship between the two blocks is difficult to ascertain. Judging from map patterns alone, it is conceivable that the fault is a normal fault, with the north side downdropped. The various map units are ascribed to cryptic and phase layering, which are better developed in the northern block.

If we make the assumption that the body is layered by gravity settling, and is approximately funnel-shaped, then the stratigraphy of the rocks in the layered group is, from top to bottom:

Map Unit	Rock Type
6	Mesoperthite mangerite
5	Norite interlayered with gabbro
4	Gabbro interlayered with troctolite
3	Troctolite interlayered with oxide-rich wehrlite

Unit 3, troctolite, contains abundant inclusions of basement complex, and marks what is believed to be the outside rim of the layered group, the stratigraphic bottom. In the field, the rock is recognized by its dark plagioclase, rusty weathering surface, and olivine content, which varies from a few percent up to 30%. Plagioclase varies from An_{47} to An_{57}. Orthopyroxene and augite are present locally in minor amounts; red biotite, occurring in clumps, is commonly present. Toward the outside of the body, the rock is locally rich in sulfides (up to 50%) and opaque oxides, which appear to be primary. The oxide-rich wehrlite contains much opaque oxide (e.g. 50%), and olivine is dominant over clinopyroxene (e.g. 35% : 15%). This rock has previously been cited (FR 1971, p. 33) as unusual in the Nain area, and it is thought to be a result of adcumulus crystallization of mafic cumulate layers.

The subdivision of rock types in the northern block reflects the changing mineralogy from the margins toward the center of the complex. An, En, and Fo contents all decrease in the sequence troctolite-gabbro-norite-mangerite. The rocks of lowest An content bear brown hornblende, opaques, minor olivine, augite, quartz, apatite, and possibly K feldspar, and appear to be the last rocks of the differentiation sequence.

Late Intrusive Rocks

Pink-weathering to yellow-weathering rocks of granitic to granodioritic composition cut all older rocks in the field area. These rocks are found most abundantly in regional linears and near contacts between major rock units. The rocks vary from pegmatitic to aplitic coarseness and commonly occur as dike swarms rather than as proper plugs. The conspicuous porphyritic adamellite texture is absent from these rocks. Only two definite plugs of porphyritic adamellite were observed in the field area.

Diabase

The island is cut by fine-grained and locally porphyritic diabase, which cuts all other rocks of the field area. Dikes are commonly vertical, and strike approximately east-west.

Structure and Field Relations

The layering of the layered group suggests the shape of a funnel, rather pinched out in the south and more evenly rounded in the north and east. The layered group contains large tabular inclusions of granulite in the basal layers, and is believed to have originally overlain the basement complex. The anorthosite appears to be locally transitional mineralogically with the layered group, and is locally cut by late members of the group. Blocky inclusions of anorthosite are found in all units of the layered group. The anorthosite is inferred to have solidified prior to the layered group, although members of the layered group now appear to overlie anorthosite. One-cm layering in the anorthosite suggests a margin, possibly against country rock, to the southwest, and a core to the northeast. It is interesting to note the absence of layering in the anorthosite at the Needles Knoll contact with the basement complex.

Layering in the layered group suggests that little deformation has occurred in the northern part of the field area. However, the southern portion has been squeezed so that layering is now commonly vertical to locally overturned, and the agmatitic contact with the basement complex is approximately vertical. It is difficult, because of the deformation, to determine whether the layered group dies out in the south next to the anorthosite, as it would in a syncline plunging steeply to the northeast, or whether it is truncated by deformation and perhaps late movement of the anorthosite mass. The presence of a southern shear zone, containing leuconorite, norite, layered gabbro and granulites, suggests that such a truncation may have occurred, although perhaps in an area where the layered group was thinned between anorthosite and granulite.

Interestingly, the deformed southern layered group rocks contain a great amount of late granite, while the shear zone contains none. The shear zone is inferred to be later than the major pulse of activity of intrusion and deformation, and it obscures the triple-joint junction of layered group, anorthosite, and basement complex.

CENTRAL AND WESTERN CONTACT ZONES

GEOLOGY OF THE HETTASCH LAKE AREA

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Contents

Introduction

Preliminary work in the Hettasch Lake area is summarized in last year's Field Report (1971, p. 43-46). Initial petrographic studies and field work in 1972 have provided many corrections and additions to the preliminary geology and interpretation.

The rocks of the Hettasch Lake area can be broadly divided into three major age groups and rock types. These are, in order of decreasing age: (1) the Archaean gneisses and granulites, (2) the Proterozoic tholeiitic (= subalkaline) plutonic rocks (anorthosite, troctolite, norite, gabbro) of the Nain complex, and (3) the Proterozoic calc-alkaline plutonic rocks of the Nain complex (diorite, granodiorite, adamellite, granite: the "adamellite series" of Wheeler, 1955, 1960).

Previously the several tholeiitic units (subophitic gabbro, troctolite, and leuconorite or leucogabbro) were considered to represent a consistent stratigraphic succession within a single pluton, with a marginal mafic granulite forming the margin of the pluton against the Archaean gneisses and granulites (FR 1971, p. 45-46). Subsequent field work suggests that the three major units of the tholeiitic suite represent at least two and possibly three separate intrusions. In addition, the viability of the marginal mafic granulite as an igneous marginal unit has been brought into serious question because it is not present south of Hettasch Lake. However the subophitic gabbro unit is not present south of Hettasch Lake either; therefore the marginal mafic granulite may represent an igneous margin to the subophitic gabbro unit, here named the North Ridge gabbro.

The geology, as it is presently understood, will be discussed using the Hettasch layered intrusion as a reference point. This troctolitic body, although it may be a homoclinal unit to the north of Hettasch Mountain (Fig. 11), opens southward into a synclinal or trough-like body. It lies between the Archaean gneisses and granulites to the west and the two-pyroxene leucogabbro to the east. North of Hettasch Mountain the North Ridge gabbro and the marginal mafic granulite lie between the Hettasch intrusion and the Archaean rocks. At the very top of the exposed stratigraphy the troctolitic intrusion has produced noritic or gabbroic rocks.

Because the intrusion has the shape of a trough and because the contact rocks on one side of the intrusion are radically different from those on the other side, it is necessary to have an efficient way of designating a given limb of the syncline for discussion purposes. The trace of the synclinal axis is crescentic through nearly 180°; therefore speaking of an east or west limb is not practical. Thus I have termed the limb of the intrusion which for the most part is in contact with the gneisses and granulites, the "outer limb" and the one which is in contact with the two-pyroxene gabbro, the "inner limb."

Outer Contact Zone

Webb Valley metamorphic complex. As can be seen on the regional geologic map (Fig. 1), the Archaean metamorphic rocks, here termed the Webb Valley metamorphic complex, occupy an oddly shaped reentrant into the main mass of the Nain complex. These rocks lie in contact with the outer limb of the Hettasch intrusion for a greater strike distance than any other unit (see Fig. 11). The lithologies present in the Webb Valley metamorphic complex are similar to those occurring on the eastern end of Paul Island, which were described by de Waard (FR 1971, p. 16-19) and termed the Ford Harbour Formation. The age of these rocks is Kenoran, with possible overprints of the Hudsonian and Elsonian orogenies (see Emslie, et al., 1972, p. 5-7).

The dominant rock types are enderbite, pyroxene granulite, and amphibolite. The plagioclase of enderbite is typically brownish when weathered, whereas the plagioclase in amphibolite is always very white, thus aiding rapid field distinction between the two rock types (compare Windley and Bridgwater, 1971). In general, the enderbite and pyroxene granulites are dominant near the Hettasch intrusion contact and the amphibolites dominate away from the contact. The transition occurs over a few meters to tens of meters at approximately 400 ± 50 meters from the contact. Also, between this transition zone and the contact, quartz is never blue in color; beyond this zone blue quartz is common.

The medium-grained, layered enderbite (hypersthene-plagioclase-quartz) locally contains biotite and is interlayered with finer-grained, layered pyroxene granulite (pyroxene-plagioclase), which can also contain biotite. Another pyroxene granulite, showing little or no layering, is found cutting across the first two rock types (compare FR 1971, p. 16, and Rubins and

Explanation for Geologic Map (Fig. 11).

SHG	Sheet Hill granite.
AD	Adamellite intrusive.
TON	Tonalite intrusive.
LZ	Lower Zone - Kiglapait layered intrusion.
IBZ	Inner Border Zone - Kiglapait layered intrusion.
OBZ	Outer Border Zone - Kiglapait layered intrusion.
HI'	5-15 cm troctolite-gabbro-anorthosite - Hettasch intrusion.
SFT	Snowflake troctolite - Hettasch intrusion.
·HI	1 cm troctolite-anorthosite - Hettasch intrusion.
LG'	Small body of 3-5 cm leucogabbro either intrusive into or intruded by the Hettasch intrusion.
LG	3-5 cm two-pyroxene leucogabbro.
NRG	North Ridge gabbro.
MMG	Marginal mafic granulite of uncertain origin.
SG	Snyder Group.
UM	Ultramafic body (peridotite).
WVM	Webb Valley metamorphic complex.

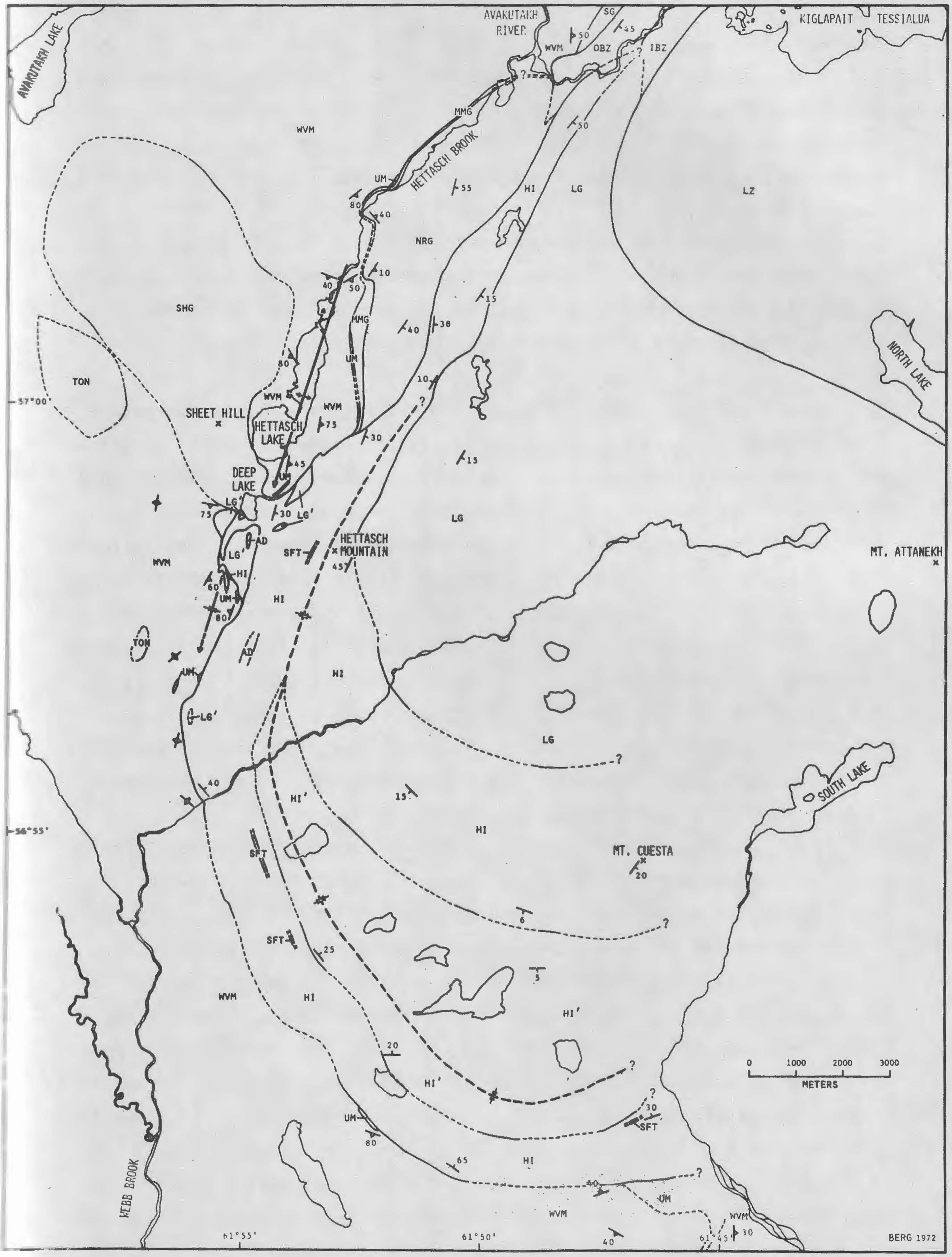

Fig. 11. Geologic sketch map of the Hettasch Lake area. Explanation on opposite page.

de Waard, 1971).

Layers, lenses, stringers, pods, and dikes of granitic to pegmatitic material are locally abundant and probably represent components of Archaean to Proterozoic acid volcanics and granites, partial melts of the metamorphic rocks, and small-scale intrusions from the Nain calc-alkaline plutonic series.

Pyroxene granulite and mafic enderbite layers locally are strongly boudinaged to the point of becoming separated as tectonic "fish" in the leucocratic matrix. Where these blocks are abundant and surrounded by sufficient amounts of the granitic material, the rock is an agmatite.

Other rock types associated with the enderbites and pyroxene granulites include cordierite-hypersthene-quartz granulites, mafic to ultramafic pyroxene-hornblende gneisses, peridotite masses, and pyroxenite lenses. The cordierite-hypersthene-quartz granulite has been found in only two localities; in both cases the rock is in immediate contact with the Hettasch layered intrusion. These granulites are extremely rich (>> 50%) in cordierite and contain lesser amounts of quartz and hypersthene. Coexisting garnet was tentatively identified in the field at one locality, but awaits laboratory confirmation. Locally, thin (1-5 cm) quartzite layers are found interlayered with the cordierite-hypersthene-quartz granulite.

Mafic to ultramafic gneisses are locally found near the Hettasch intrusion contact. They are generally coarser grained (1-2 mm) than the pyroxene granulites and contain hornblende, orthopyroxene, ± olivine, ± plagioclase, and ± diopside. These gneisses have some mineralogic similarities to the Kiglapait Outer Border Zone (OBZ, Berg, 1971). However, they are coarser grained and considerably more mafic than OBZ rocks. They may in part be related and transitional to the peridotites discussed below.

Pyroxenite lenses or pods of varying size (a few cm to a few meters) are common and may represent completely boudinaged layers. Peridotite occurs in larger lenses or layers (up to 30-40 meters thick and 2000 meters along strike) within what may be, as de Waard (FR 1971, p. 17) suggests, a specific stratigraphic level. In the Hettasch Lake area it is impossible to prove that the peridotites occur at only one stratigraphic level, but if the gross structure is interpreted correctly (see below), then a single stratigraphic horizon seems plausible. However a correlation between this peridotite horizon and that on the eastern end of Paul Island is certainly not justifiable at present.

Associated with the amphibolites are biotite-plagioclase-quartz gneisses, some "tonalitic" gneisses containing up to about 40% blue quartz, and white feldspathic quartzites. Equivalents of the cordierite-hypersthene-quartz granulites have not been recognized away from the Hettasch contact.

A discussion of possible protoliths to these rock types is not included here; for a brief discussion, the reader is referred to de Waard (FR 1971, p. 18).

The metamorphism of the Webb Valley metamorphic complex is not well-documented yet, but is probably amphibolite facies for the most part. The intrusion and crystallization of the Hettasch magma has effected contact metamorphism up to the granulite facies. The assemblage cordierite-hypersthene-quartz, in particular, indicates relatively high temperatures and moderate to low pressures. If garnet proves to coexist stably, then intermediate pressures would be indicated (Hensen and Green, 1970).

A detailed structural analysis of the presumably multiply-deformed country rocks has not been performed, partly because lineations and coherent minor folds are moderately rare. However, a few rudimentary facts about the basement structure are apparent. The major structures in the area are moderate to tight folds whose axes may have been warped by the intruding magmas. Hettasch Lake lies in the core of a large southward-plunging anticline. On an outcrop scale the rocks of this anticline appear to dip conformably under all of the surrounding igneous bodies, but on a broad scale their trends are intersected by the igneous contacts. Near Deep Lake the igneous rocks (Hettasch layered intrusion and Sheet Hill granite) breach the anticline. South of this breach the structure is a southward-plunging syncline with country rocks dipping away from the Hettasch contact. Southward either the axis of this fold is breached or the fold becomes overturned and the country rocks dip under the intrusion.

Because of the poor accessibility of and the paucity of outcrop in Webb Valley, the country rocks well out in the valley have not been examined and the structure is unknown. However, the strike of the country rocks immediately adjacent to the Hettasch intrusion contact roughly parallels that of the contact; therefore it seems likely that, to a first approximation, the fold axes parallel the contact, too.

The style of folding appears to be passive-flow. This is based on the facts that a given unit or layer is thicker at the nose of a fold than on the limbs and that there are no planar features indicating slip. Subsequent to this deformation the Hettasch magma and eventually the Sheet Hill magma were intruded, partially crosscutting the country rocks, but also producing broad folds or warps in the existing axial planes.

It should be noted that this structural interpretation is unlike that of de Waard (FR 1971, p. 23-25), who suggests that little deformation preceded the emplacement of anorthositic rocks. Here the tholeiitic (or anorthositic) rocks clearly crosscut earlier structures in the country rocks.

North Ridge gabbro. The North Ridge gabbro is a homoclinal sequence of layered and foliated gabbros and olivine gabbros. This unit occurs in the outer contact zone along the northwest side of the Hettasch intrusion. For the most part it dips under the Hettasch intrusion and has a conformable, gradational, to lit-par-lit contact. However, east of Hettasch Lake the gabbro pinches out against the Hettasch intrusion. Locally, dikes of the Hettasch intrusion invade the gabbro, and blocks of gabbro are included in troctolite. The northern extent of the gabbro is difficult to assess because of the lack of outcrop near the Avakutakh River. However, the OBZ of the Kiglapait intrusion (containing xenoliths of Snyder Group quartzite) can be seen as dikes in the gabbro, and it probably cuts off the gabbro completely.

The North Ridge gabbro is obviously older than the Hettasch intrusion, but how much older is an open question. Several lines of evidence suggest that the gabbro may be one of the oldest intrusions associated with the Nain complex. In fact, certain features indicate the admittedly tenuous possibility that the gabbro is either pre-tectonic or syntectonic to the late dynathermal event in the country rocks. These features include: (1) layering which (although locally igneous-appearing) typically has a metamorphic appearance; (2) abundant shearing and cataclasis; (3) abundant recrystallization textures (although much of the unit retains a beautiful subophitic texture); (4) rare southeast-plunging mineral lineations; and (5) an outcrop pattern which, locally, is highly suggestive of an involvement in folding with the country rocks (note map pattern of contact along

Hettasch Brook; Fig. 11).

The marginal mafic granulite, which previously was thought to occur at the interface of the anorthosite complex and the Webb Valley metamorphic complex, is now known to occur only at the margin of the North Ridge gabbro.

The plagioclase compositions in the gabbro range from An_{75-83} in the core of the intrusion to An_{55-60} at the margins. Primary mafics include augite, orthopyroxene, and olivine, in order of decreasing abundance. Near the margin, one sample contains mosaics of ex-pigeonite grains (with random sets of clinopyroxene lamellae) which have inverted to single orthopyroxenes. Several of the grains display lamellae (presumably exsolution lamellae) of plagioclase. For exsolution of plagioclase from pyroxene in the Serraina de la Ronda peridotite massif, Dickey (1970) suggests the following reaction:

$$\underbrace{CaMgSi_2O_6 + Al_2SiO_5}_{\text{Cpx}} \rightarrow \underbrace{CaAl_2Si_2O_8}_{\text{Plag.}} + \underbrace{MgSiO_3}_{\text{Opx}}$$

Whether of xenocrystic or phenocrystic origin, these formerly Al-rich orthopyroxenes must indicate that the magma was generated at considerable depth (O'Hara and Yoder, 1967; Boyd and England, 1960).

Sheet Hill granite. The previously discussed units are all older than the Hettasch intrusion. Also occurring in the outer contact zone, but in this case younger than the Hettasch intrusion, is the Sheet Hill granite, which is located to the west of Hettasch Lake. The granite is probably one of the more acidic members of the calc-alkaline plutonic series associated with the Nain complex. Mineralogically, it consists of alkali feldspar (50-80%), quartz (20-30%), biotite (5-20%), minor plagioclase, and a trace of fluorite.

Where the granite approaches the contact of the Hettasch intrusion, it narrows down into a dike-like body and intrudes along the contact between the Webb Valley metamorphic complex and the Hettasch intrusion. Adjacent to the metamorphic rocks the granite becomes strongly foliated and appears to have a gradational contact. The granite forms a very sharp contact and is chilled against the Hettasch intrusion, but has removed little if any of it by stoping. The granite magma appears to have intruded as far as the Hettasch contact, found it impenetrable, and then flowed out along the contact.

Inner Contact Zone

Leucogabbro. The rocks adjacent to the Hettasch intrusion in the inner contact zone are monotonously similar, massive, two-pyroxene leucogabbros, ranging from pure anorthosite to normal gabbro. The rock consists of 1-3 cm plagioclase with 5-10 cm megacrysts (iridescence common in both) and large, patchy-poikilitic clinopyroxene and orthopyroxene. This unit was initially termed leuconorite in the field because the bronze schiller was identified with orthopyroxene. However, thin sections show that two pyroxenes are present and sufficient data are not available to determine which pyroxene dominates. The mean color index of this unit is estimated to be 15. Layering has not been found in this body and examples of lamination are extremely rare.

Attempts to classify this unit as one of the three anorthosite facies of Wheeler (1960) have proved frustrating. Wheeler (unpublished maps) designates it as pale facies. However, the color of the feldspar varies considerably and the leucogabbro might best be classified as mixed pale and dark facies with dark facies dominant. If anything is apparent concerning the color of the feldspar, it is that color seems loosely related to grain size and color index of the rock. Pale feldspar generally occurs in finer grained, anorthositic portions of the leucogabbro, while dark feldspar is associated with coarser grained, more mafic parts of the unit.

Intuitively one would assume that the leucogabbro is older than the Hettasch intrusion. For the most part, the Hettasch intrusion appears to overlie the leucogabbro stratigraphically. Also, the migrating trend of the synclinal axis of the intrusion is extremely suggestive of structural control, such as that of the original contact of the leucogabbro with country rock.

There are, however, several serious inconsistencies under this interpretation. Near the top of Hettasch Mountain, the gently (west) dipping lamination of the Hettasch intrusion appears to be truncated by the leucogabbro. The actual contact is not exposed and therefore cannot be studied directly, but the grossly defined trend of the contact appears to be incompatible with the lamination in the Hettasch intrusion. Secondly, there are several places in the northern part of the field area where laminated to strongly laminated rocks of the Hettasch intrusion clearly dip easterly under the leucogabbro.

These questions having been raised, the leucogabbro is intuitively classified as being older than the Hettasch intrusion.

Hettasch Intrusion

General Description. The Hettasch layered intrusion is structurally an asymmetrical syncline which forms an apparent closure in the vicinity of Hettasch Lake, but whose eastward limit has not been mapped. The axis of the intrusion makes a nearly 180° curve from a southwesterly trend north of Hettasch Mountain to a southeasterly trend south of Hettasch Mountain to an east-west trend and finally a northeasterly trend south of Mt. Cuesta. The northernmost part of the intrusion is a homoclinal sequence which dips southeastward under the leucogabbro. Just north of Hettasch Mountain it opens up into a strongly asymmetrical syncline. The outer limb exhibits layering or lamination which typically dips from 30° to greater than 60°; the inner limb typically dips from less than 5° to about 25°.

The asymmetry of the intrusion is not just a structural phenomenon. The petrology, presence and types of igneous foliation, and textures also reflect the asymmetry. The outer limb of the intrusion is characterized by the presence of layered or massive, subophitic-textured rocks; lamination is rare. In the inner limb of the intrusion, lamination is ubiquitous, layering common, and massive rocks are rare. Color indices in the outer limb rocks range from 15-70 whereas the range is from 0-25 in the rocks of the inner limb.

Outer limb stratigraphy, including snowflake troctolite. Field studies clearly point to an asymmetrical stratigraphy for all but the top of the intrusion. Therefore, a two-legged stratigraphic column has been constructed for the intrusion (Fig. 12). At the base of the outer limb succession, against the Webb Valley complex, is a chill zone of olivine gabbro with varying grain size (0.2 mm-3 mm). The olivine in this rock is typically stubby, the plagioclase lath-like, and the pyroxenes and opaques patchy-poikilitic. Plagioclase and olivine compositions in the chill zone are approximately An_{53} and Fo_{55} respectively. This zone is nearly

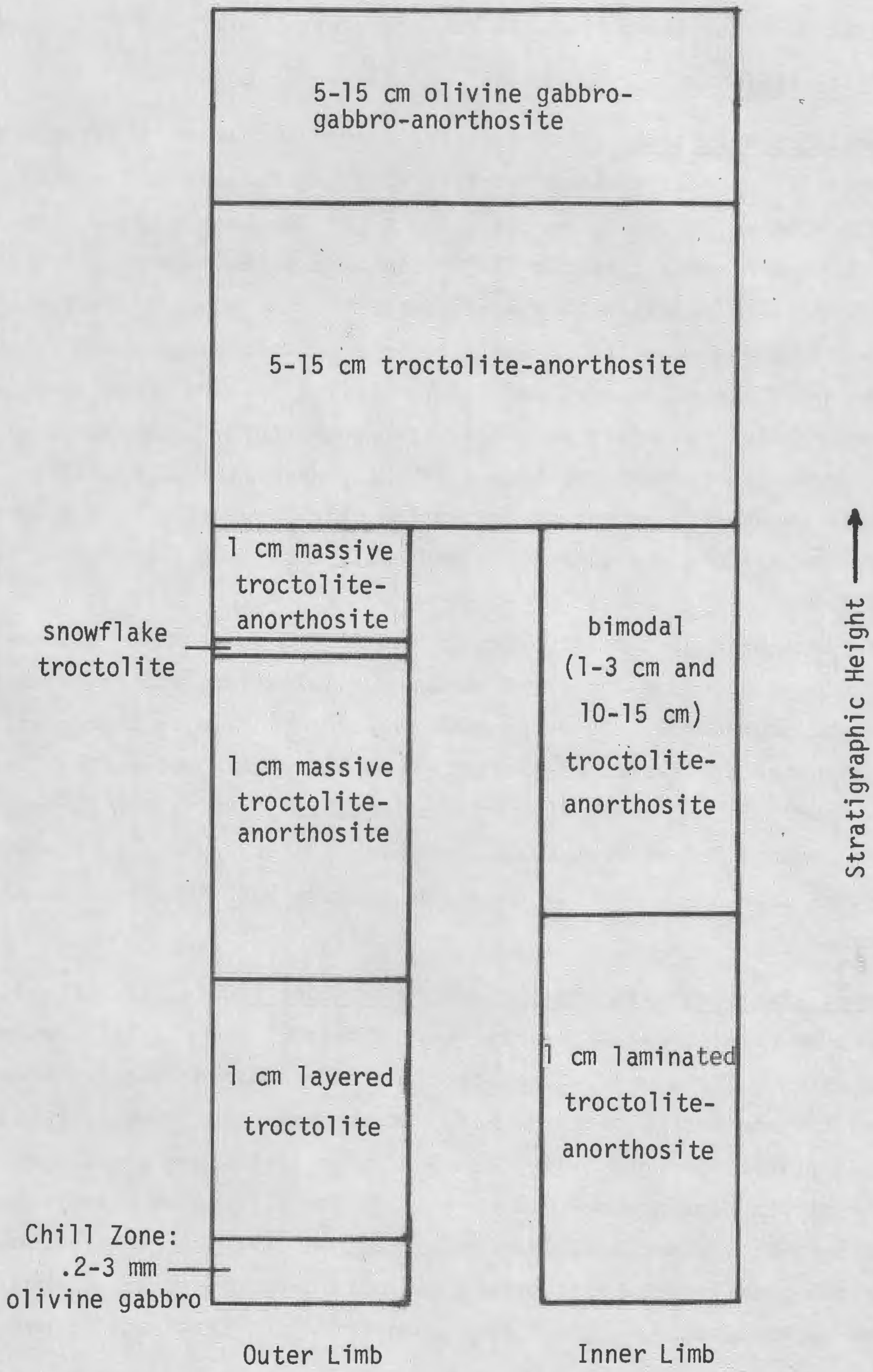

Fig. 12. Stratigraphic column for the Hettasch intrusion.

everywhere present, extending from a few tens of meters to greater than 100 meters up-stratigraphy. The finest-grained chill rock is not everywhere present, however, and is never more than a few meters thick.

The chill zone passes gradationally into layered troctolite. The grain size of this unit is normally less than 1 cm and the color index of the average rock is between 10 and 30. The layering generally consists of 3-10 cm thick layers of melatroctolite in average rock, although layers as thick as one meter have been observed. Leucocratic layers and graded layering are rare, and even the melatroctolite layers seldom extend more than a few meters or tens of meters along strike. Layering truncated by later layering (cross-stratification) is present locally, as are zones of subtle, regularly-spaced "2 cm-scale" layering. Plagioclase ($\sim An_{64}$ at the base) and olivine ($\sim Fo_{72}$ at the base) are the cumulus phases in this unit, with pyroxenes and opaques being intercumulus phases. The cumulus plagioclase and olivine ratios and compositions at the base are approximately the same as in the basal Kiglapait Layered Group (Morse, 1969).

Layering becomes less common up-stratigraphy, and the rock becomes a structureless, 1 cm troctolite with a color index near 20. Within this unit pegmatoid patches are locally abundant. These pegmatoids are one meter or less in long dimension and are commonly zoned: the outer zone consists of very coarse-grained troctolite; the next zone inward is very coarse-grained olivine norite or gabbro. This grades into a central zone of norite or gabbro within which small patches of acid granophyre locally occur. The volume of granophyre never exceeds 1/10 of the volume of the pegmatoid and normally is much less than that (assuming relative volume is approximately proportional to relative area).

Also within this massive troctolite unit is found a spectacularly textured and structured zone which has acquired the field name snowflake troctolite. This rock is a fine-grained, granular-textured, and finely layered troctolite which contains fist-size orbicules or clusters of radially arranged plagioclase megacrysts. The texture somewhat resembles the "stellate" texture described by Upton (1964) from the coarse border zone of a gabbro dike on Tugtutôq Island, South Greenland. The orbicules or clusters, when viewed on a two-dimensional surface, resemble snowflakes. The grain size of the matrix is about 1 mm, and the length of the plagioclase tablets in the snowflake averages about 5 cm, thus producing snowflakes with a 10 cm diameter. The layering consists of alternating layers of nearly pure anorthosite and dunite on a scale of a few millimeters. The layering wraps around both tops and bottoms of "snowflakes", and small drag folds having amplitudes of 2-4 cm are present. Large single plagioclase crystals or irregular clusters of plagioclase crystals may substitute for the "snowflakes." The matrix material between the plagioclase crystals in the "snowflakes" is normally fine-grained granular troctolite, although in rare instances subophitic clinopyroxene, rather than fine-grained troctolite. occurs in the interstices.

The snowflake troctolite occurs in a zone which is only 5-10 meters thick. It is probably more extensive along strike than shown in Fig. 11 (due to being covered by glacial drift or being exposed in areas not seen in the field); however, field mapping has shown that the snowflake troctolite is not completely continuous along the outer limb. In spite of its lack of continuity, the known occurrences of snowflake troctolite are all at approximately the same position in the stratigraphy. Because of this and because of its unique character, the snowflake troctolite is assumed to represent synchronous depositional and immediately post-depositional events throughout the intrusion, i.e., it defines a time horizon.

More of the 1 cm massive troctolite occurs above the snowflake troctolite, but it grades (over a short distance) into a very coarse-grained, massive or laminated troctolite. The grain size of this unit generally ranges from 5-15 cm for the plagioclase and 3-5 cm for the olivine. Up-stratigraphy the olivines develop orthopyroxene rims, and opaque oxides (and augite?) appear. The rock is thus olivine norite or olivine gabbro, or olivine leuconorite or olivine leucogabbro, depending on the color index and the kind of pyroxene.

Inner limb stratigraphy. The inner limb of the Hettasch intrusion is in contact with the leucogabbro and has no chill or border rocks. The basal unit is a moderately to strongly laminated 1 cm troctolite, leucotroctolite, or olivine anorthosite, depending on the color index. Although only one or two reconnaissance measurements have been made, olivine and plagioclase compositions at the base of this unit appear to correspond roughly to those at the base of the layered troctolite in the outer limb.

This unit grades upward into a troctolite, leucotroctolite, or anorthosite which has a strong bimodality of plagioclase grain size. The grain size of the average rock is 1-3 cm, while the plagioclase megacrysts are 5-15 cm. Both sizes of plagioclase are commonly iridescent. Layering and lamination are common in this unit. Locally the layering is defined by 30 cm thick layers, composed almost entirely of laminated plagioclase megacrysts, alternating with the normal troctolite. In other places spectacular cliff exposures display layering defined by layers composed almost entirely of 1-3 cm laminated plagioclase, alternating with laminated to massive very coarse-grained troctolite.

Eventually the layers of 1-3 cm anorthosite (or troctolite) diminish, and the rock becomes the same very coarse-grained troctolite as that described in the upper part of the outer limb stratigraphy. This grades upward into very coarse olivine norite or olivine gabbro (locally norite or gabbro) and leucocratic varieties which are equivalent to the rocks at the top of the outer limb. Thus the stratigraphies of the two limbs merge at the base of the very coarse-grained troctolite, and from there upward the intrusion has a single, common stratigraphy.

Petrologic problems. The asymmetry of the Hettasch intrusion provides unresolved problems in reconstructing the convectional and depositional history of the intrusion. The apparent absence of extreme fractionation is difficult to understand considering the abundant evidence of crystal settling. A possible explanation for the latter is that the exposed part of the intrusion is the lower part of a larger layered intrusion, the top of which has been removed by erosion.

The problem of anorthosite "facies" is again brought out in the Hettasch intrusion. The feldspar is definitely dark in some places, but is definitely pale in others. This is carried to an extreme in part of the inner limb stratigraphy where (as noted above) layers of 1-3 cm laminated anorthosite alternate with laminated to massive, very coarse-grained (5-15 cm) troctolite (± pyroxene). The plagioclase in the anorthosite layers is very pale and that in the very coarse troctolite layers is dark. Obviously the problem of plagioclase color is far from being resolved.

As a final observation, it may be noted that the abundant presence of anorthosite layers in the troctolitic Hettasch layered intrusion strongly suggests a genetic relationship between anorthosite and olivine tholeiite magma, as at Michikamau (Emslie, 1970). This is not to claim that other parental magma types are to be excluded from consideration, but only that tholeiite should be regarded as a legitimate candidate for the parental magma of anorthosite. As is common in layered intrusions, layering is not pervasive. Many large outcrop areas in the Hettasch intrusion show little or no layering and strongly resemble rocks of the anorthosite massif elsewhere. The Hettasch intrusion therefore further demonstrates the lack of a clear-cut distinction between massif-type anorthosites and the anorthosite layers of basic layered intrusions.

ANORTHOSITE-ADAMELLITE-BASEMENT RELATIONS IN THE IKKINIKULLUIT DRAINAGE BASIN

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Introduction

Former mapping along the ridge southeast of Annakhtalik Brook big oxbow (Fig. 13, 62-17 W) revealed a complex mixture of basement rocks and adamellite characteristic of some contacts between the two rocks. Since no extensive adamellite occurs around this part of Annakhtalik Brook, it was hoped that mapping around lower Ikkinikulluit Brook, to the south, would reveal the adamellite body responsible for the ridge-top mixture. It was also hoped that a junction could be made with detailed geologic mapping farther west. Much anorthosite was found where adamellite was expected, and the steep-walled, densely wooded valleys prevented the long traverses necessary to connect with the previous work to the west.

Petrology

The basement rocks in this region are divisible into the usual two units: granulites in which a component of sedimentary origin is not readily detectable, and paragranulite in which there is an obvious sedimentary component in the form of abundant garnet (altered to cordierite near the anorthosite-adamellite complex) or graphite. In this area the granulite is medium-grained, smoothly layered, and with layering crumpled only locally. The paragranulites generally show a lumpy, uneven layering resulting from augen of garnet (cordierite). Feldspar, quartz, pyribole, and biotite are recognizable in varying proportions, and layering attitude is very irregular. The paragranulites lie west of the granulites, perhaps with a transition zone between in which a small amount of garnet or cordierite is occasionally detectable.

Anorthosite is the buff-weathering facies for the most part, disintegrating almost as readily as adamellite. It has the charnockitic greenish gray color when fresh, a low mafic content, and abundant 3-cm plagioclase megacrysts in a finer grained groundmass. Iridescent feldspar is

Fig. 13. Geologic sketch map of the Ikkinikulluit drainage basin.

occasionally detectable. In a limited area northwest of Ikkinikulluit Brook First Lake (Fig. 13), pale-facies anorthosite occurs. The mafic content of this rock is very low. Occasionally there is enough to define a slight layering. Dark-facies anorthosite was found only at the west end of the massif south of Annakhtalik Bay head. Any westward extension of the dark anorthosite beyond this is concealed by Quaternary deposits. The rock is too fine grained and high in mafics (clinopyroxene and olivine) for typical anorthosite, but is tentatively mapped as this rock unit because it resembles rock considered to be a chilled margin of dark-facies anorthosite north of Annakhtalik Bay head.

Finer grained diorite, where typically developed at the summit of the massif south of Ikkinikulluit Brook First Lake, is medium grained, subophitic, with perhaps 15% pyroxene, and scattered dark 1-cm blocky plagioclase megacrysts.

The adamellite around the south side of Annakhtalak Bay head has the charnockitic greenish-gray color and disintegrates readily into rusty grus (rapakivi). It contains abundant feldspar ovoids to several centimeters across in a finer grained granular groundmass. The ovoids are probably K-feldspar, and occasionally show the striation of plagioclase at their margin: the rapakivi texture of Fennoscandia. Small insets of light and dark mineral grains are common in the ovoids. Quartz is detectable on bleached surfaces. In the freshest material of rock falls, olivine can be detected in the groundmass. It appears to accompany pyroxene in some cases, hornblende in others.

Field Relations

In the granulites south of Annakhtalik Brook mouth, a few layers suggest stretched anorthositic rocks with smeared-out large pyroxenes. Others have a high percentage of pale feldspar and very little amphibole in streaks, like rocks that grade over into pale anorthosite with iridescent feldspar north of Annakhtalik Brook near 62-10 W. In these rocks, mafic layers are remarkably straight and uniform. If any of this rock can be correlated with pale anorthosite, the degree of relationship can only be determined by petrographic studies.

Since layering in the basement complex adjacent to anorthosite, and in the margin of the anorthosite, generally trends nearly parallel to the margin, it is noteworthy that layering in the granulite south of Annakhtalik Brook mouth strikes consistently a little west of north with steep dips, but in the dark anorthosite to the east, it strikes west-northwest with moderate southerly dips. This direction seems less likely to correspond with the trend of the anorthosite margin in this area than does the more prevalent west-of-north direction.

North of Ikkinikulluit Brook First Lake, the anorthosite-paragranulite contact was mapped in some detail. It proves to be irregular, with paragranulite inclusions in the anorthosite near the contact. Since outcrop-size basement inclusions are uncommon in the Nain anorthosite complex, the field relations were carefully checked, and there is little room for doubt. Reference to earlier field notes reveals 10 other such occurrences, among them graphitic quartzite and garnet-spinel-biotite meladioritic gneiss.

Layering seems to be widely distributed in the pale anorthosite northwest of Ikkinikulluit Brook First Lake. In the cliffs north of the lakehead, where it is most easily seen, it is flat except for sinuous divergences around lenses of pale, pure, waxy anorthosite. Elsewhere the attitude is variable, but the dips are never steep. Some of the anorthosite in this area is rubbly-disintegrating, perhaps because of interlayered buff-weathering anorthosite.

Little of the finer grained diorite has been encountered in the area, so its relationships with buff-weathering anorthosite and basement rocks are uncertain. At the summit of the massif south of Ikkinikulluit Brook First Lake, it contains recognizable inclusions of coarse anorthosite and of cordieritic basement complex, fixing its age as younger than these. Farther north, there is a suggestion that it is interlayered with the buff-weathering anorthosite, but both rocks are so disintegrated that even their identities are open to question. Possibly it should be borne in mind that a similar rock occurs between anorthosite and adamellite south of Tessersoakh Lake (56-36 N, 62-32 W; Wheeler, 1968, Fig. 2 and p. 199). What is known of the diorite distribution south of Ikkinikulluit Brook does not contradict the possibility that it lies between anorthosite and adamellite here also. The diorite also resembles the diorite around the east entrance of Wyatt Harbour (56-21 N, 61-17 W; FR 1971, p.28). There it appears to lie between pale anorthosite and a troctolitic layered group.

Discussion

Contacts between adamellite and basement rocks in the area of Fig. 13 are characterized by small satellitic adamellite intrusions in the basement and inclusions of basement rock in the adamellite, and these conditions occur more than a kilometer from the contact. Similar conditions occur in some other areas, as at the north edge of the Annakhtalik Lake adamellite body (56-34 N, 62-45 W), but are entirely lacking at other contacts, as along the west edge of the Annakhtalik Lake adamellite (56-29 N, 62-47 W). A possible explanation for this difference is that a gently dipping adamellite margin might produce the complex contact while a steeply dipping margin might produce the simple contact. On this basis, the adamellite contact would be flat-lying in the Annakhtalak Bay head area. Applying this explanation to the complex of small adamellite bodies in the basement rocks of the ridge south of Annakhtalik Brook big oxbow, it might be the product of a major adamellite body not far below the surface, possibly a northwestern extension of the adamellite body south of Annakhtalak Bay head. Adamellite appears to be more abundant along the north base of the ridge than along the crest, suggesting that the main adamellite body was intruded below the present land surface rather than above it.

Where a difference in age between anorthosite and adamellite in the Nain region has been demonstrable, the adamellite has proved to be the younger rock. Therefore one might expect relations between adamellite and anorthosite similar to those between adamellite and basement rocks. Such conditions do in fact occur in some areas, as north of Tessiuyakhsoakh Bay (56-18 N, 61-53 W). However, in the region around Annakhtalak Bay head, no adamellite dikes were found cutting the anorthosite, nor were any inclusions of anorthosite found in the adamellite. Unless such phenomena have been overlooked because the two rocks have similar weathering characteristics, this poses a problem that should be investigated further. In some areas there appears to be a transitional contact between the two rocks, as west of lower Khingughutik Brook (56-52 N, 62-41 W). This implies a close approach to contemporaneity in such areas, and possibly such an age relation would inhibit mutual intrusion.

Sections of several prominent linears with westerly trends are shown in Fig. 13. They may all be members of the left-lateral fault system in the region, but it has been possible to demonstrate displacement only on the one that follows lower Usighaniat Brook valley. Even here the mapping is not complete enough to demonstrate the character of the displacement, but left-lateral displacement has been demonstrated on its westward extension.

INTERNAL RELATIONS

THE BARTH LAYERED STRUCTURE

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Contents

Introduction

Portions of a layered troctolitic mass occur on Barth (Pardy) Island, 6 km NW of Nain, and on the peninsulas north and south of the island. The present outline of the mass indicates left-lateral displacement of the three parts by strike-slip faults which presumably are located in the bays north and south of Barth Island. The accompanying map (Fig. 14) shows the reconstructed outline of the layered body after sliding the parts back a total of 5 km.

The troctolitic body, measuring about 9 by 6 km, was first delineated by Wheeler (1960). Rubins (FR 1971, p. 35-42) mapped the margins of the body against the anorthositic country rock. A contact zone of about 1 km width, consisting of adamellitic and fine-grained noritic rocks, appears to occur between the troctolitic and anorthositic rock series. Levendosky (1973) studied the modal and mineral compositions of rocks occurring in the body and found that besides rhythmic layering there is also pronounced phase and cryptic layering. Rock compositions range from troctolitic at the margin to adamellitic in the center, and the percentages of An, En, and Fo drop gradually inward.

Observations made and sampling done in 1966, 1967, 1968, and 1971

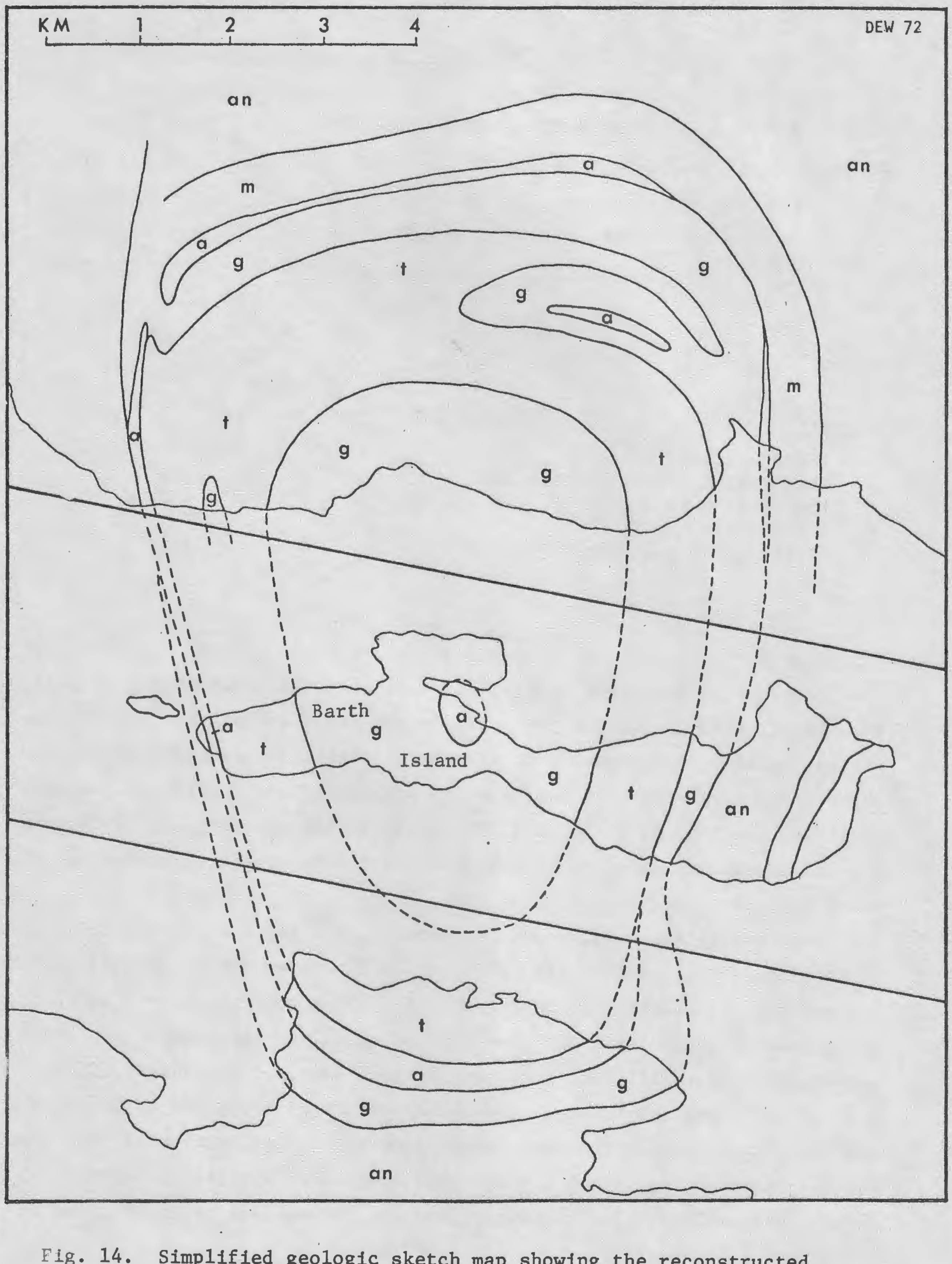

Fig. 14. Simplified geologic sketch map showing the reconstructed outline of the Barth layered structure after sliding the parts right-laterally back along the lines shown on the map. The cumulative displacement along the two lines is 5 km in this reconstruction. KEY: an, anorthosite; m, layered leuconorite to medium-grained noritic and gabbroic rocks; a, adamellitic rocks; g, fine-to medium-grained noritic, gabbroic, and jotunitic rocks; t, fine-to medium-grained troctolitic rocks.

made us realize that this area is particularly well suited for the study of some of the problems associated with the origin of the anorthosite complex, since all of the major rock types occur here in close proximity. It has been customary in the Nain anorthosite complex to divide the rocks into three major rock groups: the anorthositic rocks, the adamellitic rocks, and the troctolitic rocks. One problem is whether these three groups are congenetic, or whether perhaps two of them are, or even whether all three represent separate magmatic events.* The three rock groups are closely involved in the structure of the Barth layered body. The country rock is anorthositic, while the contact zone and the body consist of troctolitic and adamellitic rocks. During the 1972 field season we concentrated our research effort on the detailed study and sampling of the contact zone in which anorthositic, adamellitic, noritic, and troctolitic rocks occur within a kilometer-long section.

Lithologies of the Contact Zone

The sequence of rocks at the margin of the layered body is especially well developed and exposed in the northeastern sector of the body. Largely based on structural and textural differences, the following rock units, from outside inward, were distinguished:

1. Anorthositic country rock, a leucocratic, medium-grained plagioclase matrix contains large (5-20 cm) crystals of darker plagioclase and large (5-10 cm) poikilitic pyroxenes. As far away as 1.5 km from the troctolite the poikilitic patches are stretched and flattened in a direction which parallels the orientation of all of the rocks in the contact zone. This rock grades into:

2. Layered leuconorite, in which the stretched poikilitic patches have become concentrated in mafic layers which alternate with anorthositic layers. The layering is parallel to the contact zone. With a decrease of leucocratic and an increase of mafic layers this rock grades into:

3. Medium-grained leuconorite, which is homogeneous, finer grained and more mafic than the rocks described above. The plagioclase has a

*Morse (1968) suggested that the anorthositic and adamellitic rocks are congenetic and the troctolite series a separate intrusion. De Waard and Wheeler (1971) advocated congenesis of all three rock groups. Morse (1972) considered the anorthositic and troctolitic rocks congenetic and the adamellitic rocks derived from another magma.

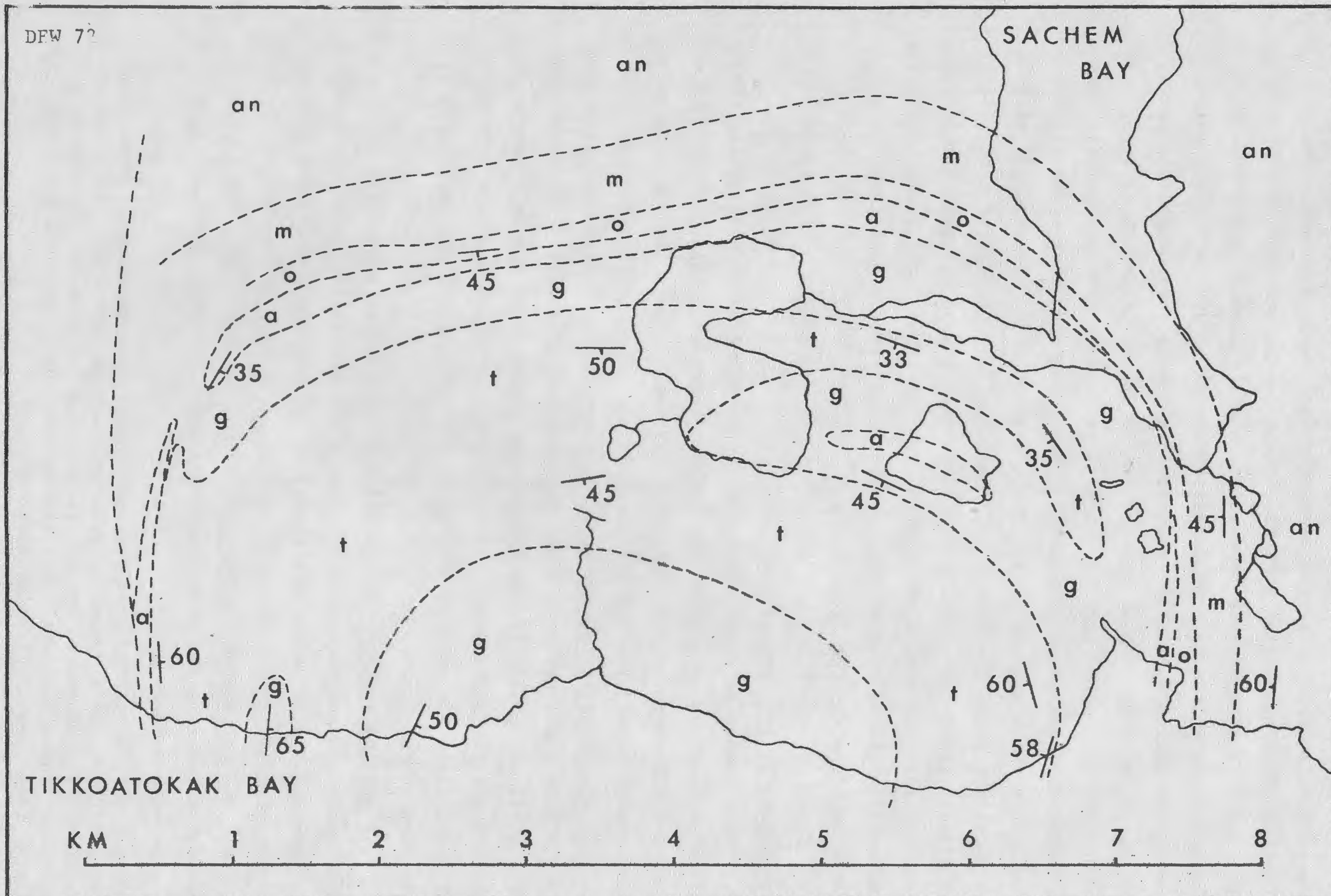

Fig. 15. Geologic sketch map of the northern part of the Barth layered structure. Legend: an, anorthosite; m, layered leuconoritic to medium-grained noritic rocks; o, ophitic gabbro; a, adamellitic rocks; g, fine to medium-grained noritic and gabbroic rocks; t, fine to medium-grained troctolitic rocks.

squatty outline and pyroxene occurs in interstitial patches. A planar orientation is commonly noticable. Over a short distance this rock grades into:

4. Gabbro, which is typically ophitic, leucocratic and medium grained. This rock occupies a relatively narrow zone, and was therefore difficult to trace throughout the contact zone. Plagioclase is characteristically lath-shaped, and the rock shows no orientation. K feldspar is commonly present, and locally olivine occurs. Over a short distance this rock grades into:

5. Adamellitic rock, which is characterized by the presence of feldspar phenocrysts in a medium-grained matrix. The rock commonly shows a strong foliation. The composition of the rock varies greatly, from monzodiorite with little K feldspar and no quartz, to granodiorite or adamellite with K feldspar as a major component, usually as mesoperthite, and up to 10% or 20% quartz. The "adamellitic" rocks show intrusive relations with:

6. Fine-grained noritic rock, which is generally homogeneous and dark, containing 30 to 40% ferromagnesian minerals. Locally the rock is porphyritic, showing phenocrysts of feldspar. Planar orientation in the rock is locally shown by strings of pyroxene and feldspar grains, by alternation of finer and coarser grained layers, and by veins and schlieren of the adamellitic rock near the contact. The composition of this rock is also variable, from monzodioritic with K feldspar and some quartz, to dioritic or noritic. Compared with other rock types the noritic rock weathers easily, and tends to form lows in the topography. Towards the contact with the troctolite the rock is invariably non-porphyritic, dark and fine grained, and thus forms a poorly defined contact with the troctolite which has here an identical nature.

7. Troctolite is distinguished in the field from the noritic rock by the presence of olivine. Being resistant to weathering the fine-grained rock at the contact stands out sharply as a ridge in the topography. Away from the contact the rock becomes medium grained. Locally, the rock shows layering due to a higher proportion of ferromagnesian minerals in density-graded bedding. The orientation of the layering is consistently parallel to the orientation found in rocks of the contact zone, i.e., a strike tangent to the outline of the body and an inward dip ranging from about 30° to vertical.

From the contact zone to the center the rock remains dark colored, medium grained, and locally layered. Near the center of the body a porphyritic texture appears, and in the center the rock has feldspar phenocrysts in a medium-grained matrix and an adamellitic composition. Levendosky's studies show that from margin to center the olivine diminishes and disappears, that K feldspar appears and increases in content, followed by the appearance of quartz, and by the appearance of fayalite in the center of the body. He found that the An percentage of plagioclase drops from 73 to 25, the En percentage of orthopyroxene from 76 to 24, and the Fo percentage of olivine from 73 to 58, reappearing in the center as fayalite.

The Layered Structure

Contacts between the rock types in and outside the body appear to be gradual, or transitional over short distances, with the exception of the adamellitic rocks in the contact zone which show intrusive relations with the fine-grained norite. Veins of adamellitic material, sheared and stretched parallel to the foliation of the fine-grained norite, demonstrate that the noritic rock was in a ductile state while being deformed and intruded by adamellitic material of still higher ductility. That the adamellitic material had the highest ductility of all rocks in and outside the body, and was last to consolidate, is further shown by the local occurrence of adamellitic masses which intruded the sequence and developed agmatitic contacts with the troctolite.

The sequence of rock types in and outside the layered body is essentially the same. Beginning with the troctolite, inward and outward the rock grades into a noritic or gabbroic rock, becomes porphyritic with increasing K feldspar content, and further grades into a rock of adamellitic composition. The main difference between the inward and outward sequences is in their structure. The outward sequence is intensely sheared and stretched, and thus decreased in thickness, while the density-graded bedding of the inward sequence shows little deformation in most places and thickening of the sequence by compressive folding in the center of the body. The compositional similarity of the two sequences suggests that they are one and the same, compressed in the core of the synclinal structure and stretched in the flanks of the anticlinal structure. The lowermost unit of the sequence, the troctolite, thus is shaped like an egg cup or a chantarelle mushroom, or perhaps a lopolith, having an inverted conical base topped by a hemispherical depression. The overlying rock units are draped over this struc-

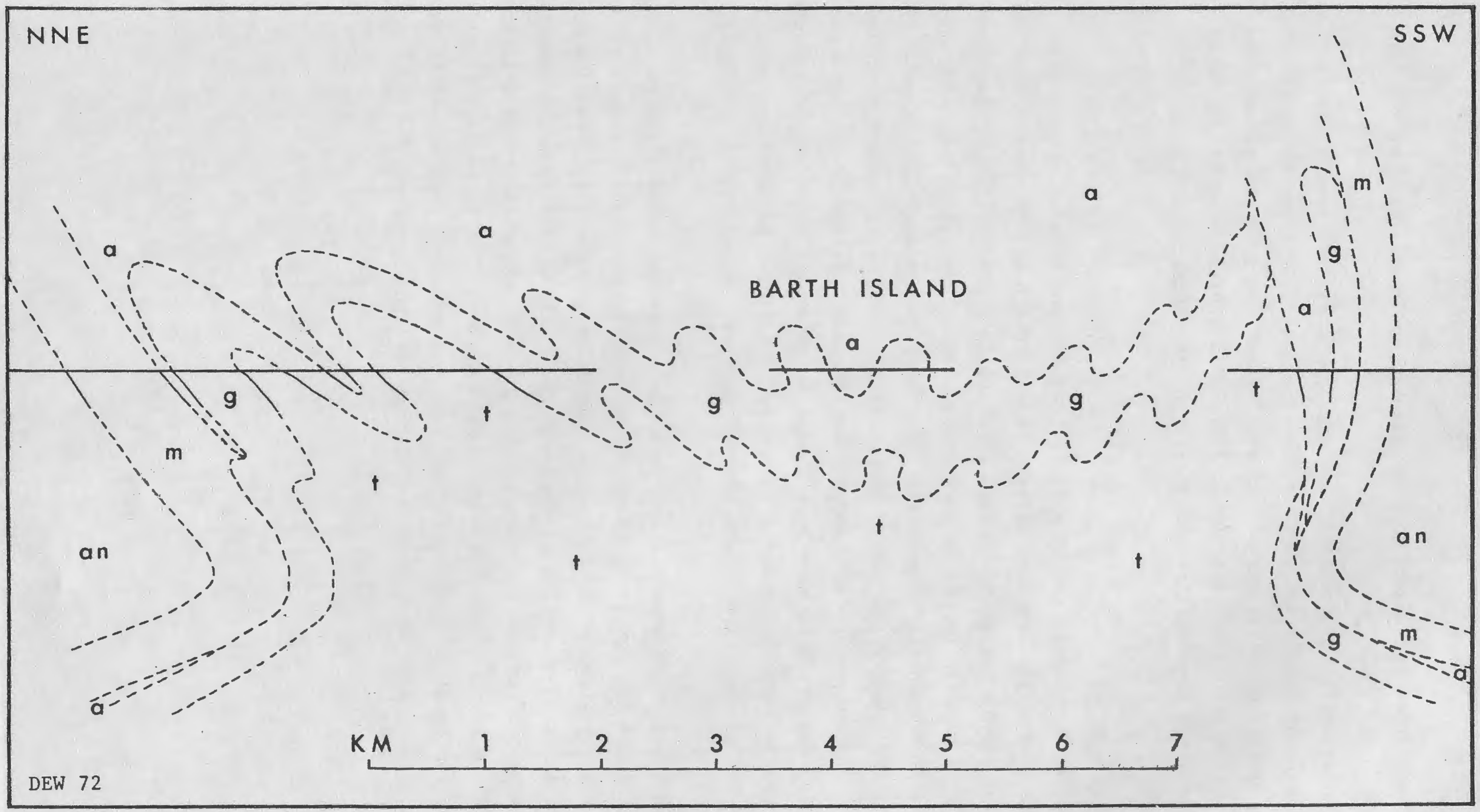

Fig. 16. Geologic section across the Barth layered structure showing possible vertical extrapolations. Legend as in Fig. 15.

ture, overturned and thinned in the flanks, and undisturbed or thickened on top.

The adamellitic rocks are thus the uppermost unit exposed in the layered body. An indication of what may have overlain it may be derived from the succession of units exposed in the flanks. Next to the adamellitic rocks lies a thin zone of gabbroic rocks with ophitic texture, followed by medium-grained leuconorite, and finally by anorthosite with poikilitic pyroxene.

A Tentative Model

Our observations seem to suggest that the anorthosite complex here represents a strongly deformed layered mass in which from bottom to top the following layers may be recognized: troctolitic rocks, grading upward into gabbroic or noritic rocks, in turn grading into porphyritic rocks of monzodioritic to monzonitic composition, and those into adamellitic rocks. The adamellitic layer grades into a leuconoritic layer which becomes more leucocratic and coarser upward, and grades into anorthositic rocks. The sequence is considered to have been formed by crystallization-differentiation from a single magma. The Barth structure is believed to represent an intensely deformed portion of the layered complex, shaped like a lopolithic fold.

The cause of deformation is considered to be the density change in the residual magma during crystallization differentiation. The presence of an increasingly lighter adamellitic residuum below anorthositic crystal mush resulted in local inversion of the sequence. Like a salt dome the adamellitic magma pierced its way upward, through an almost circular hole in the anorthositic mass, dragging along adjacent layers. The Barth layered body may thus represent a structure formed from pre-existing layers, rather than a magmatic intrusion that produced igneous layering in place.

Appendix: Adamellitic Rocks of the Barth Layered Structure

	qu	kf	pf	bi	hb	cp	ol	&c	Johannsen:
BB-34-C	12.5	30.8	43.7	-	2.0	5.5	3.9	1.6	adamellite
AL-10	7.2	22.8	52.8	0.1	2.3	5.7	6.5	2.6	granodiorite
BB-21	4.3	13.7	51.2	-	2.5	14.4	9.5	4.4	granodiorite
BB-28-E	0.3	21.2	55.3	0.2	1.8	10.0	6.4	4.8	syenodiorite (monzodiorite)

Table showing the range of modal compositions of the 'adamellitic' rocks of the Barth layered structure, and their names according to Johannsen's classification. All rocks contain fayalite and micro- or mesoperthite. For the purpose of classification perthitic feldspars are divided into their components and added to K feldspar and plagioclase in the table.

BB-21 is from the central part of the layered structure on Barth Island; the other three are from occurrences along the northern margin of the structure.

ANORTHOSITE-ADAMELLITE CONTACT ON ZOAR PENINSULA

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Several days were devoted to searching out the anorthosite-adamellite contact on Zoar Peninsula (56-08 N, 61-22 W) in the hope that the results might give information on displacement along linears in the area.

Petrology

The main rock types of the peninsula can be divided between anorthosite and adamellite. The anorthosite is divisible into several units: 1. Dark-facies, low-mafic anorthosite, some with very elongate 5-cm plagioclase crystals scattered in 1-cm rock. Locally the laths define a well-developed foliation. 2. Paler 1-cm noritic anorthosite in which the mafics tend to be localized in diffuse clots. 3. Medium-grained noritic anorthosite with well-developed subophitic texture. Possibly a variant of this rock has equant-granular texture.

The adamellite occurs as two major facies. The most abundant is a medium-coarse rock in which quartz with a bluish tinge and a pyribole with the high luster of hornblende are recognizable. This rock tends to be greenish gray on fresh surfaces and bleaches pale gray or pale pinkish. Less commonly the adamellite is medium grained with medium-coarse feldspar megacrysts containing small insets of light and dark minerals, a feature characteristic of adamellitic rocks. In this rock also the mafic appears to be hornblende. In both types of adamellite the dark minerals are granular rather than subophitic. There are also dikes of medium-fine-grained biotite granite with equant-granular texture that may be related to the adamellite.

Several diabase dikes traverse the adamellite with northwesterly trends, weathering out to form minor linears.

Field Relations.

The finer grained adamellite occurs at the anorthosite margin, but is not restricted to this relationship, a considerable area of it occurring along the peninsula south shore towards the bay head.

Anorthosite near adamellite shows waxy feldspar with pink-stained grains, and altered pyroxene. This alteration makes recognition difficult, but the interstitial character of the mafic areas between feldspar laths often survives to distinguish the rock from adamellitic rocks with their granular mafics. There are even rare inclusions of anorthosite in adamellite and adamellite dikes in anorthosite. These features demonstrate that the adamellite is intrusive and the younger rock.

The explanation for finer grain and more pronounced subophitic texture in the anorthosite adjacent to adamellite is less obvious. To paraphrase the question of an associate on R.V. Pitsiulak about a similar problem: how does the anorthosite know where the adamellite will be intruded? Possibly the adamellite followed the anorthosite margin.

Where the contact crosses the summit of the peninsula south shore ridge, there is a zone some 400 m wide in which the rock is high-mafic with equant-granular medium-grained texture. It may be a textural variant of the medium-grained subophitic noritic anorthosite, but is sufficiently different so that it may be an independent granulite zone where the invading adamellite deviated slightly from the anorthosite margin to cut off the nose of a reentrant angle.

An apparently independent adamellite body with anorthosite inclusions forms the northeast hill of the peninsula. Contact effects are not as obvious adjacent to this intrusion as they are adjacent to the main body, and the anorthosite shows no change as this adamellite is approached. This suggests that the adamellite is a small satellite of the main body.

Such irregularities of the boundary between anorthosite and adamellite make it difficult to draw any conclusions about displacements in the area without more detailed mapping, but available data can be interpreted to indicate a left-lateral displacement along an east-west linear through the bay south of the peninsula. Reddened zones of very closely spaced fractures on the south shore of the peninsula could be part of such a fault zone.

THE BRIDGES AREA

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The Bridges area southeast of Nain is a rectangle of eight by ten km, including Palungatak I. and the western part of Paul I.

Three major geologic units occur near The Bridges Passage:

1. The Bridges layered group (LG)
2. Dark facies anorthositic group (δ)
3. Pale facies anorthositic group (λ)

Additionally, a 500 m wide adamellite dike trends northwest across Palungatak I.; small (1-3 m) granitic dikes are very common. Numerous diabase dikes with aphanitic margins, up to 25 m total width, are widespread and have varied trends.

The Bridges Layered Group

The layered group is a monoclinal layered intrusion trending northeast and dipping steeply to the southeast, about 2 km thick (a minimum thickness; the LG is cut off by the dark facies group at its top). A preliminary description was given in FR 1971, p. 47-60. The overall composition is gabbroic. Primary phases are plagioclase, augite, hypersthene, olivine and Fe-Ti oxides. All may occur as cumulus minerals. The cumulate layers are from less than a centimeter to a few meters thick and vary from ultramafic, oxide-rich pyroxenite to anorthosite. Layering may be simple or complex. Layers are variously massive, flow banded or finely bedded; they may have sharp or diffuse boundaries, be homogeneous or graded, and have granular or subophitic textures. Some bedding is irregular and gives the impression of confused lenses and scours. Tops, by good graded bedding, are always up to the southeast. Much layering is regular and in places very delicate; dips range from 75° to 35° southeast.

Slumping, often extensive, shows that the mafic-rich layers were brittle relative to more leucocratic layers, which flowed around the mafic

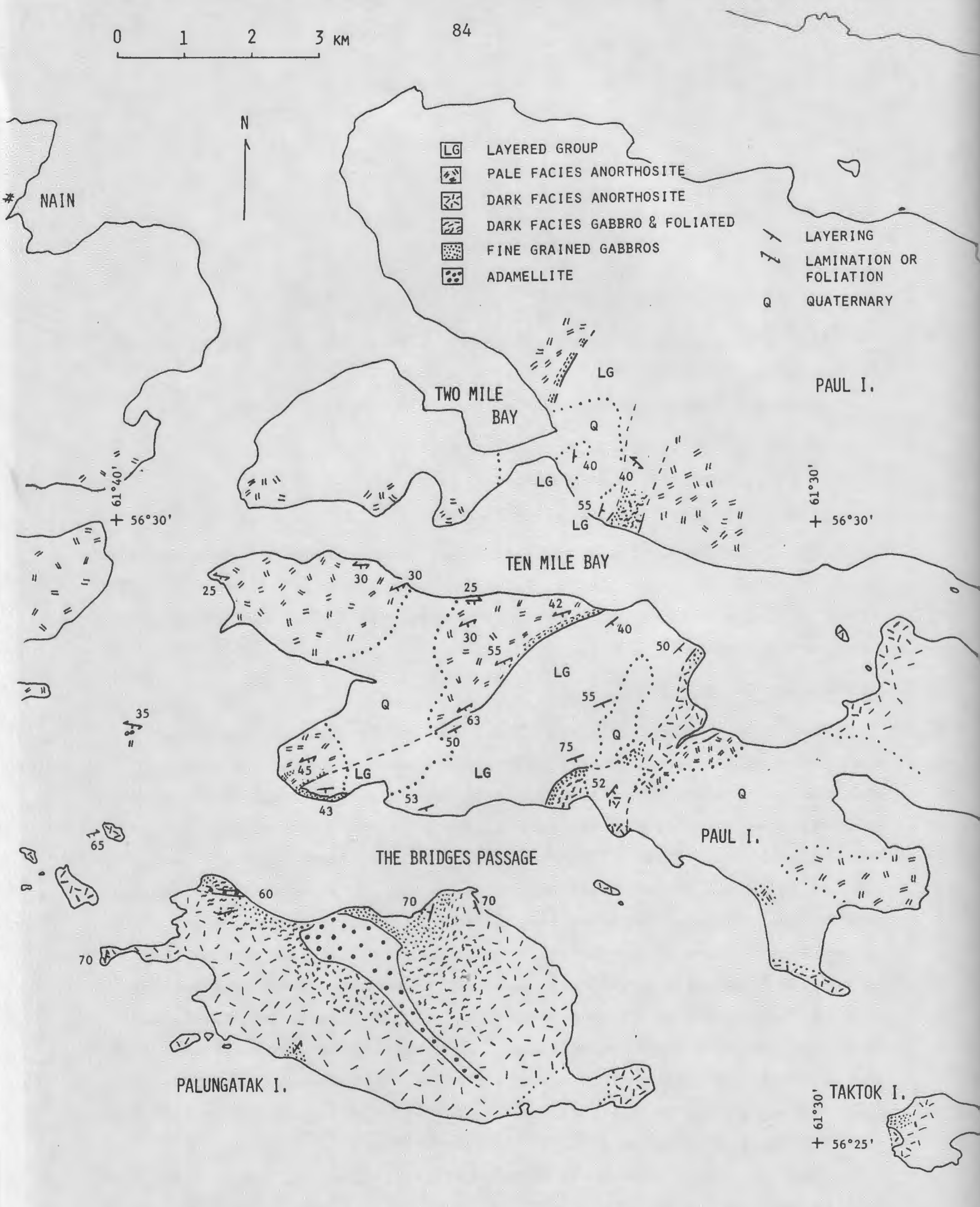

Fig. 17. Geologic sketch map of The Bridges layered zone and adjacent areas.

blocks. This suggests that the mafic layers solidified rapidly and isothermally as adcumulates, while the leucocratic layers solidified more slowly with falling temperature as orthocumulates. Whether the slumping and related tectonic features are due to a primary depositional slope or a post-depositional disturbance is uncertain. The occurrence of the very fine and regular extensive layering suggest that the depositional surface was formerly closer to the horizontal (see FR 1971, pp 55-56).

Mineral compositions* at the base of the LG are, in Mole %:

plagioclase	An 81
cpx	En 84, Ca:Mg:Fe 46:46:8
opx	En 80
ol	Fo > 75

Plagioclase near the top of the LG is An 64. Thus the temperature of crystallization decreases upwards as expected.

The LG segment north of Ten Mile Bay is displaced several km to the west of the segment south of the bay. This accords with a common left-lateral displacement on linears in the Nain area, as for example at the Barth Island troctolite to the northwest of Nain (see de Waard and Mulhern, this report).

Dark Facies Group

The dark facies (δ) group includes the δ anorthosite of Wheeler (1960, 1968) and rocks gradational through leucogabbro to olivine gabbro and troctolite. It is here identified on the basis of dark plagioclase color, mafic content, and field relations. Textures are subophitic and grain size varies from 0.5 to 25 cm. The δ group is on the whole massive, though locally it has flow lamination and rare layering. More common is a block structure, generally of fine-grained rock engulfed by coarser varieties, sometimes of several generations. Pegmatoid patches of very coarse plagioclase, pyroxenes, and olivine are common in the anorthosite. In places these have biotite books and quartz-K feldspar intergrowths, but these may be associated with nearby granitic dikes and veinlets. Along the margins of the δ group the rocks are more foliated, finer grained and hetero-

*Optical and reconnaissance electron microprobe values.

geneous. Fine-grained marginal gabbros occur at contacts of the LG with δ and λ facies rocks, and on Palungatak I. where the LG is not exposed but is inferred nearby (underwater).

The δ group intrudes and transgresses the east end of the LG, and has a fine-grained, granular, flowbanded, often oxide-rich olivine gabbro at the contact on Ten Mile Bay and the north shore of the Bridges Passage, east end. At the last locality this marginal gabbro grades eastward with increasing grain size through foliated subophitic olivine gabbro, leucotroctolite and leucogabbro to δ anorthosite. The marginal olivine gabbro is less than 50 meters wide here.

The LG is not seen on Palungatak I. The equivalent δ rocks east of the marginal olivine gabbro on the south (Palungatak) shore of the Bridges Passage, east end, show igneous layering which dips to the southwest <u>under</u> the marginal gabbro and the inferred contact with the LG. Tops with fair certainty are up into the marginal gabbro and here the δ rocks appear to have accumulated against a roof. Generally finer grained, foliated δ rocks occur along the north shore of Palungatak I. and higher topographically than coarser rocks to the south.

Mineral compositions in the δ group are:

marginal olivine oxide gabbro, N. Bridges Passage E.	An_{59}, Opx En_{64}, Cpx En_{66}, Ca:Mg:Fe = 37:52:11
leucogabbro	An_{51}, Opx En_{74}, Cpx En_{74}, Ca:Mg:Fe = 45:41:14
anorthosite	An_{59}
pegmatoid patch	An_{43}, Opx En_{64}, Cpx En_{79}, ol Fo_{66}

At the northwest tip of Palungatak I. (S. Bridges Passage W.) there is a fine-grained, flow-banded marginal gabbro that grades into a medium- to coarse-grained, foliated, olivine gabbro, which further appears to grade into δ anorthosite. The fine-grained marginal gabbro contains ultramafic xenoliths up to a few meters long with hornblende reaction rims. Mineral compositions are:

xenoliths	An_{79}, Opx En_{79}, Cpx En_{78}
marginal gabbro S. Bridges Passage W.	An_{60}, Opx En_{70}, Cpx En_{77}

foliated olivine gabbro	An_{83}, Opx En_{81}, Cpx En_{83}, Ca:Mg:Fe = 37:52:11, ol Fo_{81}

The xenoliths may be cognate or they may be LG pyroxenites. The overall impression is of an active margin during intrusion of the δ magma. The lower An in the marginal gabbro may be due to supercooling at the contact.

A similar fine-grained gabbro occurs at the west contact of the LG with pale facies leuconorite on the north shore of the Bridges Passage, west end. Here the gabbro intrudes the LG lit-par-lit fashion and there are hornblende reaction rims on inclusions of LG pyroxenites. Mineral compositions are:

contact gabbro N. Bridges Passage W.	An_{67}, Opx En_{75}, Cpx En_{78}
LG	An_{81}, Opx En_{80}, Cpx En_{84}

The similar appearance and mineral compositions of these two gabbros on the western Bridges Passage leads to a tentative classification of both as marginal variants of the δ group. The ultramafic xenoliths are accordingly identified as LG pyroxenites. A slice of similar gabbro occurs about 300 meters west of the LG and the contact gabbro, in laminated leuconorite. Veins of coarse leuconorite pass into this gabbro, which has no evident chill margin. Thus it appears here that the gabbro is older, but it might be cognate with the leuconorite or it may have been intruded before the leuconorite completely solidified.

Pale Facies Anorthositic Group

The pale facies (λ) anorthosite and leuconorite occur west of the LG. The group is here identified on the basis of pale plagioclase color, low mafic content, absence of olivine, and field relations. There is a gradation between the iridescent pale gray anorthosite (5-25 cm) and the strongly laminated subophitic leuconorite (2-20 cm). Block structures, such as meter-scale anorthosite in leuconorite, are common, and locally the rocks are very heterogeneous with variable grain size, color index and lamination. Much of the λ group has an igneous lamination, in places additionally sheared, and other structures that are roughly conformable with the layering in the adjacent LG. Farther to the west and north the sense of these fabrics appears to diverge from the LG. The contact of the λ group with the LG is also conformable to the LG layering.

Plagioclase in the λ group is about An_{55}. The few data now available indicate more sodic plagioclase going westward away from the LG, but this is as yet a tentative generalization. Pyroxenes are largely altered to chlorite and no compositions are available.

In general the λ rocks appear to have suffered considerably more alteration and shearing than the LG and especially the δ rocks. Monomineralic pyroxenite and oxide layers exist within some block structures, usually much deformed, and suggest that the whole mass was once more structurally regular, with bona fide igneous layering. C. Rubins (FR 1971, p. 39) has found such features in his area and offers the same conclusion.

Discussion

A fine-grained contact gabbro about 30 meters thick occurs between the LG and the λ laminated leuconorite, seen on the south shore of Ten Mile Bay and northeast of Two Mile Bay. This gabbro grades by increasing grain size, lamination and plagioclase content into the λ leuconorite beneath it. The basal horizons of the LG include some fine-grained, granular, massive layers very similar in appearance to the gabbro and the relation between them is as yet uncertain. The contact gabbro is tentatively considered to be a basal gabbro of the LG. Alternatively it may be a chill zone of the λ rocks, or part of the δ group equivalent to the intrusive gabbro at the LG-λ contact, north Bridges Passage west. Very possibly the LG-λ contact includes both an LG basal contact gabbro and a later (δ?) gabbro intruded favorably along the contact zone. This is the current working hypothesis.

The inferred relations among the LG, λ and δ groups depend largely on the nature of the fine-grained contact and marginal gabbros. The δ group, by its intrusive and transgressive contact with the eastern LG, is definitely the younger of these two. The LG and the λ group have similarly oriented igneous fabrics, fairly consistent over large areas, while the δ group is heterogeneous and lacks a regular fabric.

Apparently the λ group has suffered more alteration and deformation than the other two groups and this suggests it is the oldest. The interpretations of δ intruded along the LG-λ contact, and of an LG basal gabbro, indicate, if correct, that the λ group is the oldest, the δ group the youngest, and the LG in between. Particularly thorny field relations at the east contact of the LG likewise indicate that the δ group intrudes both the LG and the λ group. This is supported by Rubins' report (FR 1971, p. 39) of λ anorthosite inclusions in δ anorthosite.

This still tentative interpretation is different from the one (model 1b) adopted in FR 1971 insofar as it provides a pale anorthosite floor to the LG (model 2b).

Summary

Field relations among three contiguous plutons, pale facies (λ) anorthosite, The Bridges layered group (LG), and dark facies (δ) anorthosite indicate that the δ rocks are the youngest, and further suggest that the λ rocks are the oldest and are a floor to the LG. This follows from the identification of a marginal δ contact gabbro against the LG, and the tentative interpretation of other fine-grained marginal gabbros as a basal member of the LG against the λ anorthosite, and δ gabbro intruding both λ and LG rocks. Investigation of this area is continuing.

GEOPHYSICS

PALEOMAGNETIC STUDY OF THE NAIN ANORTHOSITE: PRELIMINARY RESULTS

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INTRODUCTION

Reconnaissance sampling of the Nain anorthosite massif and the Kiglapait intrusion was conducted during August 1972 as part of a continuing paleomagnetic study of anorthosites and related rocks. All specimens collected were oriented hand samples. This was done in view of previous work (Hargraves, 1968, unpublished data) on vertical drill cores from the Kiglapait in which the magnetic vectors appeared to be aligned essentially parallel to the present day earth's magnetic field. A magnetization induced during the drilling process was suspected. Hence, with hand specimens, laboratory studies could be performed on small cores taken at various orientations to test whether drilling in the field had affected the earlier samples.

This report consists of a description of the sampling sites, together with preliminary magnetic results. To better acquaint himself with the sampling site locations, the reader is directed to the maps accompanying Wheeler (1968) and Morse (1969).

SAMPLE SITE DESCRIPTIONS

Five sites in the Nain anorthosite and one site in the Kiglapait intrusion were sampled. Four separate specimens (five at MLRP-1) were collected at each site, the sample locations at any given site being separated by not more than fifty meters.

Although there is a large variation in the mafic mineral content of the rocks in the area (< 5% to > 60%), deliberate care was taken to sample plagioclase-rich rocks (% plag. > 90). Granitic dikes associated with the Manvers granite have intruded the anorthosite and caused the local alteration of pyroxene to hornblende and biotite. All attempts were made to collect unaltered rocks.

STATION 1: MLRP-1 (56-58.0 N, 61-32.0 W)

Five samples of anorthosite were collected from the Mary Lake Roof Pendant (Morse, 1969), a roof pendant of Nain anorthosite in the Kiglapait Layered Group. The site is situated just north of the junction of Man o' War Brook with Port Manvers Run.

STATION 2: KI-3710 (56-58.8 N, 61-23.2 W)

These four samples are from leucocratic portions of the Kiglapait Lower Zone troctolite. The site is along the north shore of Port Manvers Run, 1/2 km west of Village Bay.

STATION 3: PMR-1004 (56-53.3 N, 60-34.8 W)

These include four samples of dark facies anorthosite (Wheeler, 1968).

STATION 4: PMR-1027 (56-47.8 N, 61-38.0 W)

Here, three samples of dark facies anorthosite and one sample from a plagioclase megacryst (*ca.* 30 cm) were collected.

STATION 5: PMR-1037 (56-51.6 N, 61-38.0 W)

At this site, three samples of dark facies anorthosite and one sample of banded "ribbon rock" anorthosite (alternating 1 cm layers of mauve and blue-green plagioclase) were collected.

Stations 3, 4 and 5 are all located along the east shore of Port Manvers Run; see Fig. 19, p. 104, for locations.

STATION 6: PL-003* (56-29.6 N, 61-37.7 W)

These four samples are pale facies anorthosite (Wheeler, 1968) collected on Paul Island near the southwest corner of Ten Mile Bay (Fig. 17).

MAGNETIC RESULTS

The paleomagnetic data, both natural and after A.C. demagnetization, obtained on single specimens from each sample collected, are summarized in Tables 1 and 2. These measurements were made in the Rock Magnetism Laboratory

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*Collected by G. Planansky, Harvard University.

at Princeton by Mrs. N. Dorety, using the P.A.R. S.M.-1 spinner magnetometer and standard AC demagnetization equipment.

TABLE 1. Natural remanent magnetic data for 6 Nain sample sites.

NRM[1]

	Site No.	n	D	I	k	α_{95}
KI-3710	30	4	314	67	14	26
MLRP-1	31	5	65	64	52	13
PL-003	32	4	75	83	6	40
PMR-1004	33	4	62	52	27	18
PMR-1027	34	4	152	72	3	63
PMR-1037	35	4	89	54	17	23
	Mean	(6)	71	73	12	20
			(100 - 200 - oe)			
	30	3	285	28	39	20

NRM MEAN POLE

N	LAT	LONG	K	α_{95}
6	55	350	5	34

[1] D = declination, deg. east of north; I = inclination, (+) ve downward; k = Fisher's precision parameter; α_{95} = radius of 95% confidence circle (degrees).

TABLE 2. Results of AC demagnetization. Abbreviations as in Table 1.

500 - 700 oe AC Demag.

	Site No.	n	D	I	k	α_{95}	Pole Lat.	Pole Long.
KI-3710	30	3	83	31	11	39	18S	144W
MLRP-1	31	4	107	-27	7	37	21N	158W
PL-003	32							
PMR-1004	33	4	111	10	3	63	7N	172W
PMR-1027	34	3	137	37	14	35	4N	159E
PMR-1037	35	3	97	-3	18	30	5N	156W
	Mean (5 sites)		106	10	7	32		

Mean Pole after AC Demagnetization

	N	Lat.	Long.	α Lat.	α Long.
	5	4N	168W	16	32
Mackenzie Dikes (Mean) (Fahrig & Jones, 1969)		$3\frac{1}{2}$N	171W	$\alpha_{95} = 4\frac{1}{2}°$	
Michikamau (Murthy et al, 1969)		1S	145W		

DISCUSSION

The NRM of all samples is moderately consistent (Table 1). On systematic AC demagnetization of most specimens the magnetization decreased in intensity and changed in orientation in fields up to 150 to 200 oe; thereafter it tended to be relatively stable, up to fields of 1000 oe in some cases.

On the whole, however, despite the generally stable magnetic behavior, the within-site consistency decreased. The stable magnetization of two or three samples would agree, and the fourth would be approximately reversed; at two sites two samples were similar, a third reversed and the fourth completely different.

In experiments to date, AC demagnetization to 1000 oe does not improve the grouping. If only the two or three consistent samples at each site are considered, however, a modest between-site consistency is apparent. Pending further measurement of second specimens from each sample, and thermal demagnetization experiments, the following subjective selection and analysis of vectors has been made:

STATION 1. Magnetic site No. 31. MLRP-1.

One sample rejected, one reversed, and combined with 3 others, n = 4.

STATION 2. Magnetic site No. 30. KI-3710.

One sample rejected; 3 samples used, n = 3.

STATION 3. Magnetic site No. 33. PMR-1004.

One sample reversed and combined with the other 3, n = 4.

STATION 4. Magnetic site No. 34. PMR-1027.

One sample rejected; 3 samples used, n = 3.

STATION 5. Magnetic site No. 35. PMR-1037.

One sample rejected (the ribbon anorthosite sample); 3 used, n = 3.

STATION 6. Magnetic site No. 32. PL-003.

No apparent consistency - abandoned.

Excluding Station 6; of 21 samples, 17 have been used in the analysis, the RM vector of two of these being arbitrarily reversed.

The mean vector obtained from 5 sites. (D = 106, I = 10, k = 7 and α = 32) gives a pole at 4°N, 168°W, Table 2. The agreement with the Mackenzie dike pole has little significance because of the great scatter in the Nain data available at present. A much greater consistency in remanence orientation must be obtained from Nain rocks, both within and between sites, for the results to be interpreted with confidence in terms of the Precambrian polar wander curve for North America.

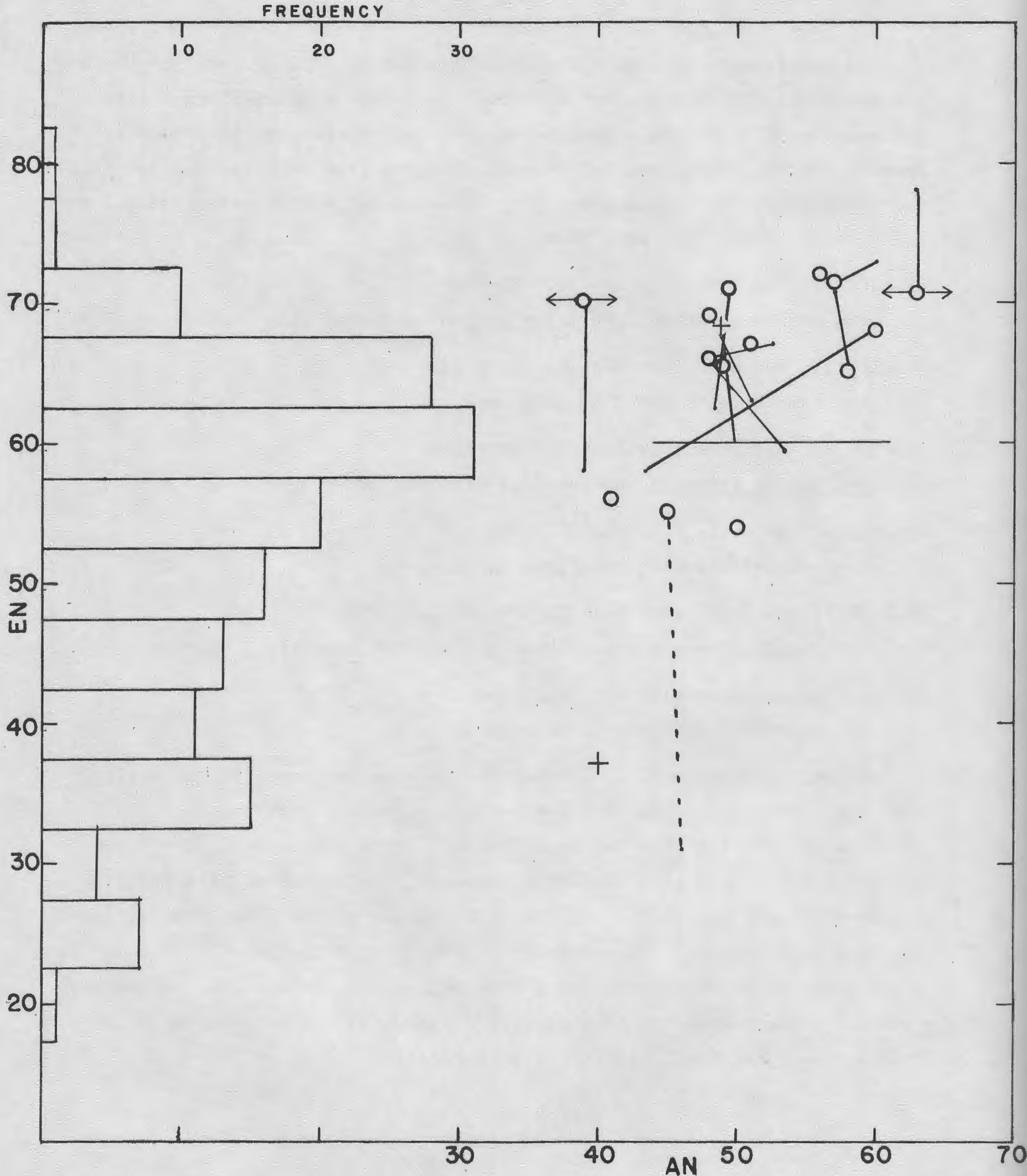

Fig. 18. Compositions of giant orthopyroxene with associated plagioclase, and of orthopyroxene and plagioclase in the enclosing anorthositic rocks, with histogram (N = 158) of orthopyroxene composition frequencies in the Nain anorthosite-adamellite complex. O Giant orthopyroxene and associated plagioclase; ←O→ giant orthopyroxene with unknown associated plagioclase composition; · orthopyroxene and plagioclase of enclosing rock; + orthopyroxene diorite "sweat dike" in anorthosite. Tie lines connect giant orthopyroxenes with their host rocks. Dashed tie line is based on rock analysis norm of nearly pure anorthosite.

MINERALOGY

GIANT PYROXENES IN ANORTHOSITE

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Introduction

In last year's report (FR 1971, p.66), attention was drawn to unexpected compositions of giant orthopyroxene crystals in anorthositic rocks. A comparison of giant orthopyroxene compositions and the compositions of intergrown or associated plagioclase with the orthopyroxene and plagioclase compositions of their host rocks in the Nain anorthosite complex is not yet sufficiently extensive to show a comprehensible pattern. However, the limited results available are suggestive and are offered as a base line for further studies.

The Problem

If a melt of appropriate composition cools as a closed system, the orthopyroxene with the higher Mg/Fe ratio or the plagioclase with the higher Ca/Na ratio will crystallize at the higher temperature. Therefore, increasing An and En in Fig. 18 indicate higher crystallization temperature, hence earlier period of formation if a single magmatic cycle is assumed.

There has been a tendency among field workers to consider giant pyroxene with associated very coarse plagioclase as late, possibly pegmatoid crystallizations in the anorthosite. If this were the case, they should have lower temperature compositions than the compositions in the finer grained enclosing rocks.

The Data

The orthopyroxene and plagioclase compositions reported in this study are based on refractive index determinations, using the dispersion techniques discussed in the 1971 Field Report (p. 69-71). In Fig. 18 the En values of orthopyroxene are plotted against the An values of associated plagioclase. Circles represent the giant orthopyroxenes with their associated plagioclase, and dots represent the plagioclase and orthopyroxene of the enclosing rock. Tie lines connect the giant orthopyroxene values with the corresponding host-rock values. Horizontal arrows on giant pyroxene symbols indicate lack of information on the composition of the associated plagioclase, the giant pyroxene composition being plotted at the same plagioclase composition as that in the host rock. The dotted tie line indicates that the En value of the enclosing rock is based on the norm of a rock analysis, groundmass orthopyroxene for refractive index determination not being available. Some of the first giant pyroxenes were collected without specimens of the enclosing rock, but their compositions are included in Fig. 18 to give a more complete picture of giant orthopyroxene composition range.

Along the En axis is a histogram showing the distribution of 158 orthopyroxene compositions that have been recorded from rocks of the Nain anorthosite-adamellite complex. These compositions have been determined over many years by various refractive index techniques and with varying precision. Also the criteria for including rocks in the complex have varied over the years. Thus the histogram is no more than a first approximation, but it should give a fair idea of orthopyroxene composition distribution in the complex.

Field evidence strongly indicates that several occurrences of very coarse pyroxene formed late in the consolidation history of the rock. In one case, the pyroxene is involved with a granophyre pocket near the anorthosite margin on Paul Island (56-30 N, 61-19 W). This proves to be one of the very few big clinopyroxenes encountered in the study.

In the other cases, a "sweat dike" with indistinct margins 0.5 m wide, composed of very coarse plagioclase An_{40}, orthopyroxene En_{37} and opaque oxide, cuts finer grained pale anorthosite. This rock is plotted as a cross on Fig. 18. Values for the adjacent pale anorthosite are not available, but in a pale anorthosite with above-average mafic content 0.8 km away, the orthopyroxene composition is En_{47}, much higher temperature than that in the dike rock. Its plagioclase is more ambiguous with megacrysts An_{47} and groundmass An_{37}.

After the above was written, work on another "sweat dike" gave values of An_{49} and En_{68}. This occurrence is also shown as a cross in Fig. 18. In this case, data for adjacent anorthosite are available. The tie line is drawn to the average feldspar composition, and the horizontal line indicates the unusually wide range of its composition.

Discussion

If the compositions of the giant orthopyroxenes are compared with the orthopyroxene composition distribution shown by the histogram in Fig. 18, it is evident that the great majority are more magnesian than the maximum frequency, and none except that of the late "sweat dike" are far below it. In fact the giant orthopyroxene composition range is remarkably limited. Hargraves (1962) found similar orthopyroxenes "up to 20 cm" with a similar, though slightly more magnesian, composition range (En_{71-74}), and he cites references to pyroxenes of similar character and composition in many other anorthosite bodies. Thus the phenomenon is not peculiar to the Nain anorthosite. The high-magnesian composition of the giant pyroxenes indicates that as a group they formed at a higher temperature than the majority of the orthopyroxenes in the complex.

The relationship between giant orthopyroxenes and the specific rocks in which they occur is more ambiguous. Five out of nine are higher temperature. It is noteworthy that the reverse relationship of the others is not because they are lower temperature than other giant orthopyroxenes, but because they occur in rocks with exceptionally high-temperature mineral compositions.

Prof. A. F. Buddington, who called attention to the Hargraves reference, has suggested that if opaque oxides accompanying giant pyroxenes have a higher state of oxidation than those in the enclosing rock, ferrous oxide that would normally go into pyroxene may have been prevented from doing so by oxidation, thus raising the magnesium-iron ratio of the pyroxene (personal communication, 1972). No study of the oxides has been made, so direct evidence on this point is lacking. However, it may be noted that opaque oxides rarely accompany giant pyroxenes in significant amounts. Also such an oxidation process would not account for the lower Ca/Na ratio of groundmass plagioclase so prominently displayed by the pair with the longest solid tie line in Fig. 18. It was this material which prompted the investigation. It is the only case where the plagioclase associated with the giant pyroxene occurs as granular zones within the crystal, making contemporaneity of the plagioclase and the giant orthopyroxene difficult to question. In the other cases, there is less assurance that the plagioclase associated with the giant pyroxene is in equilibrium with it rather than with the enclosing rock. Some of the smaller differences in plagioclase compositions shown by the tie lines could represent small variations in groundmass plagioclase composition, and in any case, they approach the range of experimental error.

In most cases, the field relations of giant pyroxenes and plagioclases to the finer grained anorthositic rocks that enclose them are susceptible of alternate interpretations, especially when the giant crystals are assembled in aggregates with indistinct outlines, as they commonly are. These aggregates could be rafts of early-crystallized material that have been incorporated in the later-crystallizing rock that encloses them. Alternatively, they could be pockets of residual material that crystallized after the enclosing rock, their coarse grain and late crystallization being promoted by the presence of mineralizers. By decreasing the size of raft or pocket, the argument would seem to be applicable to apparently isolated giant crystals of either mineral.

To the extent that higher formation temperature can be interpreted as earlier time of formation, the weight of evidence presented in Fig. 18 indicates that the giant pyroxenes formed early in the course of crystallization, and that in the majority of cases examined, they formed earlier than the rocks in which they are embedded. In most of the remaining cases, they occur in rocks which are themselves among the earliest crystallizations, as indicated by the orthopyroxene frequency histogram.

The "sweat dike" whose mineral compositions are shown as the lower cross in Fig. 18 is one occurrence where field relations give clear evidence of relatively late age. It supports the hypothesis that lower-temperature mineral compositions indicate later crystallization. However, Hargraves (1962) describes "coarse" orthopyroxenes of the same high-magnesium composition occurring along well-developed joints. In some outcrops, the joints transgress a primary foliation, and the pyroxenes have unmistakably been introduced subsequent to the consolidation of the anorthosite. The compositions of the second "sweat dike" shown in Fig. 18 agree with Hargraves' data. Such occurrences cannot be accounted for by the hypothesis set forth here, and strongly indicate the need for more work on the problem.

As knowledge of the Nain anorthosite-adamellite complex becomes more detailed, accumulating evidence suggests that it may be a group of similar but non-contemporaneous plutons. To the extent that this is so, early crystallizations in one occurrence may be products of crystallization in a different pluton from those in another, and thus not of the same chronological age. The occurrence interpreted as a "sweat dike" might actually be a case where material from one such pluton has penetrated another, but in general no evidence has developed to indicate that relations between giant pyroxenes and their host rocks in any given occurrence are complicated by such an interpenetration of plutons.

Too few giant clinopyroxenes have been encountered to justify any conjectures about the conditions under which they form. It may prove significant that one is involved with a late-stage dike and another with a granophyric pocket.

The process by which high-temperature giant crystals form remains a problem. There appears to have been an early stage during the consolidation of magma from which anorthosite was derived when centers of nucleation were widely spaced. During this period, currents may have carried the relatively few growing crystals through zones favorable to growth in a manner analogous to the way air currents promote the growth of hail stones. Then, when the centers of nucleation increased, the giant crystals were trapped in regions where they were out of equilibrium with the enclosing material to varying degrees. This could account for some of the inconsistencies in Fig. 18.

The process involved seems to have been effective through the crystallization history of the anorthosite-adamellite complex, producing a generation of big plagioclase crystals as well as pyroxene in the anorthosite, the oversized K-feldspar ovoids in associated adamellite with rapakivi texture, and bimodal grain sizes in the intermediate rocks of the complex.

These observations and the hypothesis derived from them lead to a number of conclusions about the processes involved in the consolidation of the Nain anorthosite-adamellite complex and the nature of magma from which they were derived.

The prevalence of bimodal crystallization throughout the anorthosite-adamellite series suggests that these textures are the result of magma-chamber conditions rather than magma composition.

If the giant pyroxene crystals did form early in the crystallization history of the magma from which the anorthosite formed, they demonstrate that this magma contained sufficient mafic material that the course of crystallization reached the pyroxene-plagioclase cotectic at an early stage in the history of consolidation.

They also demonstrate that the particular magma in which they formed was already silica saturated, or olivine would have crystallized instead. That this was not true of all the magma in the complex is demonstrated by the occurrence of olivine-bearing anorthositic rocks.

If there was sufficient mafic in the primary magma so that the pyroxene-plagioclase cotectic was reached at an early stage, feldspar crystals must have been concentrated by some sorting process in order to produce anorthosite.

Acknowledgement

The laboratory work reported here is supported by National Science Foundation Grant GA-34024, for which the writer expresses his thanks.

PLAGIOCLASE COMPOSITION VARIATION

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Introduction

A number of local studies of plagioclase composition variation have been initiated, with a view to characterizing the range and pattern of composition variation in anorthosite bodies of the Nain massif. Among the possible results of such a study are the delineation of pluton boundaries or structure by compositional criteria, the establishment of composition ranges within areas of various sizes, and the eventual estimation of the plagioclase composition range and mean in the Nain massif as a whole. The large scale of the massif does not encourage the establishment of a sophisticated sampling grid at this time, but the distribution of local studies will be chosen with that end, as well as others, in view.

Results from the 1972 sampling shed light on systematic plagioclase compositional variation along Port Manvers Run, and on the spectrum of compositions in anorthosite xenoliths at Nukasorsuktokh I.

Port Manvers Run

This ship passage has been sampled at roughly 300 m intervals along the shoreline from Challenger Cove (56-45 N, 61-40 W) to Second Rattle (56-55 N, 61-32 W). The area sampled lies just to the east of Berg's Hettasch intrusion area described in this report; see Fig. 1 for the relation between the two study areas. The rocks along Port Manvers Run have been mapped by Wheeler (1968) as dark anorthosite. They contain, for the most part, dark plagioclase (locally iridescent) and minor olivine or augite, and thus range from leucotroctolite to leucogabbro with associated pure anorthosite and few if any mafic layers. Olivine-bearing rocks appear to dominate at the north and south ends of the Run, with augite-bearing rocks toward the middle. Primary layering and lamination appear to be lacking or very weak, except in the northern part of the Run, where poorly developed layering and lamination display consistent southerly dips.

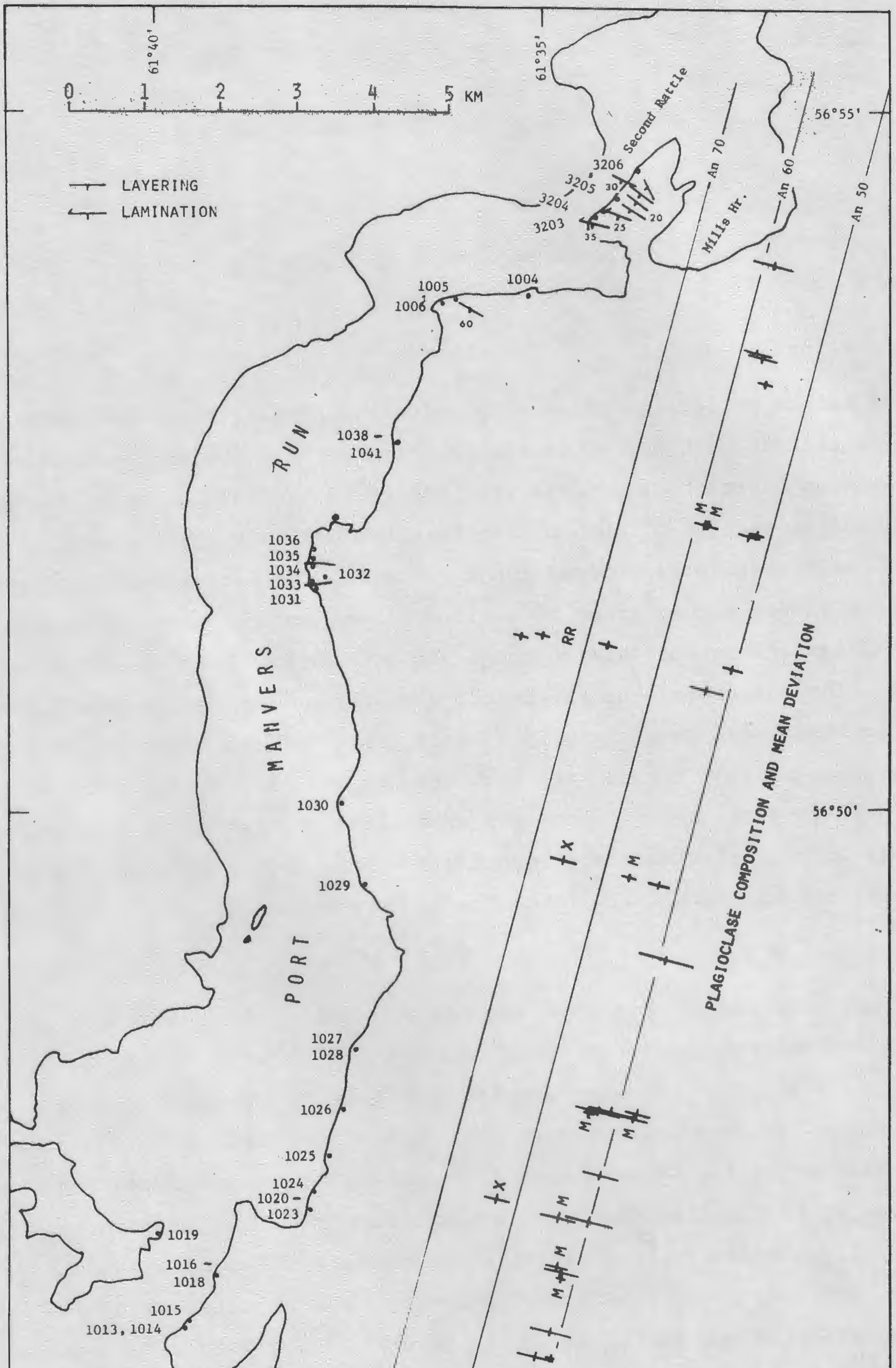

Fig. 19. Port Manvers Run plagioclase composition. The map shows sample locations, and the plagioclase composition section is projected from these locations. M = megacryst, X = xenolith, RR = ribbon rock: see text.

The relation of the Port Manvers Run (PMR) anorthosite body to the adjacent Hettasch intrusion is poorly known, but the southerly dips and locally sharp contact with the Kiglapait intrusion at Hare Pt. (Morse, 1969) suggest that the PMR body is older, and cut by the Kiglapait.

About midway in the sampled section is an extensive exposure of "ribbon rock", a fine-grained, granular, pale-green to pale-brown pure anorthosite with cm-scale banding of the green and brown colors. Samples PMR 1032-1034 are from this unit.

Sample locations and plagioclase compositions (in mole % An) are shown in Fig. 19. Compositions were determined aboard ship for 10 or more grains in each sample, by the dispersion method (Morse, 1968). The ranges shown are mean deviations ($\Sigma|X-\bar{X}|/N$). The mean composition varies from $An_{56.3}$ at the south end to a minimum of $An_{47.8}$ near the middle of the sampled section, and back up to $An_{57.7}$ near the north end. This rather smooth variation appears to define a "compositional syncline", with lower temperature, presumably younger rocks in the center. The available structural information--southerly dips in the north and a contact with country rock in the south--is consistent with a synclinal form, and the compositional variation suggests that the rocks are plagioclase floor cumulates in a syncline or basin. A roof accumulation model is prohibited; such a model would require inverted compositional variation. Therefore an *in situ* flotation origin for the PMR body is precluded.

The unusual "ribbon rock", found also at Nukasorsuktokh I. (see below), is composed of calcic labradorite to bytownite ($An_{67.1}$-$An_{77.2}$). Similar fine-grained pure anorthosite occurs as xenoliths elsewhere in the Run: sample PMR 1025b, $An_{62.9}$, and sample PMR 1030b, $An_{65.8}$. No mafic grains have been noticed in "ribbon rock". The fine grain size (and proximity to a contact at Nukasorsuktokh) leads one to infer that this is a rock from a contact zone; if so, it must be a foundered block from the roof in the PMR occurrence. The small variability of plagioclase composition (mean deviation 1.0-1.4 % An) is consistent with adcumulus growth or, perhaps more likely, a prolonged autometamorphic annealing under rotational stress, which the granular texture seems to suggest. The lack of mafics is unexplained, unless the rock is a roof cumulate. Quite clearly, a detailed field and geochemical examination of these unusual rocks is indicated.

A histogram of PMR plagioclase compositions is shown in Fig. 20. Compositions more calcic than An_{60} are "ribbon rock" or similar fine-grained xenoliths. A number of megacrysts were sampled, and these are shown with a separate symbol. Fig. 21 shows a histogram of composition ranges within samples. These ranges are the differences between maximum and minimum compositions for the grains within a sample. The megacrysts show little zoning, as inferred from the low composition range. About half the PMR whole rocks also show little zoning, and are, by inference, nearly adcumulates (Wager, Brown, and Wadsworth, 1960). The other half, with zoning over a range of more than 9% An, could appropriately be classed as mesocumulates.

The relation between plagioclase megacryst versus host rock composition is illustrated in Fig. 22. Quite clearly, most of the megacrysts are isocompositional with the host rock; three megacrysts are slightly more calcic, and none are more sodic. The high-temperature megacrysts are in accord with Wheeler's findings (this report) on the common occurrence of high-temperature giant pyroxene. Apparently, most of the PMR plagioclase megacrysts grew isothermally in the same average environment as their host rocks, but a few dropped in from some other environment, where growth was also isothermal to judge from the essential lack of zoning.

The PMR traverse shows that useful information on cryptic variation and pluton symmetry can be gained from a reconnaissance of plagioclase compositions. It leads to helpful inferences on the manner of accumulation and solidification of the anorthositic rocks, and on the growth history of plagioclase megacrysts. Finally, it reveals occurrences of unusually calcic plagioclase in "ribbon rock" and possibly related fine-grained xenoliths.

Nukasorsuktokh Island Block Structure

"Block structure" is the anorthosite student's pet name for an assemblage of anorthositic xenoliths in an anorthositic matrix. The structure is a hallmark of massif-type anorthosite, especially near contacts, and it is perhaps the most spectacular proof of a magmatic origin of anorthosite, as well as one of the most helpful sources of information on the crystallization history of anorthositic rocks. The structure is nowhere better displayed, in the Nain area, than on the northeast arm of Nukasor-

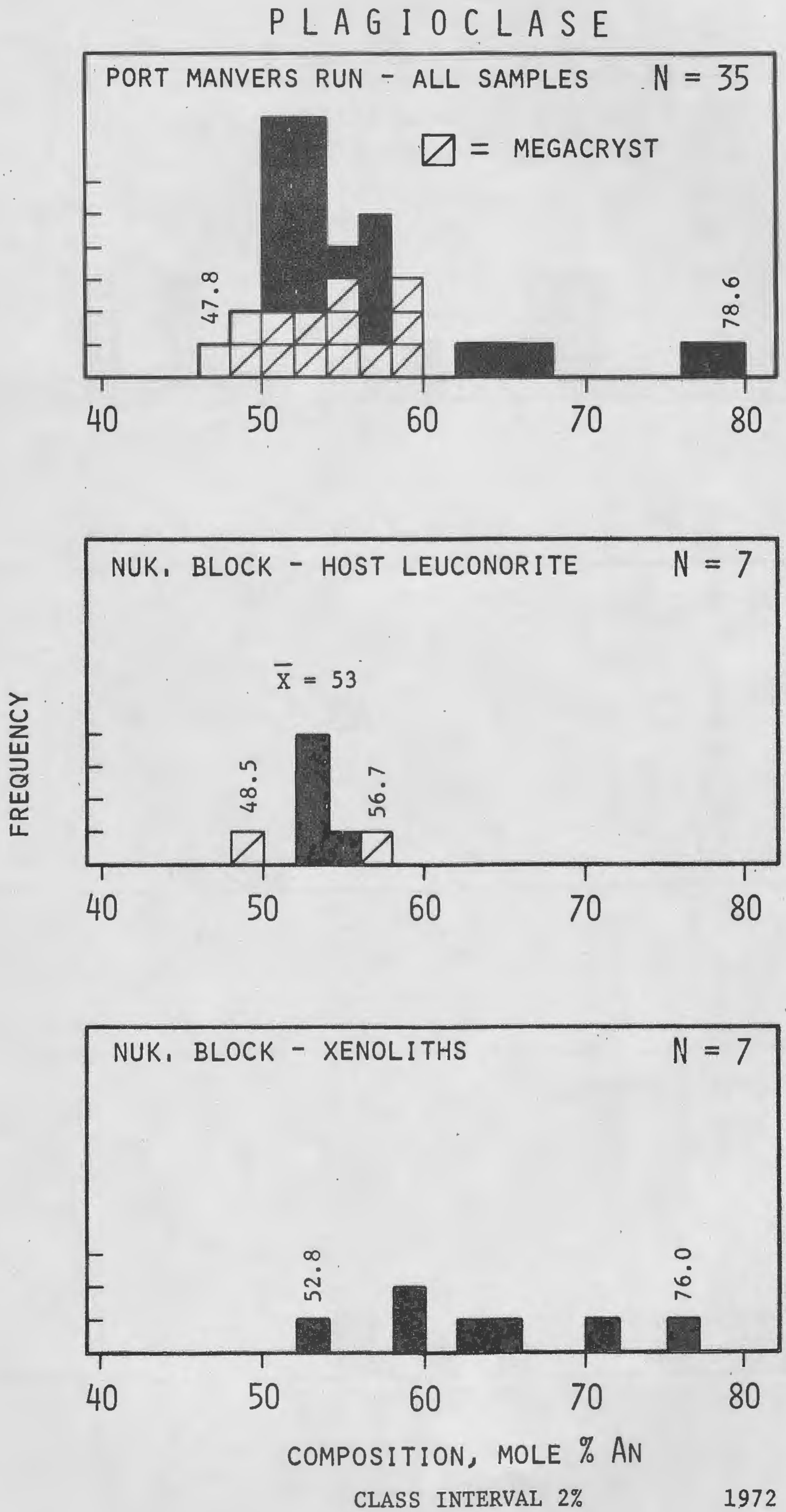

Fig. 20. Plagioclase composition histograms for Port Manvers Run and the Nukasorsuktokh I. block structure.

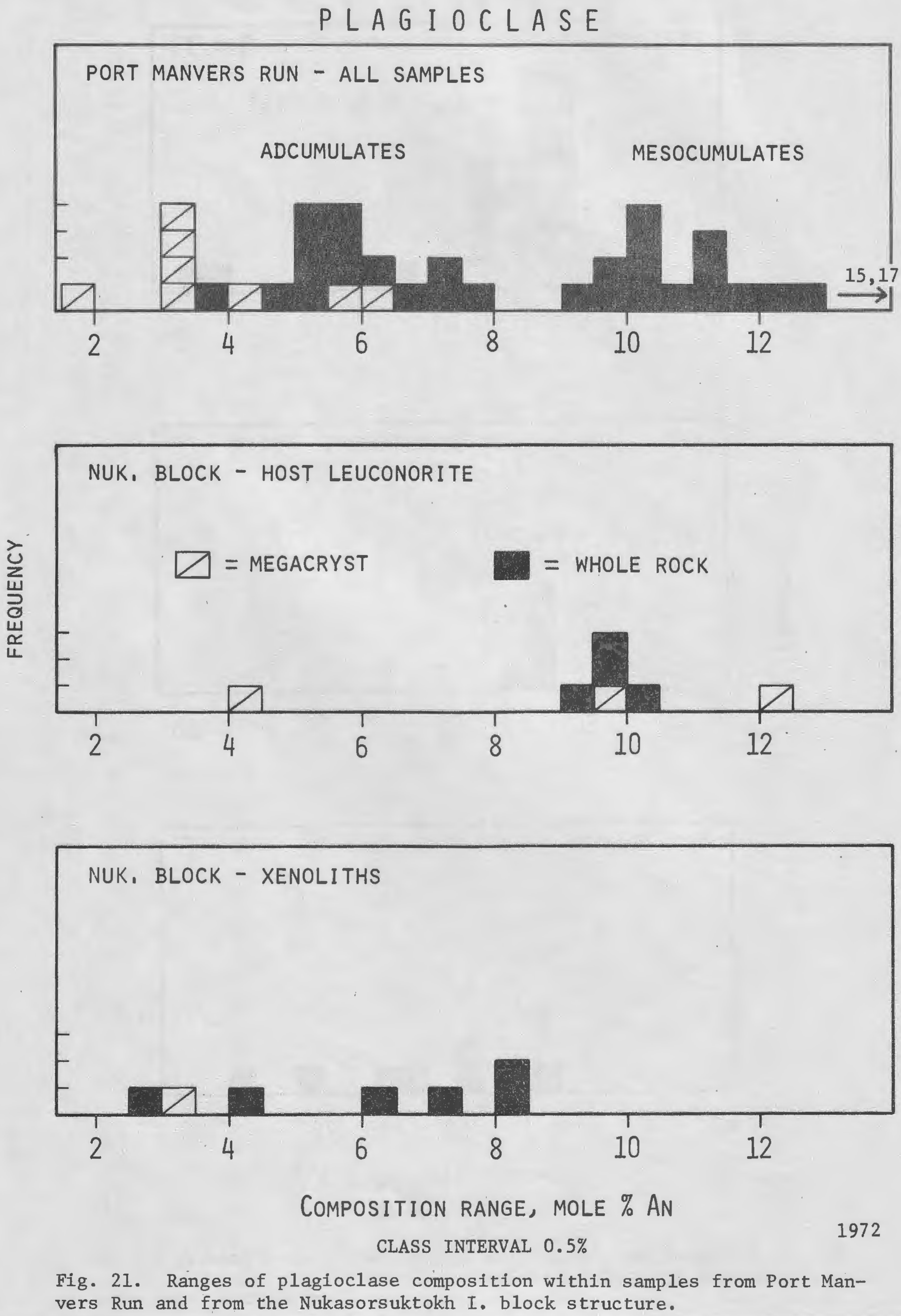

Fig. 21. Ranges of plagioclase composition within samples from Port Manvers Run and from the Nukasorsuktokh I. block structure.

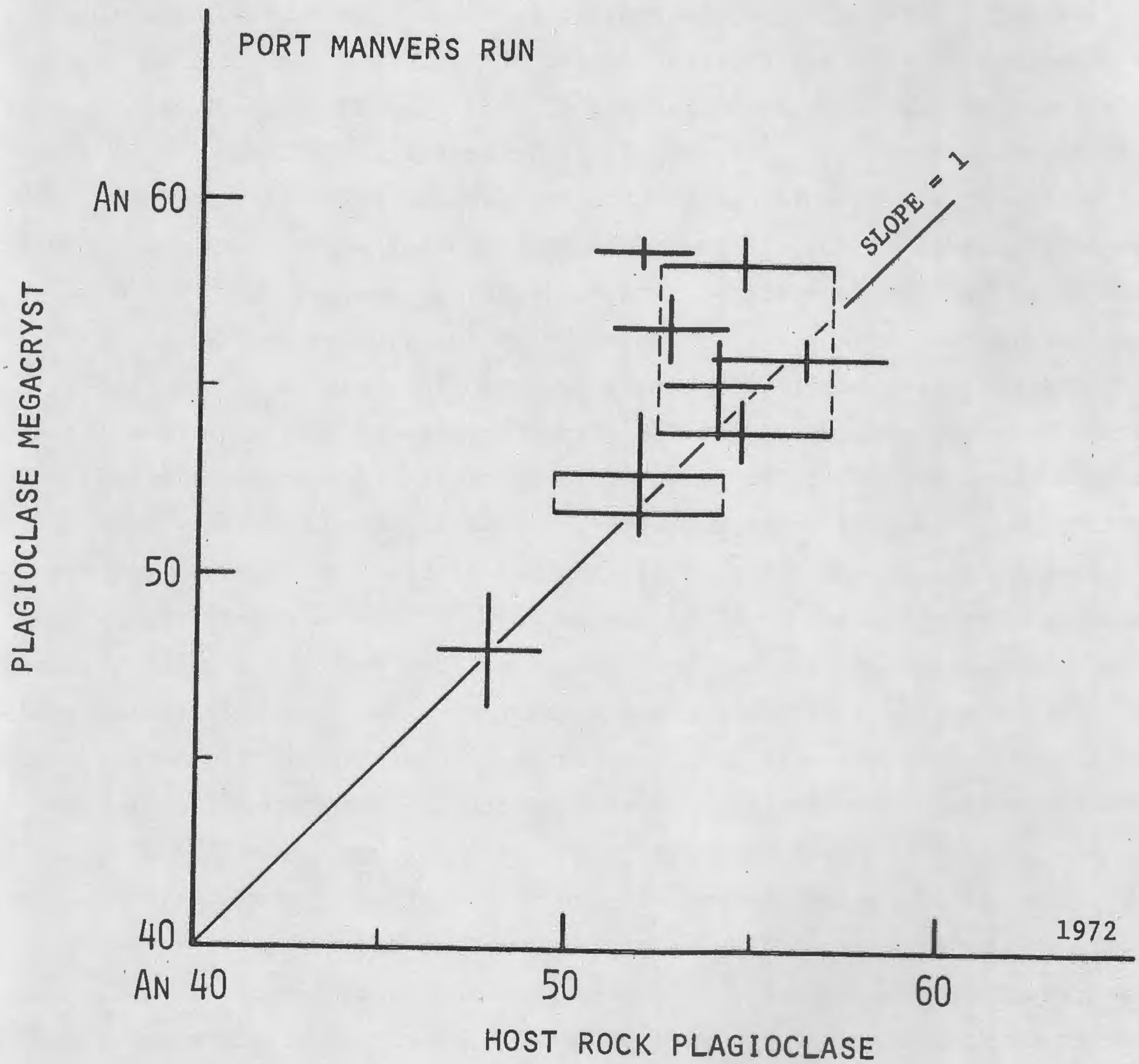

Fig. 22. Compositions of plagioclase megacrysts versus their host rocks at Port Manvers Run. Error bars reflect mean deviation among ten or more grains per sample determined by the dispersion method.

suktokh I. (56-20 N, 61-15 W). Here a wide variety of anorthositic rock types occur as blocks in a rather uniform leuconorite matrix. The blocks themselves can be classified according to many combinations of grain size, fabric, mafic content, and block size. Almost all are accompanied by a mafic rind which belongs to the matrix rock, and which appears to have resulted from a chilling of the matrix magma against the block. In places, these mafic rinds are of pegmatitic coarseness.

The Nukasorsuktokh block structure was visited briefly in 1972 to prepare for a detailed study in another season. Grab samples were taken of a variety of blocks and matrix rocks. Plagioclase compositions from this sampling are illustrated in Figs. 20 and 21. Xenolith (block) compositions range from $An_{52.8}$ to $An_{76.0}$. A large block of "ribbon rock" similar to that found in Port Manvers Run furnished a composition of $An_{70.5}$; the calcic limit of An_{76} is furnished by a smaller sugary-textured xenolith with 5% mafics (unidentified). Other blocks are coarser and vary from anorthosite to leuconorite. Iridescence is locally present ($An_{58.7}$).

The host leuconorite has plagioclase ranging from $An_{48.5}$ to $An_{56.7}$, with a mode and mean at An_{53}. The normal host rocks appear to have a very limited mean composition range, the two extremes cited above both being megacrysts. The more sodic megacryst is from a gabbro pegmatite rind near the margin of a block; the rind is composed of giant plagioclase and pyroxene blades oriented normal to the contact. The more calcic megacryst is of 10-cm diameter, and may be a xenocryst from one of the blocks. Among the xenoliths, the most sodic composition is from a leuconorite block similar in texture to the host rock and probably cognate with it. With this sole exception, the xenoliths are more calcic and far more variable than the host rock. As shown in Fig. 21, they are also more restricted in their individual composition range (zoning in part). The xenoliths tend toward adcumulates, and the host rocks toward mesocumulates in terms of inferred plagioclase zoning. The xenoliths record an apparently extended history of adcumulate anorthosite formation over a relatively wide temperature range; this was followed by emplacement of the more rapidly cooled (more strongly zoned) leuconorite matrix.

<u>Summary of Anorthosite Plagioclase Compositions</u>

Recent plagioclase determinations by the dispersion method are summarized in Fig. 23. Adamellite series rocks are excluded, and the summary is restricted to plagioclase-rich rocks (probably more than 60% plagioclase). The range is from An_{39} to An_{84}. The calcic limits are from The Bridges and Hettasch intrusions described by Planansky and Berg, respectively, in this report. The histogram makes no pretense at being a random sampling of the Nain massif; it is simply a running compilation of routine shipboard and home-laboratory determinations, which will be augmented in future seasons. The extremes of composition are almost certainly overemphasized in terms of the whole Nain massif, but they are instructive in showing the very large range of plagioclase composition developed during the history of this remarkable complex. This range, coupled with known field relations, speaks strongly for the emplacement of many different anorthosite-producing magma batches during the history of the Nain massif.

Acknowledgements

Some of the laboratory work was supported by NSF grant GA 31343. The assiduous help of R. F. Dymek in collecting, and of R. E. Hodgson in microscopy, is gratefully acknowledged.

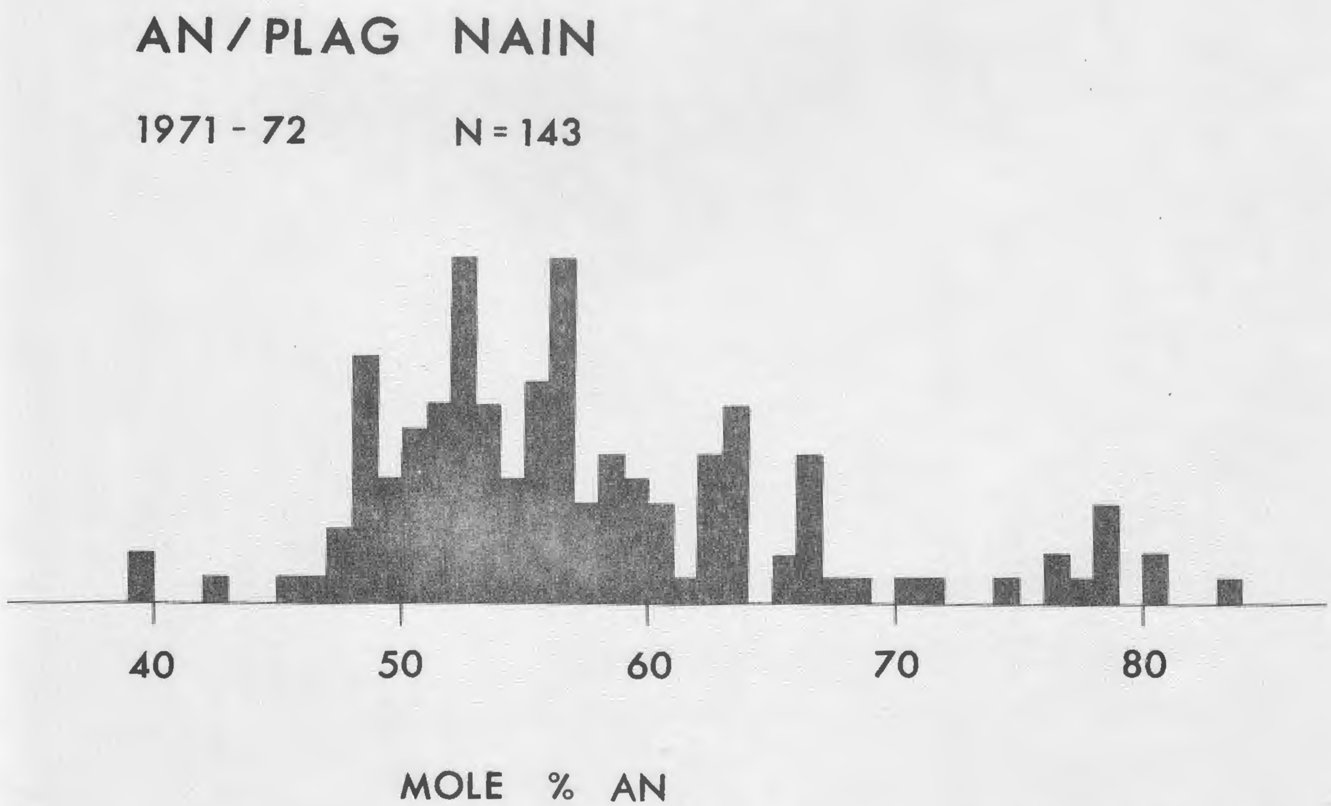

Fig. 23. Histogram of recently determined plagioclase compositions from anorthosite and related basic rocks of the Nain area.

THE FELDSPAR/MAGMA DENSITY PARADOX

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Feldspar flotation models of various kinds continue to enjoy favor among students of anorthosite (e.g. Morse, 1968; Emslie, 1970). Without doubt, such models afford an attractive way of generating anorthosite from basic or intermediate magma, provided the liquid or settled cumulate counterpart can be identified. The models are beset, however, with an unresolved ambiguity and a paradox in the observed field relations. The ambiguity is that no proof of flotation has yet been recognized in the field--the problem may simply lie in not knowing what to expect by way of proof, so that it will have to hit us in the face if we are to recognize it. I refer here only to equilibrium, in situ flotation, as opposed to elutriation by magmatic currents for which some evidence exists (Morse, 1968, p. 180).

The paradox is that we see, or suppose we see, evidence of crystal settling (layering, lamination, channel scouring) even in rocks so ferrous iron-enriched that stable settling should have been out of the question. If flotation seems reasonable, by calculation, for basic and intermediate liquids in general, why do we seem to see the opposite motion in rocks whose parent liquids surely would appear to have been much denser?

The Upper Zone of the Kiglapait intrusion provides a nice example of the paradox. Graded layering, lamination, and erosional features have been observed at least as high up in the stratigraphy as the 99.8 percent solidified level (see for example Morse, 1969, Plate 25). The mean density of all samples of the Upper Zone (UZ) is 3.10 g/cc (N = 63). The mean density rises to as high as 3.28 near the top of the intrusion; the range in uppermost rocks is 2.89 to 3.34. These densities are vastly greater than those of feldspars, and remain so even after the rocks are "converted" to liquid. The following sample calculation illustrates the severity of the paradox.

Assume a density for mesoperthite of 2.60 and a volume thermal expansion of 2.7% at an arbitrarily chosen reference temperature of 1100°C (expansion estimated from Table 6-1 in Clark, 1966), giving 2.53 at 1100°C. This calculation is based on a linear mixing of An_{15} plagioclase and Or_{90} alkali feldspar, and the positive volume of mixing is ignored; this tendency toward overestimation of density is balanced to some degree by ignoring also the appreciable Ba content of these feldspars. The mean density of two uppermost analyzed rocks is 2.93. When the averaged analyses of these rocks (unpublished) are converted to partial molar volumes according to the data of Bottinga and Weill (1970), a liquid density of 2.63 at 1100°C is obtained. This amounts to a 10% volume change on melting, a reasonable value consistent with volume changes reported for pure plagioclase (4%) and pure diopside (15%) in Clark, 1966, Table 6-2. The liquid is denser than the mesoperthite by 0.1 g/cc. Applying the same 10% volume change to an "average" Upper Zone of density 3.10, the density at 1100°C is 2.78, and the density contrast 0.25 g/cc. By either estimate, the feldspar should have had a strong tendency to float.

This problem has also been addressed by Bottinga and Weill (1970). These authors find the paradox in the Skaergaard intrusion, using Wager's calculated liquids. The Skaergaard case is of course complicated by uncertainties regarding the granophyres and contamination (e.g. Taylor and Epstein, 1963) as well as inadequacies of the model parent (e.g. Chayes, 1970). In any event, Bottinga and Weill point out that the paradox can be resolved if a moderate amount of H_2O is assumed to have been dissolved in the original magma, thereby lessening its density sufficiently to sink plagioclase.

A similar calculation for the Kiglapait intrusion shows that the amounts of H_2O required are wildly unreasonable. Using the examples above, 7.5 wt % H_2O would be required in the most favorable case of the uppermost rocks with solid density 2.93 and calculated liquid density 2.63. This is about 10 times the plausible value, based on the observed mineralogy and chemical analyses. The requirements of H_2O for an "average" upper zone of density 3.10 would be much worse. It is commonly supposed that H_2O may be treated as a "vanishing" component, discharged into the country rock during crystallization. In this case, such a supposition fares poorly. No avenues of escape such as hydrothermal veins or fluid inclusion trains are found in the overlying UBZ rocks. The initial magma appears to have been so dry as to <u>absorb</u> H_2O up a thermal gradient into the Outer Border

Zone from Snyder Group metasediments (Morse, 1969; Berg, 1971). The oxygen isotope data of Taylor (1968) suggest no late-stage interaction with roof-rock or wall-rock waters, as found in many higher-level intrusions (see Taylor and Forester, 1971). The very latest stages of interstitial crystallization in the uppermost rocks show only traces of blue-green amphibole rims, and no mica. A more formal estimate of H_2O fugacity awaits data on minor biotite rims which occur at lower levels of the Upper Zone, but which disappear as apatite becomes a cumulus phase, suggesting that fluorine will be found to dominate over OH in the biotite. Qualitative evidence, in summary, suggests a nearly anhydrous Kiglapait magma.

Fluorine (in apatite) and sulfur (in pyrrhotite) occur in upper Kiglapait rocks, and these would decrease the density of the parent liquid. However, unless their partial molar volumes are radically greater than that of H_2O, it is very unlikely that their abundance would sufficiently lower the density of liquid to that of feldspar.

If the possibility of equilibrium sinking of feldspar in ferrodioritic or ferromonzonitic liquid seems remote, as deduced above, then processes involving metastable equilibrium must be considered. A familiar class of metastable equilibrium is the atmospheric or oceanic phenomenon of inversion, previously cited by Hess (1960) and Morse (1969) in a magmatic context, but in the latter case to explain roof accumulation of plagioclase by elutriation in currents of presumably less-dense magma. In the present case an opposite result is desired. When crystals nucleate from magma, the mixture of crystals plus liquid constitutes a "package" of greater density than pure liquid. At the same time, viscosity increases (rather sharply), so that such a crystal-laden "package" will tend to move as a unit. If we consider the downward motion in the outer part of a convection cell, this package will move due to the combined effects of thermal difference and suspension of crystals. If the heating rate (from the main body) is slow compared to the rate of pressure increase, further nucleation will result, and the package will accelerate. Downward transport of feldspar in this mode offers no problems. Along the floor, mafic minerals will drop out, and it has been proposed by Speed (1963) that the downward motion of mafic minerals may pull down feldspars as well. The proper visualization of feldspar accumulation at the floor is difficult unless one assumes the formation of a rather fluffy metastable layer or densely populated crystal mush in which perhaps grain-to-grain adhesion of feldspar plays a role.

In summary, feldspar should float in ferrodioritic liquids, but does not appear to have done so in what must count as a most favorable instance. The existing knowledge of magma densities under natural conditions is still scanty, but observations and calculations show little prospect of resolving the paradox without the assumption of unacceptable amounts of fugitive components. Appeal to hydrodynamic effects suffices to explain large-scale transport of feldspar-laden magma, but leaves gnawing uncertainties about the final separation of feldspar from magma. This unsatisfying account of an unsatisfactory dilemma is offered as a goad to close and critical review of field relations, and to toilers in the experimental vineyards who may be in a position to shed some light on the matter.

A plagioclase-flotation or elutriation model for anorthosite is favored by calculations such as those of Bottinga and Weill (1970), but is paradoxically contradicted by the appearance of settling in layered intrusions. Satisfactory hydrodynamic models which can account for both cases have yet to be developed.

MISCELLANEOUS TOPICS

Deformational history of the Ford Harbour Formation (Wheeler, Morse). In his original description of the Ford Harbour Formation, de Waard (Field Report 1971, p. 15) concluded that the formation was only weakly deformed when the anorthosite complex invaded it. Rocks of similar lithology and deformational style occur widely on the Labrador coast, including much of the area from Hopedale to Okhakh Bay and possibly farther. Both Berg and Speer, elsewhere in this report, have cited evidence that deformation and metamorphism of the basement complex preceded the emplacement of the Hettasch and Kiglapait intrusions and the deposition of the Snyder Group. Further afield, biotite in rocks with this metamorphic style northwest of Tessiuyakh Bay head (57-19 N, 62-07 W) gives a K-Ar age of 2.035 Gy* (Lowdon et al., 1963, p. 115), far in excess of the estimated anorthosite emplacement age (less than 1.5 Gy; see Morse, 1964). Speer's study of the Snyder Group (this report) demonstrates an aureole of only a few km width to greenschist facies around the Kiglapait intrusion. However, the recrystallization of the Ford Harbour Formation is pervasive and regional in character, and it can be argued that such a regional metamorphism at the time of anorthosite emplacement would have reset the Tessiuyakh biotite age.

In the light of this evidence, it is suggested that the deformation and regional metamorphism of the Ford Harbour Formation must have preceded anorthosite emplacement, and that structural conformity with the anorthosite contact is an accident of the emplacement mechanism. Alternatively, if in fact the deformation is contemporaneous with anorthosite emplacement, the Ford Harbour Formation would have to be regarded as a younger basement unit, not correlative with other units of similar lithology and deformational style near anorthosite margins to the northwest and southeast.

*Gy = Gigayear = 10^9 year.

<u>Anorthosite dark and pale facies</u> (Wheeler). Many outcrops of undoubted dark-facies anorthosite occur along Annakhtalik Bay north shore, but at the east end of this shore the rock is undoubted pale-facies anorthosite. Part of the August field conference was devoted to an examination of the contact zone. In searching for the boundary between the two facies, it was possible to pick a shore outcrop at the west entrance of Dead Bird Brook estuary (56-29 N, 61-46 W) through which the contact passed, but the distinction between the two rocks was not altogether convincing. Proceeding westward from this point, the characteristics of the dark anorthosite became increasingly distinctive in the field, but preliminary refractive index determinations on plagioclase indicate little change in composition over a traverse of about 1 km from the supposed contact into the dark facies.

<u>Reconnaissance sampling of country rocks along Tessersoakh Lake</u> (Dymek). This lake at the head of Nain Bay (56-37 N, 62-15 W to 63-08 W) affords easy access by canoe to the gneisses west of the largest anorthosite body. A three-day trip was devoted to reconnaissance sampling of these gneisses for petrographic study, to see if this traverse will permit analysis of the regional metamorphic grade and the contact effects of the anorthosite. In preliminary examination, hypersthene-garnet assemblages are common, but biotite is stable both in the western limit of the traverse and as rims on garnet close to the anorthosite-adamellite contact. Other minerals of interest include sillimanite, gedrite (?), and hercynitic spinel. The retrograde formation of biotite near the anorthosite-adamellite contact may be due to the adamellite body described by Wheeler (1968) rather than to the anorthosite, and indeed the abundance of adamellite along much of the western contact zone renders difficult the interpretation of anorthosite contact metamorphic effects. Petrographically identical ultramafic bodies occur on both the north and south shores near the west end of Tessersoakh Lake, and restoration of their positions yields a left-lateral displacement of 6.5 km on the prominent Tessersoakh-Nain Bay linear, as compared with about 4 km obtained on the same linear 80 km to the east at Barth I. (this report, Fig. 14).

<u>Catalog of layered intrusions or parts thereof</u> (Morse). Locations are shown in Fig. 24. Possible extensions of known plutons, some of which

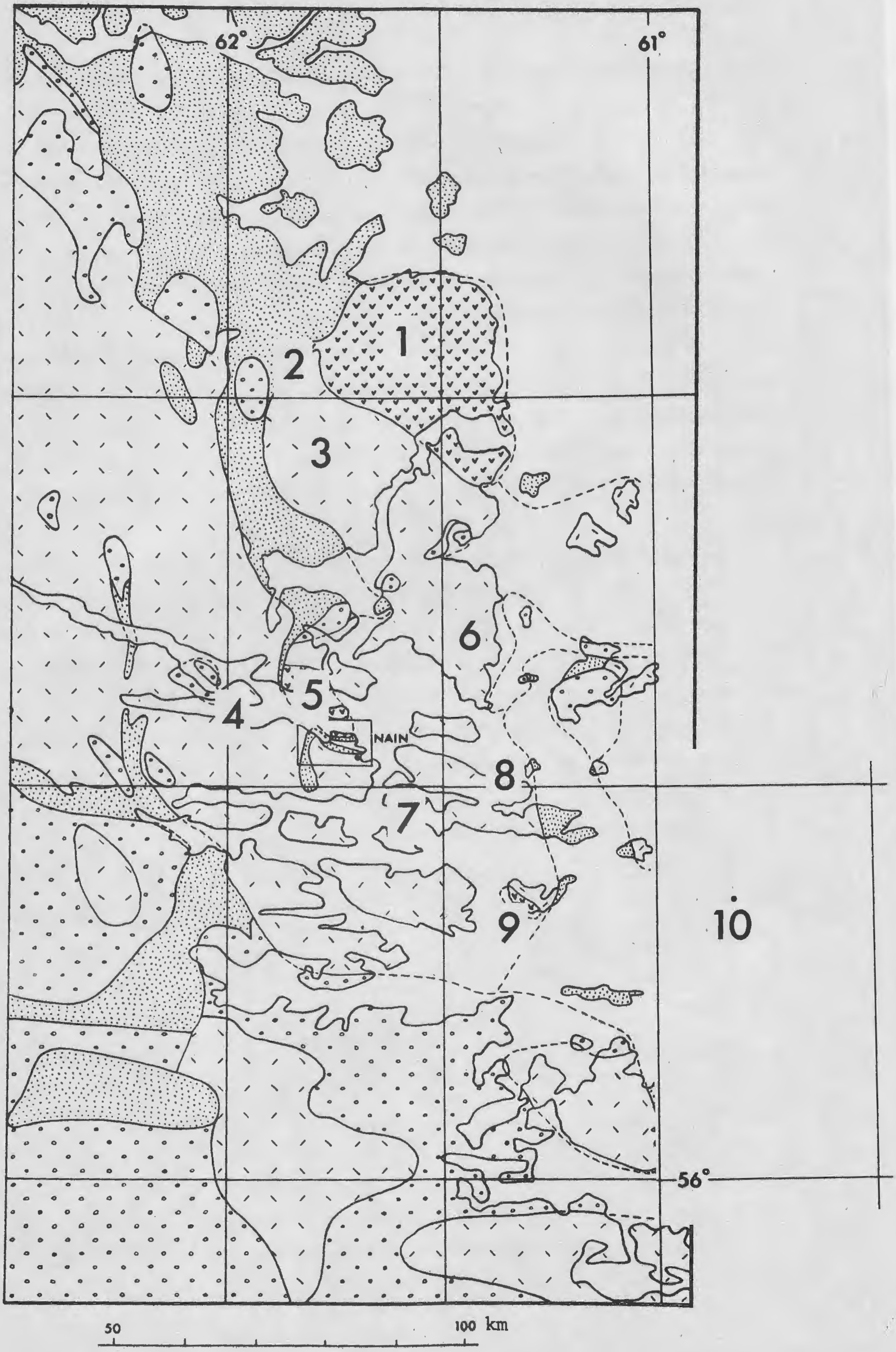


Fig. 24. Locations of layered intrusions in the Nain region. See text for key.

could be separate layered bodies, are cited in the list below.

1. Kiglapait intrusion (Morse, 1969). 560 km^2 area, upright basin. High-alumina, low-K olivine tholeiite, fractionated from troctolite to ferrosyenite. Upper Border Zone (UBZ) present; no evident contamination except in outer walls (Outer Border Zone). Cuts anorthosite.

2. North Ridge gabbro (Berg, this report, p. 56). About 15 km^2, homoclinal sheet. Olivine gabbro and gabbro, An_{83} to $_{55}$ maximum range known. Possibly pre-anorthosite.

3. Hettasch intrusion (Berg, this report). Greater than 150 km^2, synclinal. High-alumina olivine tholeiite chilled margin, fractionated from troctolite to gabbroic anorthosite and gabbro. Layered anorthosite at the north end of Port Manvers Run (Morse, this report, p. 97) is either a lower level of Hettasch, or more probably part of a separate layered body.

4. Tikkoatokhakh Rattle layered anorthosite (Morse, FR 1971, p. 65). Area unknown; may be very large, as layering was observed from a distance here and there along the whole length of Nain Bay (just to the south) in 1972. Homoclinal 15-cm anorthosite with thin, continuous leuconorite layers at the one outcrop visited: An_{51}, En_{54}.

5. Barth Island layered body (Wheeler, 1960; Rubins, FR 1971, p. 35-42; de Waard and Mulhern, this report). About 50 km^2, upright basin. Troctolite to granodiorite, with olivine hiatus. An_{73} to $_{25}$, En_{76} to $_{24}$, Fo_{73} to $_{58}$, then fayalite after hiatus.

6. Newark I. layered complex (Woodward, FR 1971, p.29-33; this report). More than 100 km^2? Faulted basin? Troctolite to mangerite, An_{57} to mesoperthite.

7. West Red I. layered intrusion (de Waard, FR 1971, p. 21). About 5 km^2, homoclinal sheet. Gabbroic.

8. The Bridges layered zone (Planansky, FR 1971, p. 47-59; this report). About 15 km^2? Homoclinal sheet. Ultrabasic, Stillwater-type: An_{81} to $_{64}$, En_{80}, Fo_{75+}.

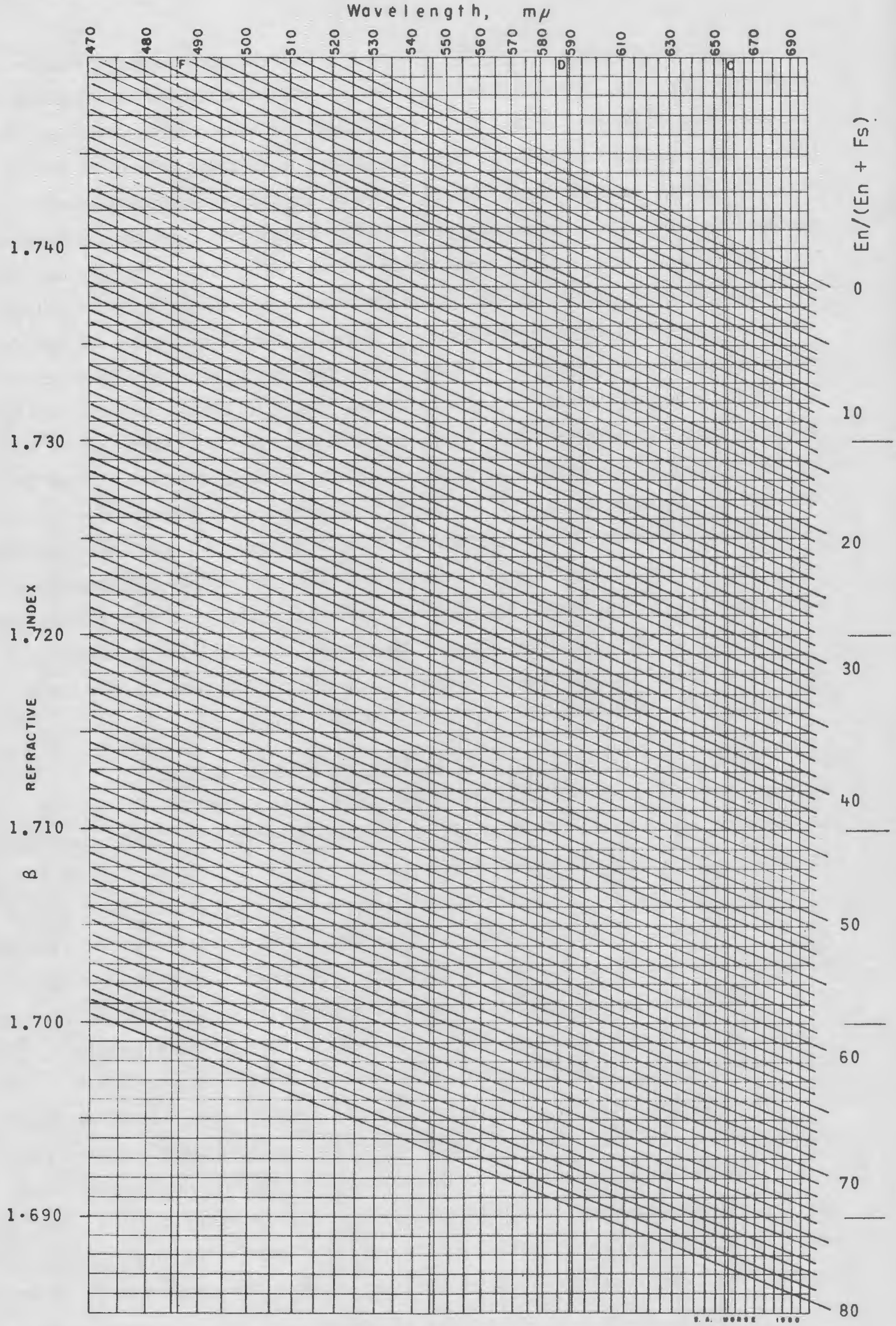
9. Wyatt Harbour intrusion (Morse and Speer, FR 1971, p. 60-65). 5 km^2, elongate syncline? Troctolite to olivine gabbro: An_{56} to $_{49}$, Fo_{70} to $_{56}$.

10. The Castle layered body (Wheeler, this report, p. 32). Less than 1 km^2 exposed. Possibly dioritic, with numerous large xenoliths of anorthosite near sea level (base not exposed?).

Dispersion chart for augite (Morse). The current working version is shown in Fig. 25. This is based on twelve analyzed Kiglapait augite-series samples for which the beta refractive index and dispersion have been determined (unpublished data). Beta is linear within experimental error over the range En_{70} to En_0. These samples contain exsolved plates of magnetite-ulvöspinel and ilmenite and very fine basal lamellae of pigeonite (Morse and Ross, unpublished data). The ratio En/(En+Fs) is calculated after recalculation of all other pyroxene molecules, and hence is slightly higher than bulk Mg/(Mg+Fe), some of the Fe but none of the Mg being allocated to other molecules. The diagram is probably applicable with little error to similar samples from the Nain area, but should be applied only with caution to pyroxenes elsewhere. The chart may be used by overlaying a dispersion plot of selected liquids, derived either from the manufacturer's tabulated values for dispersion or preferably from direct measurement of n_D and dispersion with a modern Abbe-type refractometer. Appropriate temperature corrections must, of course, be applied. It should be noted that dn/dX (X = composition) for the augites is only about half that for olivines, which means that precision is only inherently about half as good, although subequal in practice because of the higher frequency of grains parallel to Y in the augites.

Plagioclase dispersion and olivine exsolution of ilmenite (?) (Morse). Dispersion of the vibration directions is a familiar sight in Nain and Kiglapait plagioclase. Perhaps it is a long-noticed but little-mentioned phenomenon in other plutonic plagioclases, and if so, I would appreciate hearing of published references which have escaped my eye. It is common for us to notice distinct shades of blue and brown near the extinction position, and the effect was studied in one 1972 sample (PMR 1027-3, $An_{52.5} \pm 3$). No dispersion of the vibration directions is seen in (001) cleavage flakes. It is easily seen in (010) cleavage flakes of this sample. Grains lying on or near the (010) cleavage and therefore showing off-centered Bxa figures show $X'_F \wedge X'_C$ from 2 to 3°, possibly more in some grains, where F and C are the standard Fraunhofer blue and red wavelengths respectively. This amounts to crossed dispersion. It is not noticed in interference figures because of a distinct axial angle dispersion $r > v$ superimposed on it (note that this is contrary to $r < v$ given, in some standard tables, for labradorite). Ordinarily, one infers the influence of minor

AUGITE SERIES



AUGITE SERIES HARTMANN NET

Fig. 25. Dispersion chart for augites.

elements, especially Ti and Fe, from marked dispersion. This sample shows abundant plates of ilmenite, typically 2 x 10 μm and very thin, flattened in (010) of plagioclase and elongate mostly parallel to c, some parallel to a. The host plagioclase could therefore be characterized as saturated with ilmenite component, and Ti may indeed cause the dispersion effects seen. The utility of the effect lies chiefly in its power to discriminate (010) cleavages from (001) cleavages which show no twin lamellae.

A thumb-sized olivine crystal collected by Plananasky (his sample No. PAO-101, $Fo_{66} \pm 1$, by the dispersion method; see FR 1971, p. 70) was observed to have very distinct (100) and (010) cleavages, and to contain sparse but very straight blades of a light brown, translucent mineral in (100). These blades are typically 2 μm wide in the c direction of the host olivine and of effectively infinite length (as long as the host crystal is wide?) in the b direction of the host olivine. There are also rare plates, somewhat wider, elongate parallel to c in (100) of the olivine. The blade thickness is not known, but if the blades are ilmenite, as appears likely from their resemblance to translucent ilmenite blades exsolved from augite (see above), they are probably only a few unit cells thick. Whereas exsolution of ilmenite from pyroxene involves two phases of the same metal: oxygen ratio (2:3), that from olivine yields a lower M:O ratio (2:3) in the exsolved phase than in the host (3:4). This could imply either that the ilmenite be produced by an "oxyexsolution" reaction or by constant-stoichiometry exsolution from an initially cation-deficient olivine.

HYDROGRAPHIC REPORT

S. A. Morse

University of Massachusetts

INTRODUCTION

R. V. Pitsiulak continued to make reconnaissance sounding tracks in uncharted waters whenever conditions were favorable. A total track length of 250 nautical miles was sounded in 1972. Fathometer charts and edited field sheets are being submitted concurrently with this report to the Canadian Hydrographic Service.

Aside from its obvious use in logistic operations, our hydrographic charting program has geological utility in helping to localize the prominent east-west linears of the Nain area where their topographic expression is obscured by water. These linears have important implications for the tectonic history of the region. At least some of them are left-lateral faults, and from their frequency and known offsets one may eventually be able to infer the total amount of left-lateral displacement in this coastal area.

Knowledge of bathymetry is also important for the interpretation of gravity data now being compiled by the Earth Physics Branch, Ottawa.

The Nain area, with its long fjords, fresh water discharge, and highly complex island fringe, is fascinating from the standpoint of oceanographic mixing (Nutt, 1963). Additions to bathymetric knowledge will be important in selecting new sites for oceanographic studies, and such studies in turn will be essential for interpretation of bottom thermal history in any heat flow investigation.

NOTES

The 1972 sounding tracks are listed in Table 3 along with mileage and the identity of the plotting sheet. A few 1971 sounding tracks, not previously reported, are appended to the table. The main listing follows the conventional order from south to north along the coast, and is divided into three groups, south, in, and north of the published Nain sheets. Figs. 26 to 29 show the locations of sounding tracks, by number.

Position control was visual, aided when necessary by radar ranges. Tracks were followed by means of compass course, whenever possible augmented by landmarks. Positions along tracks were determined by bearings abeam, or infrequently by dead reckoning, back-corrected by bearings abeam. Soundings in fathoms were continuously recorded on a JRC fathometer, and in some critical areas were corrected in plotting to approximate low water springs.

The following notes summarize the notable features of each track or area.

SOUTHERN AREA

Track No. (see Table 3)

1. The track from Nukasusutok* I. to Zoar appears to be free of dangers in the area of sheet 14 C/6. Continuous bathymetric profiling reveals at least three pronounced submarine valleys with depths of 97, 70, and 93 fm. These valleys are part of a pervasive system of east-west topographic linears in the Nain area, some of which are known to be left-lateral faults. The 93-fm valley is part of a major fjord which lies south of Kikkertavak Island; this valley shows also on track 2. On sheet 14 C/3, a 6-fm shoal occurs, but the bottom is smooth, and by local report there are no dangers to small vessels along the track.

Zoar is an abandoned town site located at 56°-08' N, 61°-23.5' W. The site is mislocated some 8 km to the north on current maps (14 C). The correct location was verified by local report and by on-site inspection of old building foundations, conducted by Dr. and Mrs. E. P. Wheeler II in August, 1972.

2. The track from Nuasurnak to Nochalik I. appears clear of dangers as far as Chart 4748.

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*Spellings in this part of the report are those of published charts. Those of Wheeler (1953) are preferred.

NAIN ANORTHOSITE PROJECT - R.V. "PITSIULAK."

Table 3. Sounding tracks,
listed by area, from south to north.

(Note: Spellings are those of published hydrographic charts.
Sheets designated 14--- are Canada Topographic Series 1:50,000.)

	Date	Plotted on	Reported on	Mileage
I. Area south of Nain	1972			
1. Nukasusutok I. to Zoar	25 Aug	14 C/6, C/3	same	18.0
2. Nuasurnak I. to Nochalik I.	25 Aug	14 C/6	same	6.5
3. Murder I. to Anaktalak Bay	31 July	14 C/5, D/8	same	18.5
4. Anaktalak Bay to Palungitak I.	1 Aug	14 C/5, D/8	same	20.5
II. Area of charts 4748 and BA 265	1972			
5. Harmony Run	31 July	4748	14 C/12, C/11	8.5
6. Aulatsivik I. to Ogârsuqautik B.	31 July	14 C/11	same	9.5
7. Red Rocks to Henry I.	15 July	4748	14 C/11	2.0
8. Aulatsivik I. east shore	18 July	4748	14 C/11	1.6
9. Moskie I. to Kungmuk Passage	18 Aug	14 C/11	same	3.0
10. Saporatsuk to Spruce I.	15 Aug	14 C/11	same	5.0
11. St. Johns Hr. (near Black I.)	24 Aug	14 C/14	same	1.0
12. Ringbolt Tickle I. to Black I.	24 Aug	BA 265	14 C/14	4.1
13. Queens Lakes to St. John's I.	15 July	4748	14 C/11, C/10	1.5
14. Area north of St. John's I.	15 July	265	14 C/10	1.5
15. Port Manvers to Bulldog I.	14 July	265, 4763	14 C/14	6.8
16. Solomon (Saddle) I. to David I.	14 July	14 C/14	same	5.0
17. David I. to Queens Lakes	14 July	265, 14 C/14	14 C/11	10.0
18. Crossbones I. to Skull I.	8 July	4748	14 C/6	4.1

Table 3, Cont.

	Date	Plotted on	Reported on	Mileage
	1972			
19. Sandy I. toward The Twins	8 July	4748	14 C/7	1.1
20. Sandy I. to Lost Is.	10 July	4748	14 C/7	13.0
21. Gamma It. to The Castle	10 July	4748	14 C/7	4.8
22. The Castle to "Wyatt Hr."	10 July	4748	14 C/7, C/6	16.9
23. Topsy Pt. to Ungagivik B.	9 July	4748	14 C/12	2.4
24. Sachem Bay	9 July	Photo LAB 43-193	14 C/12	2.2
25. Challenger Cove to Sachem B.	13 July	265, photo	14 C/12	5.2
26. Challenger Cove to Igloo I.	14 July	265, photo	14 C/12, C/13	4.7
27. Igloo I. tickle	14 July	LAB 59-036	14 C/13	3.0
28. Palungitak (Palungatak) I. south shore	31 July	4748	14 C/5	5.0
III. Northern areas: Kiglapait Hr. to Mugford area. 1972				
29. Kiglapait Head to Snyder Bay	21 July	4763	14 F/4	4.3
30. Snyder B. to Angutausugevik	21 July	4763, 14 F/4	14 F/4	19.0
31. Tessiujak B. entrance, to Okak B.	22 July	4763, 14 F/4	14 F/4, F/5	16.5
32. Outer Okak B. to Ublik B.	27 July	4763	14 F/5	8.0
33. Ublik B. to Graveyard I.	27 July	4763	14 F/5	14.0
34. Okak Bay south shore	27 July	4763	14 F/5	2.0
35. Horr Harbour (Calm Cove)	25 July	14 E/16	same	1.5
36. Kai-Kai Inlet (Lost Channel)	22 July	14 E/16	same	4.0
			TOTAL 1972	250.3
IV. 1971 tracks covered in this report.				
37. Bald I. to Queen's Lakes Tickle	28 Aug	4748	14 C/11	7.3
38. Base Pt. to Ungagivik (Ungujivik)	25 Aug	4748	14 C/12, C/11	4.1
39. Rattle Rock to Ungagivik entrance	10 Aug	4748	14 C/11, C/12	4.4
40. Pat Rocks to Rattle Rock	19 Aug	4748	14 C/11	2.6
41. Rattle Rock to Uigomigak I.	20 Aug	4748	14 C/11	2.9
42. Skull I. south side	9 Aug	4748	14 C/6	1.0

Table 3, Cont.

	Date 1972	Plotted on	Reported on	Mileage
43. Sandy I. south side	18 Aug	4748	14 C/6	2.8
44. Nukasusutok I. east shore	9 Aug	4748	14 C/6	3.4
45. Nukasusutok to Nochalik I.	18 Aug	Photo	14 C/6	2.6
46. Wilcox Pena. to Snyder B.	31 Aug	4763	14 F/4	5.5
			TOTAL 1971	36.6

3. The track from Murder I. to Anaktalak B. is deep and free of dangers in the area of sheet 14 C/5. In the area of sheet 14 D/8, the passage north of the island contains a 2-fm shoal, although the bottom appears smooth. Foreshore flats encumber the SW extent of Anaktalak Bay, as shown on the sheet. The anchorage there is well-protected from winds, but is rather too deep (12 fm) for small vessels. The NW arm of the bay may be entered at high tide by motorboats. An old sawdust pile is readily visible on the north shore of this arm, at the former site of a sawmill.

Name: Murder I. is the local name for the small island just south of Kauk Bluff I. (56°-28.5' N, 61°-41.7' W).

4. The track south of the island in Anaktalak Bay has a least depth of 7 fm. Elsewhere, the track is deep all the way to the east end of Satosoak Island. This track incorporates some soundings of 16 Aug. '71 at the west end of Palungitak (Palungatak) I., specifically around the largest of the Pitsyulatsuit (Pigeon) Island group. The two tracks shown around this island are those commonly used by local residents; in both, the safest water is found by leaving the island close aboard.

AREA OF CHARTS 4748 and BA 265

5. Harmony Run was long favored by the Moravian Mission supply boat "Harmony", but eventually abandoned as the main approach to Nain in favor of the more direct Strathcona Run. There are somewhat similar encumbrances in both runs. From our single track, it appears that the bathymetry of Harmony Run resembles that of Strathcona Run in having a deep (50 fm) basin inside a sill (7 fm, between Hillsbury and Aulatsivik Islands). The discharge of interior drainage from Finger Bay through Harmony Run is probably considerable, to judge from the large size of the Kingurutik River. Therefore, Harmony Run should be an interesting site for expanding the oceanographic mixing studies initiated by Nutt (1963) in Nain Bay - Strathcona Run.

6-7. The track from a salt water pond on the east shore of Aulatsivik (Newark) I. to Ogârsuqautik Bay on Dog. I. is adequate for small vessels. A shoal, already shown on sheet 14 C/11, extends far to the northeast from Central I., and a shoal with a 4-fm passage extends southward from Misfit I., as shown on sheet 14 C/11.

Near the entrance to Ogârsuqautik B., the shoal shown on Chart 4748

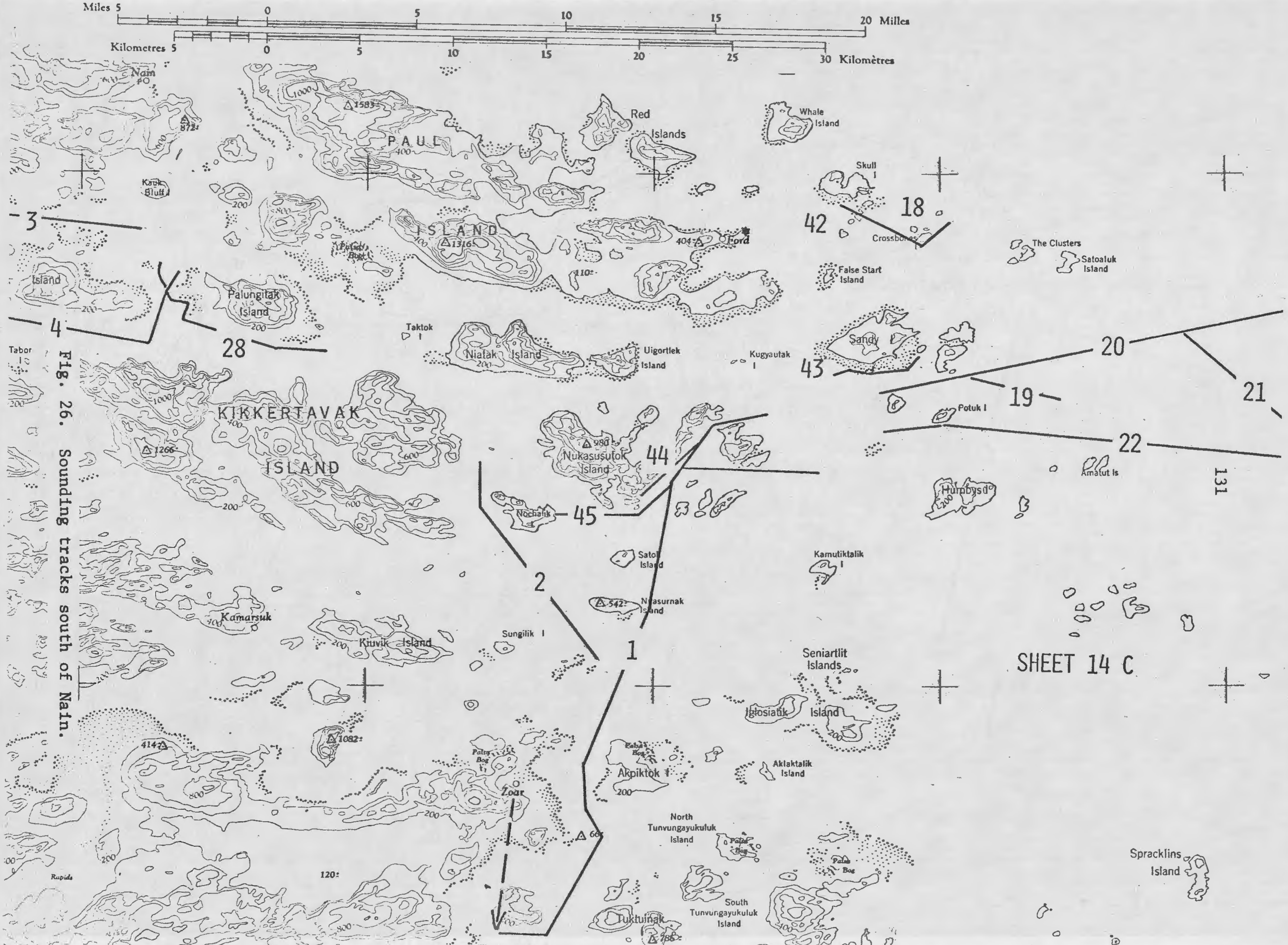


Fig. 26. Sounding tracks south of Nain.

Fig. 27. Sounding tracks northeast of Nain.

is mislocated, and should be moved to the more southerly position correctly shown on sheet 14 C/11. Shoals and rocks shown on sheet 14 C/11 between Henry I. and the Bay entrance are nonexistent; they lie within the soundings of Chart 4748, and local knowledge and 1972 observations tend further to confirm their absence.

Entrance to Ogârsuqautik Bay is gained over a smooth, sandy sill of 2 fm depth; the south side of the entrance should be favored. Deep water (to 16 fm) is found in the bay, and good holding can be had in 6 fm at the head of the bay, although this is not a comfortable place in westerly winds.

8-9. These tracks cover the area from Needles Knoll to Moskie I. The passage is well-known to local inhabitants, and is reported to be clear of dangers except those shown. The passage between Needles Knoll and Loon I. appears clear at 4 fm depth. A 4-fm spot occurs at the SW end of the Mary I. group, and a 3-fm spot occurs between the northern part of the Mary I. group and the main body of Aulatsivik I. Two rocks in the eastern part of this passage are shown on Chart 4748 but not on sheet 14 C/11. They have been added on the sheet accompanying this report.

10. The track from Saporatsuk (BA 265) to Spruce I. is deep and without dangers known to local report.

11. St. John's Harbour, south of Black I., was possibly used in emergencies by fishing schooners entering at highest tides. The entrance has an estimated least depth of 8 feet; the bottom is relatively smooth except for small, rounded rocks. A current estimated at 2-3 kt sets into the harbour 2 hours after low tide at Nain (observation of 24 Aug '72). The basin itself is deep (26 fm), and therefore hardly a choice anchorange for small vessels.

12. The track from Black I. to Ringbolt Tickle is used by local inhabitants. The plotted track encounters a least depth of 6 fm just SW of Amagvik I.: presumably this is the shoal reported in approximate position on BA 265, some 0.4 mi to the south-southeast.

13-14. These tracks from Queens Lakes to St. John's I. follow near the normal motorboat route past September Hr., encountering a least depth of 3 fm near the islet in the mouth of September Hr.

15. The passage from Willis Rocks in the entrance to Port Manvers to Bulldog I. is deep and without apparent dangers. A least depth of 20 fm

is encountered off Little Fish I.

16-17. The passage from Solomon (Saddle) I. to David I. is deep (30-90 fm) and safe. Deep water also occurs along the southeast shore of David I. An unnamed harbour is present in south-central David I., with a 10-fm anchorage. Two fishing rooms (buildings) on the south side of this harbour appeared to be in good condition in July, 1972.

The track from David I. south to Queens Lakes encountered a 2-fm shoal in the southern approach to the harbour on David I. This shoal was not known to local informants. The rest of the track to Queens Lakes appears clear of dangers.

18 and 42. The south half of Crossbones I. may be skirted with a least depth of 2 fm between Crossbones and the islet immediately to the southeast. Much of the water between Crossbones I. and Skull I. is deep, but the bottom is very rough, as might be expected from the density of islands in the area. The southern approaches to Skull I. are encumbered by a number of shoals, four of which are approximately located on sheet 14 C/6. These are foul waters and should be entered with caution, if at all.

19 and 43. Deep water lies off the southern side of Sandy I. The southeast side of the island may be approached with caution along the sounded track, with a least depth of 2 fm, and a landing can be made on a beach just south of the 280-ft hill marked on Chart 4748.

Reference to a ruined light house on Chart 4748 (western tip of Sandy I.) should be deleted -- no ruins can now be seen from the water.

A partial track was sounded from the large island east of Sandy I. to The Twins. Pack ice prevented the completion of the middle part of this track.

20. The long track from a point 1 mi south of Sandy I. to Lost Islands shows deep water over most of its length, with a broad 8-fm shoal near 60°-57.5' W and a relatively sharp 17-fm spot near 60°-45' W.

The water amid the Lost Islands appears clear of dangers, with a least depth of 2 fm in the passage between the two most northeasterly islands of the group. The track from the south entrance to the middle of the island group was "swept" by ice pans to which the vessel was moored, the pans having an estimated draft of at least 1.5 fm.

21. Approaches to The Castle from Gamma Its. show a number of shoals of 10, 8, and 2 fm depth, indicating a rough bottom within 2 mi of the Castle. These waters should be entered with caution.

22. By contrast, the track west of The Castle runs for a great part of the way along the axis of a submarine valley with depths locally in excess of 100 fm. This valley is probably a glacial channel, and it appears to be on line with Anaktalak Bay (see track 4) to the west. The 80-90 fm depths jump suddenly up to 42 fm, 2 mi ESE of Potuk I., indicating the presence of an abrupt scarp.

The track continues westward in good water to Nukasusutok I., encountering a least depth of 7 fm near 61°-09.7' W.

A plan of "Wyatt Harbour" on Nukasusutok I. is attached as Fig. 30, which is based on last year's survey (FR 1971, p. 94-95). This harbour is the terminus of track 22, and a principal base of operations for this project.

23 and 38. These tracks cover the western approach to Ungagivik (Ungujivik) B., and together with tracks 39, 40, and 41 provide a route from Noazunaluk I. to First Rattle in Port Manvers Run. This route is one mile shorter than the Harmony Run route. A shoal area occurs north-northeast of Nixon Hill, with a least depth of 4 fm if the northern part of the sounded area is favored. Ungagivik Bay can be entered in deep water to about half its length, where anchorage is found in 5 fm.

Note: Delete "conspicuous landslide" shown on the north side of Ungagivik B. on Chart 4748. This feature is now overgrown and inconspicuous.

24. Sachem Bay contains deep water and can be entered so as to avoid a 6-fm spot in the northern passage. Local report recognizes no dangers in the region of the sounded tracks.

A freshwater estuary extends westward from the bottom of the bay. This can be entered for a short distance by motorboats, but the head of the estuary is shoal, much of it drying at low tide.

Name: BA 265 applies the name "Sachem Bay" to the northwest arm of this bay, but sheet 14C applies it without prejudice to either arm. The latter is more nearly correct, according to E. P. Wheeler II (personal communication, August, 1972), who originally supplied the name to the makers of BA 265, and who intended that it should apply to the southern arm.

This arm is used by local fishermen; the northwest arm is rarely visited.

25. Track needs no comment. The bitter end of Challenger Cove affords excellent shelter and a secure anchorage (mud) in 4 fm.

26. This track across the mouth of Webbs Bay appears clear of dangers, consistent with local report.

27. The tickle north of Igloo I. can be negotiated with a least depth of 2 fm by favoring the south side. However, a 1-fm area is difficult to avoid unless visibility is excellent, and the tickle is comfortable for small vessels only at high tide. The bottom appears smooth. The continuation of this track to the north, inside Double I., encounters a least depth of 3 fm in the tickle; this is the standard route for motorboats and some fish collecting vessels.

28. The waters south of Palungitak (Palungatak) I. are deep (60 fm), consistent with the fjord-like nature of Anaktalak Bay, of which this area is an extension.

NORTHERN AREAS

29, 30, 46. Snyder Bay, called the "Bottom of the Bay" by visiting cod fishermen, has been a major fishing area in good years for schoonermen based in Kiglapait Harbour. The several tracks reported here show a smooth, flat-bottomed hole (52-57 fm) northeast of Snyder I. Just northeast of this hole, a 10-fm spot rises sharply from 42 and 50 fm. The rock plotted some 2/3 mi north of this on Chart 4763 may lie about one cable SE of its plotted position.

The track from Tikkerarsuk (Tikkigaksuk, Wilcox) Peninsula into Avakutak Bay appears clear of dangers. Although the 6-fm shoal has not been examined, the smooth gradient leading to this shoal, and its position on line with the shoal making out from the southeast corner of Tikkeratsiara I., suggest that it is a bay-mouth bar, and probably sandy.

The mouth of Tessiujak Bay, between Sutton I. and the mainland, appears to have a least depth of 6 fm. Farther in, a 4-fm spot is found near the foreshore flats, but it is possible that a deeper track can be found somewhat to the east. A small cove near the mouth of Angutausugevik (Brook) affords a sheltered anchorage in 5 fm.

31. The 4-fm shoal off Tikkeratsiara appears related to a baymouth

Fig. 28. Sounding tracks north of Cape Kiglapait.

bar, as discussed above under track 30.

Islets off the SW corner of Iglosoatalialuk I. (Chart 4763) should be corrected to conform with sheet 14 F/5, which is hereby verified. Specifically, the northerly islet marked doubtful (57°-18.5' N, 61°-46.6' W) does not exist. The southerly islet marked doubtful (57°-17.7' N, 61°-46.9' W) does exist, as does also a small islet not plotted on 4763, hard against the shore at about 57°-17.5' N, 61°-49.4' W.

The sounded track into Okak Bay appears clear of dangers, consistent with local report.

Of geological interest, the fathometer record shows two sharp 34-fm trenches flanking the northernmost 22-fm sounding in track 31.

32. The track into Ublik (Udlik) Bay has a least depth of 10 fm in the mouth of the bay. Deep water (9 fm) occurs even at the head of the bay, making a poor anchorage for small vessels.

33. An islet shown on Chart 4763 (57°-20.2' N, 61°-52' W) does not exist.

This track runs past South Ametok I., to the SW end of Iluvertalik I., where a shoal of 4 fm depth occurs hard by the island, and continues past the Orne Islands to join published soundings west of Buckets Bite on Graveyard I. (misnamed Thomas I. on 4763).

NOTES ON CHART 4764

Okak anchorage: Chimney no longer exists. "CHY" on plan and chart should be deleted.

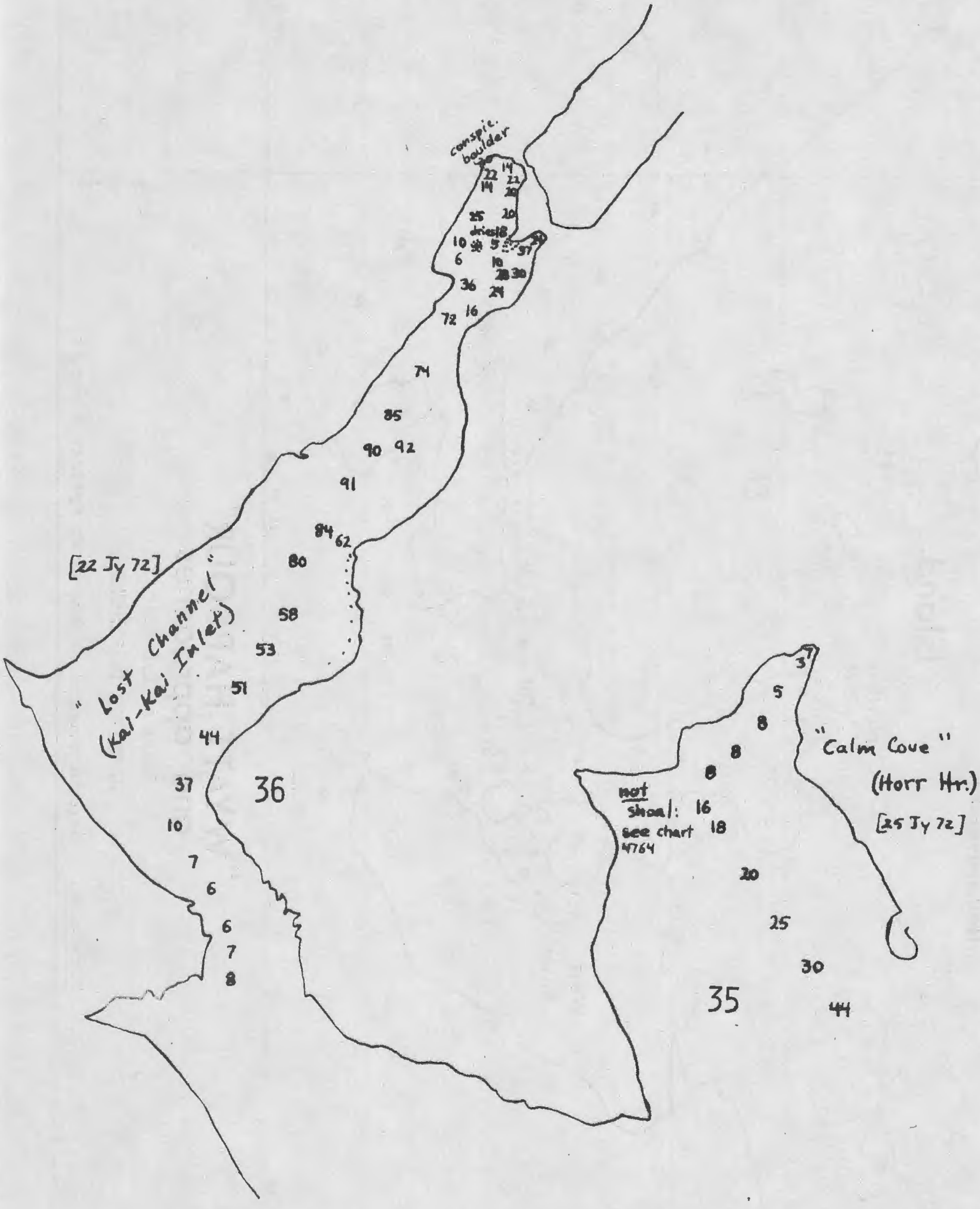
Nutak: Delete "Hudson Bay Co." Houses remain, but are not used.

Semekutak I.: Delete "Stages."

Sutherland Inlet (Anchorstock Bight) at 57°-46' N, 61°-51' W: The deep salt-water pond off the main Bight is accessible to motorboats at high tide only (visual observation from shore and local report).

35. Horr Harbour or Calm Cove (57°-49' N, 62°-04' W). Chart 4764 shows this cove correctly to be deep and safe for vessels. Chart 4775 and topographic series map "Finger Hill" (14 E/16) erroneously show the harbour to be shoal, and these charts should be corrected.

The small northeast cove provides a good anchorage for small vessels north of the 16 fm spot on Chart 4764. There is a sill of about 3 fm depth across the mouth of this cove, and inside this a basin of 7 fm with



Canada Topo Sheet Finger Hill, 14 E/16
Hydrography: R.V. Pitsiulak, 1972.

Fig. 29. Sounding tracks in the Mugford area.

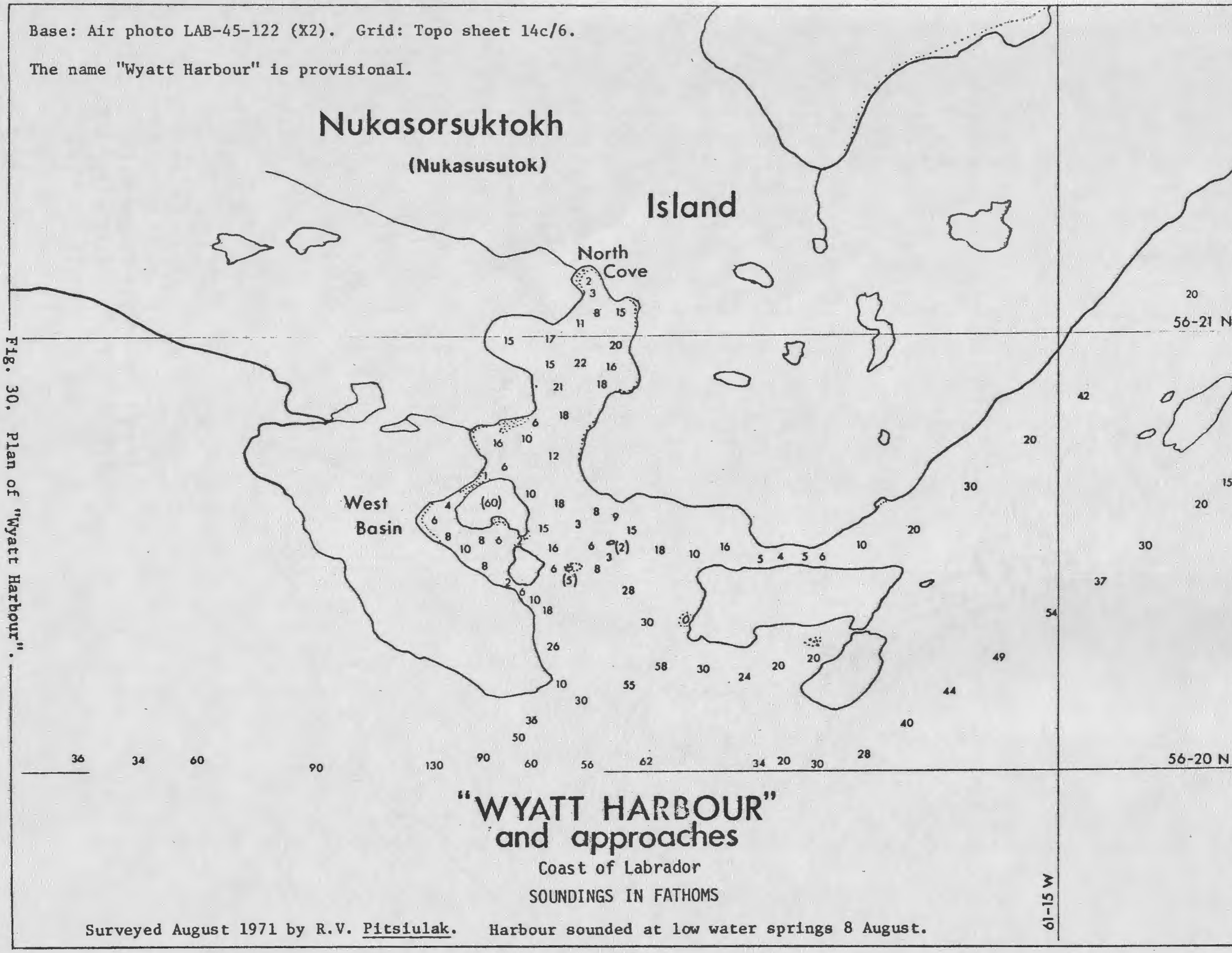


Fig. 30. Plan of "Wyatt Harbour".

level bottom. The bottom is black mud heavily encumbered with seaweed, and it provides a tenacious holding ground.

Names: It is suggested that Horr Harbour be retained for the feature so named on Chart 4764, and that the name Calm Cove be applied to the small northward extension.

36. Kai-Kai Inlet or Lost Channel. Older soundings stop at 62 fm about half-way to the bottom of the Inlet. The new track shows depths to 92 fm in mid-channel, and even the narrowest part has a central depth of 72 fm.

A reconnaissance was made of the bag end of the inlet, which provides excellent shelter but poor anchoring depths. A shoal which dries at low water blocks the center of the entrance to the bag end. This can be skirted on the west with a least depth of 6 fm, and deep water is found hard by the west shore all the way in. Anchorage in 14 fm or less is possible at the end of the cove only in northeasterly winds, as swinging room is limited toward shore. There is a shoal running out from the point which separates the small eastern cove from the main cove (see track).

1971 TRACKS

37. The track from Bald I. to Queens Lakes Tickle finds frequent use by local vessels. A least depth of 14 fm was found off Amikoyuak I., and another of 10 fm near the entrance to Queens Lakes Tickle. The track appears clear of dangers, consistent with local report.

38. See 23.

39, 40, 41. See also 23. A 7-8 fm sill can be inferred about 1.2 mi east of Rattle Rock. The possibility of lesser depths should not be discounted. Rattle Rock, as the name implies, is in an area of strong tidal currents with easterly and westerly set.

A shoal area of 7-10 fm occurs SSW of Nuluk Knoll, but no shallower depths have been noted here in a number of passages along the track.

42. See 18.

43. See 19.

44. Frequent passages along and near this track suggest that it is clear of dangers. The northeastern end of the track runs along a bold shore. The southern terminus of the track at the eastern entrance to

"Wyatt Harbour" is discussed in the 1971 Report (FR 1971, p. 95). See also Fig. 30 of this Report.

45. A deep channel (130 fm) occurs just off the southern tip of Nukasusutok I. This deep is probably coextensive with the 97-fm deep encountered on track 1, hence a submarine valley is inferred. However, this deep is very near the western head of the valley, probably defined by a 50-fm contour on Chart 4748.

46. See 30.

OPERATIONS

S. A. Morse

NARRATIVE REPORT

Breakup of winter ice finally came to Nain Harbour during 2-3 July, and on 3 July R.V. Pitsiulak was launched by local crews and moved in slow stages through the ice to the Government wharf, where she was secured. An advance party of research personnel reached Nain on 5 July and began shakedown and supply operations immediately. Geological research was begun at Wyatt Hr. on Nukasorsuktokh I. on 7 July at 2115 h, lasting until 2230 h when dim light rendered work unprofitable.

For the next two weeks, conferences, research ashore, and shakedown-supply operations were interleaved during a period of splendid weather. A second group of research personnel arrived 8 July, and three field parties were established in their camps on 9 July: de Waard at Sachem Bay, Planansky at The Bridges, and Woodward on Newark I. Inshore waters by that time were clear of pack ice. The vessel, with Wheeler, Berg, and Dymek aboard, spent two most profitable working days among pack ice in the outer islands, 8 and 10 July, reaching most objectives and finding no seaward limit to anorthositic rocks. In this work, Pitsiulak passed her first tests in pack ice, proving her maneuverability, navigational ease, and soundness of hull and sheathing. On 12 July, camps at Hettasch Lake (Berg) and Snyder Bay (Speer) were established by charter aircraft, and Berg returned to the vessel for work in Port Manvers Run before leaving on 14 July by foot to reach his camp via geologically interesting terrain. More work in the outer islands followed, one day without ice, and another with ice which eventually halted further seaward progress. On 16 July, a gale of westerly wind damaged two of the upland tents, which were eventually repaired or replaced. Several days were devoted to engineering details, resupply operations, conferences, and laboratory work, and on 19 July the first phase of the summer's work closed with the departure of Wheeler by aircraft for an inland lake on Ikkinikulluit Brook, and the arrival of guest investigators from UCLA.

A northern trip for geochronological and geochemical sampling was begun on 20 July. It was hoped to proceed as directly as possible to the Nakhvakh region of Northern Labrador, and thence to work southward. Ice-free conditions were found around Cape Kiglapait and westward into Tessiuyakh Bay, where sampling was begun on 21 July. Another easy passage, with some ice, was made to the Mugford area on 22 July, where sampling was continued in Kai-Kai inlet during an afternoon of worsening weather. Refuge was taken in Horr Harbour, west of Mugford Tickle, where a northeast storm held sway till 25 July. This had the unfortunate but predictable effect of driving the enormous ice pack of the Labrador Current ashore, and although Pitsiulak was finally able to pass through Mugford Tickle on the evening of 25 July, she was met by a vast expanse of tight, pressure-ridged arctic ice at the northern end, and reluctantly turned back from this limited "farthest north." Although in fact two boats found passage further north in the succeeding few days, the northern coast was very heavily encumbered with ice for a long period thereafter, and further commitment of the vessel's time in a renewed attempt at northing was out of the question. Collections were resumed on the way south through 29 July, principally at Okhakh, Udlik Bay, and the Kiglapait intrusion.

Routine operations, resupply, and laboratory work followed until 4 August, when the routine was interrupted by an injury to a field assistant (David Borns), who suffered a hairline fracture of the fibula in a fall. By coincidence, the vessel arrived at the site of the accident soon after it occurred, and a rapid transit to the International Grenfell Association (IGA) hospital in Nain was effected. After X-rays were taken aboard the IGA hospital ship Strathcona on 7 August, a cast was applied, and Borns elected to resume duty in the laboratory aboard R.V. Pitsiulak.

During the period 7-9 August, Dymek and Atsatata conducted a successful shoreline geologic reconnaissance of Tessersoakh Lake (about 55 km long) via 20-ft freight canoe. During the next week, sampling for petrographic and paleomagnetic studies was conducted in Port Manvers Run, geochronology samples were collected on the eastern end of Paul I., and a series of diamond drill cores was collected on Dog I. for de Waard, while numerous operational details and laboratory studies were completed on the side.

The annual "grand tour" August field conference was held from the 18th to the 21st in developing dampness and discomfort, as in 1971. Nevertheless, the conference served for the illustration of critical field relations at Barth I. and Newark I., and included a seminar on Berg's more inaccessible Hettasch intrusion and a traverse, also conducted by him, across the upper stratigraphic levels of the Kiglapait intrusion. This traverse was, it must be admitted, blessed with fine weather, and during the same time Pitsiulak paid a visit to Speer's camp in Snyder Bay, taking along guest investigator D. A. Hewitt and fresh supplies. The grand tour closed in Khaukh Harbour after being rained out of The Bridges area, and on 23 August the Syracuse contingent departed to attend an early inauguration of the academic year.

Field work was resumed on 23 August and continued for five days in the outer islands, at Zoar, and in Snyder Bay, where a conference was reconvened to examine the Snyder Group and the Kiglapait north coast. This conference terminated in a cool northeast breeze with snow squalls, and when the vessel reached her berth in Wyatt Hr. at midnight on the 27th, snow lay on the ground at sea level. The last field camps were taken aboard in Zoar and in Ten Mile Bay on the 28th; the 29th was devoted to storage of equipment at Khaukh Hr., and all research personnel left the field area on 30 August.

TOPICAL SUMMARIES

Ice.

The breakup on 2-3 July was the latest in a generation or more, and heavy pack ice lay offshore and among the islands throughout July and intermittently until mid-August. Ice came within sight of Nain village on 9 August, and a loose band of it lay across Strathcona Run on 10 August. Despite this, our work was not materially hindered by ice except at Mugford Tickle, and in fact the quiet water inside the pack ice permitted many landings to be made in the outer islands which would have been dangerous or impossible with normal Atlantic swells running. The landing sites included a rock normally awash. The 1972 season thus provided a cogent demonstration of the importance of wintering Pitsiulak in Nain, where she was available and free to work from the day breakup occurred. A successful passage into the Nain area from the south through the ice would have been subject to uncertain timing at best, and to delays more serious because of the excellent weather for working in early July.

The vessel worked in ice on all or a good part of six days: 8, 10, 15, 25, 26, and 27 July. Despite frequent contact, an inspection of her sheathing while she was dried out at Nain wharf showed little more than scratches in the paint.

Weather.

July was splendid for the most part, barring the westerly gale which blew out two tents on the 16th and the three-day northeaster which clamped the ice onto the Mugford coast and kept the vessel crew busy with anchors 23-25 July. The log shows 85% of the 27 working days in July to have been decent for working, and 67% of these to have been downright fine.

August, in contrast, gave a poor account of itself. The log shows 53% of its 30 days decent for working, only 33% fair, and 47% bad or very bad, with wind, rain, and finally snow. Such weather is particularly inhibitive of good field work, although many man-days were certainly laid in by field crews during marginal or worse weather. The vessel, however, counted only two days lost to weather during August, her laboratory facilities being designed expressly for taking advantage of bad weather, and her mobility in resupply operations being unhindered except by storms with heavy wind.

Vessel maintenance.

Spring painting and mechanical inspection were completed in Nain during late June and early July. A new battery charger was installed 5-6 July, and this proved to be a great improvement in maintaining the ship's batteries at charge. Electrical problems continued to be serious at times, however, first with the breakage of alternator belts on the main engine, which were replaced with spares and then with new ones sent by air from Newfoundland. A more serious problem, however, has arisen in the auxiliary generator which is used to charge the main batteries when the main engine is not running. This second-hand generator has deteriorating wiring which at the end of the season was beginning to fail excessively often. The generator will have to be replaced.

Other problems encountered during the season were largely those capable of solution in the field. A hot bearing was coaxed into adjustment, a strainer was installed over the engine's salt-water intake to prevent clogging by seaweed (this was left off at first in anticipation of clogging with young ice, which can be cleared only by ramming out the intake from within the vessel), a broken anchor was temporarily supplanted by a 40-S Danforth, which holds well in good ground, and was eventually replaced at no charge by the supplier. A freshwater tank leak which developed late in the season is scheduled for repair in Nain. A leak in the stern timbers is also scheduled for repair if the cause can be correctly diagnosed.

Although the vessel was able to fulfill her major obligations in support of shore-based research, the time lost on several occasions to the deteriorating generator was excessive, and the threat which this condition poses to operational effectiveness and safety can no longer be countenanced.

Communication.

Field and ship radios furnished adequate communication except to the furthest camps during a three-day period of worse-than-average radio blackout caused by ionospheric conditions. A routine maintenance program has been established for radios and antennas to insure their continued effective operation. Radiotelephone communications from Nain to outside stations were at times unsatisfactory or impossible, but a new transmitter and antenna are being installed by the telephone company, and an improvement should result. Four new field radios were added in 1972.

Flying.

Charter aircraft were used for the major movements of research personnel between Goose Bay and Nain and for a number of camp and personnel movements during the season. Access to Nain has been greatly improved by the addition of a twice-weekly scheduled flight via the communities along the coast to the south, which also carries limited amounts of air freight. It was occasionally possible to do local charter flying with aircraft coming to Nain for other purposes, and this was a great help. Such local flights will become a more important component of our program when field parties begin to investigate the areas deeper inland from the coast.

Laboratory.

On-site determination of mineral compositions and routine microscopic mineral identification have been an important part of our program from its inception. Samples are processed with a jaw crusher (occasionally first with a diamond saw) and sieves, and in some cases mineral separations are made with heavy liquids. A single petrographic microscope equipped with a monochromator is used; a second one would prove advantageous. In 1972, 124 mineral composition determinations and 190 identifications were made. Some of the data appear in this report, and all data are in the hands of field investigators to supplement their own shore-based determinations. The laboratory facility continues to be a valuable aid in field mapping, as well as a source of publishable data.

Subsistence

A stock of staples has been built up in Nain, and is replenished increasingly by sea freight as the need for rapid resupply by air diminishes. Increasing amounts of food are also purchased locally. Arrivals of fresh foods by boat were timely in 1972, and no serious shortages occurred except for a few items delayed by a dock strike in Montreal. Freeze-dried foods continued to be a mainstay of most diets ashore, and a backlog of these is now on hand for the beginning of the next season's work.

A further and complete deterioration of the cod fishery occurred in 1972: no codfish were caught or seen. Arctic char were available for most of the season to native licensed fishermen.

Health

Time was lost in two injuries during the 1972 season. The first involved a minor head injury to a field assistant with a previous history of concussion, and upon medical advice the patient was returned home to the care of his family doctor, where recovery was eventually complete. The second injury was a minor fracture, previously mentioned in the narrative, and the patient was allowed to resume limited duty in the laboratory aboard R.V. Pitsiulak. In addition to these injuries, a small amount of time was lost to a particularly acute but short-lived form of "flu" which most of the vessel's crew escaped.

Wintering

The Government slip in Nain was enlarged in the fall of 1972, and R.V. Pitsiulak was hauled out there on 10 November, in her own cradle. This successful conclusion resulted from much effort by the people of Nain, and there is hope that with continued improvements in hauling-out facilities, this annual chore will present increasingly fewer problems.

Shore Facilities and Field Gear

Storage space for field gear and provisions is retained in a Moravian Mission building in Nain and in a smaller private building in Khaukh Harbour. A 16 x 20-ft house used for storage and personnel during past summers in Village Bay was unfortunately carried away in a December gale, and was demolished.

The Project's operational affairs ashore continue to be most ably arranged by the personnel of Haynes Store in Nain.

Two 17-ft freighter canoes and one river canoe were added in 1972, and these proved very useful. Canoes are presently stored for the winter on a scaffold in Khaukh Hr. Two Mt. Logan tents were also added during the past season.

SUMMARY OF OPERATIONS

The 1972 working season lasted 56 days, beginning 5 July after a long-delayed breakup of winter ice. Detailed geologic mapping and sampling were conducted in eight field areas by shore-based parties, and in the outer islands and Port Manvers Run by the staff of R.V. Pitsiulak. In addition, sampling for geochronology was undertaken in the area between Nain and Mugford Tickle by vessel-based crews. The shipboard laboratory furnished 124 mineral composition determinations and 190 mineral identifications in support of field mapping. The season included peripatetic field conferences at the beginning, and an organized conference in August for the exchange and demonstration of research results. Hydrographic surveys totalled 250 miles of tracks; these are reported separately. The calendar of operations below summarizes the main events.

Calendar

July 3	Vessel launched
5	First research personnel to Nain; start of operations
7	Geological research started
8	Second research group to Nain; vessel in outer islands
9	Conferences and deployment of three shore parties
10	Vessel in outer islands
12	Berg and Speer field camps established
19	Wheeler to Ikkinikulluit area, UCLA investigators to Nain

20-29	Northern trip
31	de Waard from Barth to Dog I. area
August 1	Wheeler returned from shore camp
7-9	Tessersoakh trip, Dymek; Wheelers to Annaktalakh B.
10	Port Manvers Run work begun
13	Paul I. and Nukasorsuktokh I. research
15	Diamond drilling - Dog I.
18-21	"Grand tour" geological conference
23	Syracuse research group out
24-27	Outer islands, Zoar, Snyder Bay
30	Field operations terminated and research personnel out
Nov. 10	Pitsiulak hauled out on cradle, Nain

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Operating Staff

A. Atsatata, Nain	Pilot-Engineer
N. Andersen, Nain	Mate (half-season)
J. Kajui, Nain	Mate (half-season)
Messrs. H. and H. Webb, Nain	Expediters
Haynes Store, Nain	Agent
D. F. Morse, Amherst	Cook
S. A. Morse, Amherst	Master

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