Current Research (1990) Newfoundland Department of Mines and Energy,
Geological Survey Branch, Report 90-1, pages 227-236

RESEARCH ON THE ARCHEAN ROCKS OF NORTHERN LABRADOR, PROGRESS REPORT 1989

D. Bridgwater, F. Mengel[1], L. Schiøtte and J. Winter[2]
Geologisk Museum, Oster Voldgade 5-7, DK-1350, Copenhagen K, Denmark

ABSTRACT

The early Archean Uivak gneisses of the Saglek Fiord–Hebron Fiord area, northern Labrador, were affected by varying degrees of late Archean metamorphism and migmatization, which U–Pb ion-probe results from zircons show to have occurred between 2.77 and 2.71 Ga. The gneisses from the outer coastal zone show a prograding transition from amphibolite facies to granulite facies, modified by later retrogression. Three stages of transition are distinguished: (1) Uivak gneisses that retain their early Archean structures and lithological integrity: the only evidence that these were affected by late Archean granulite-facies metamorphism is that mid-Archean dykes (Saglek dykes), which intrude them, contain retrogressed granulite-facies assemblages; (2) gneisses that have been strongly modified during late Archean ductile deformation so that original layering and discordant contacts between the gneisses and the Saglek dykes are rotated: these commonly contain orthopyroxene or its relicts; and (3) gneisses that are strongly modified by the injection of syntectonic late Archean pegmatites (ca. 2.7 Ga), which in some parts of the area, permeated into their early Archean host rocks to form complex migmatites: the pegmatites, which caused this migmatization, were emplaced after the regional metamorphic transition between granulite and amphibolite facies had developed in their country rocks. Some pegmatites contain granulite-facies mineral assemblages, others amphibolite-facies assemblages.

From a combination of field characteristics and Sm–Nd and Lu–Hf isotopic results, the data indicate there are at least three suites of supracrustal rocks interlayered with the gneisses: 1) the 3.78 Ga Nulliak assemblage found as inclusions in the Uivak gneisses; 2) a suite dominated by basic volcanic rocks, associated with subsidiary semipelitic units corresponding to most of the units previously called the 'Upernavik' supracrustals, and which has an estimated age of ca. 3.4 Ga for its deposition; and 3) a suite represented in the Saglek Fiord–Hebron Fiord area by units in outer St. John's Harbour and Big Island having a high proportion of clastic material, probably deposited in the period between 3.25 Ga and the late Archean metamorphism at ca. 2.77 Ga.

Archean gneisses from Ford Harbour, 35 km east of Nain, are polymetamorphic and polygenetic and contain a high proportion of migmatized metasedimentary rocks. The Ford Harbour gneisses were affected by late Archean granulite-facies metamorphism and migmatization comparable to that of the Saglek–Hebron area.

INTRODUCTION

Project Description

Field work was carried out in the Hebron Fiord area in 1989 as a supplement to the regional mapping studies by the Newfoundland Department of Mines and Energy in 1982 and 1983 (Ryan *et al.*, 1983, 1984) and to provide a link with the more recent mapping carried out by the Geological Survey of Canada in the Okak area to the south (Ermanovics *et al.*, 1988, 1989). One of the main reasons for this work is that the Saglek–Hebron–Okak area of northern Labrador (Figure 1) provides an almost unique opportunity to study the effects of late Archean thermal events on an early Archean gneiss complex, as they are manifested at different erosional levels of the late Archean crust. Field, geochemical and isotopic studies in the area, over the past 15 years, have suggested that the effects of this 'reworking' vary from one outcrop to another, and in order to better interpret the available data, new field observations are necessary. Other objectives were to document the effects of Proterozoic metamorphic overprint on the area and to determine the extent of the early Archean rocks southward toward Nain. As a chronological framework, U–Pb zircon ages are used where these are available (Baadsgaard *et al.*, 1979; Schiøtte *et al.*, 1989a,b), augmented by further U–Pb zircon studies, Pb–Pb and Sm–Nd whole-

[1] Memorial University of Newfoundland, St. John's, Newfoundland, A1B 3X5

[2] Whitman College, Walla Walla, Washington, U.S.A.

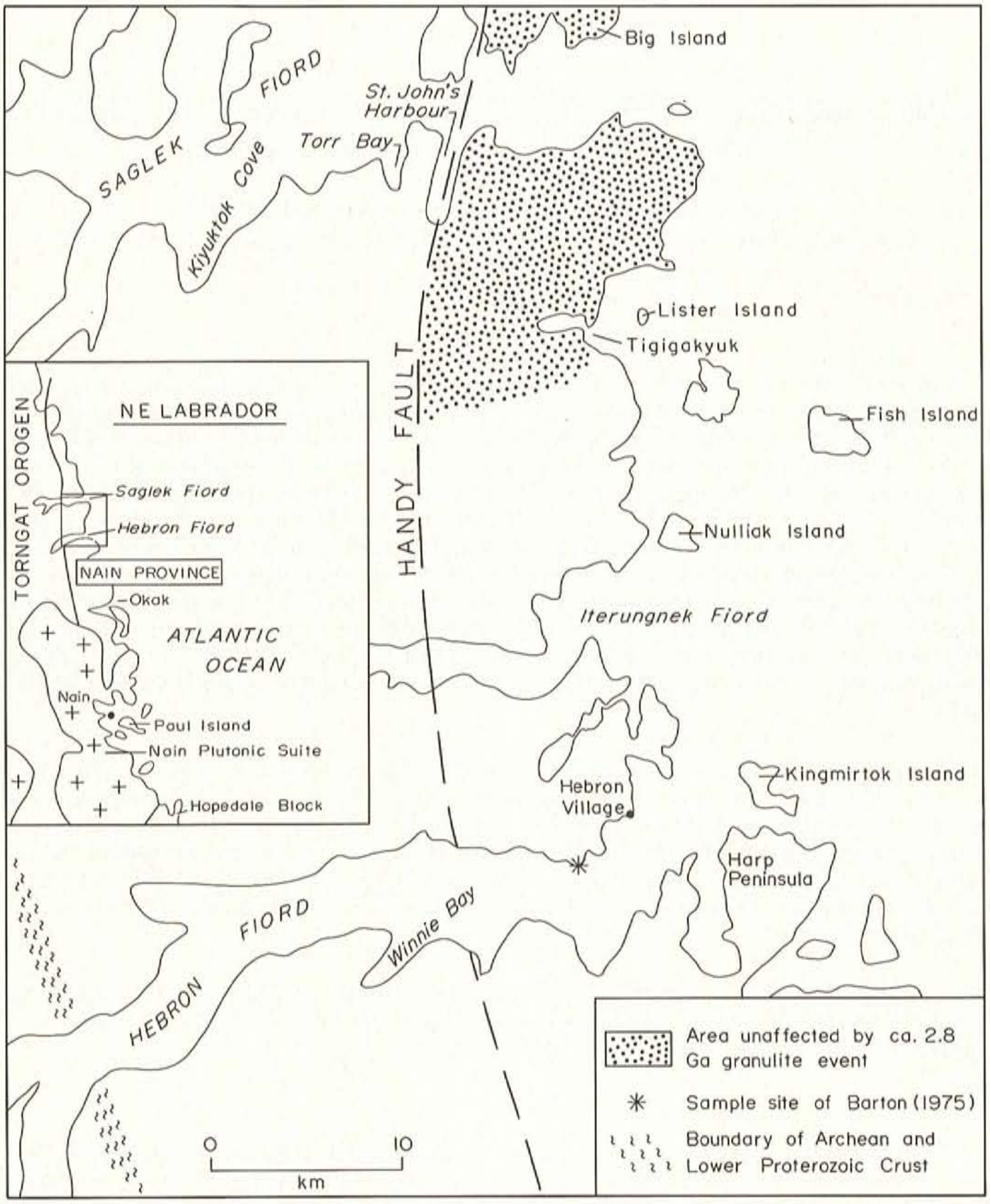

Figure 1. *Sketch map of northern Labrador showing localities mentioned in the text.*

rock studies in the Nain Province, currently being carried out by one of us (L.S.).

FIELD RESEARCH IN THE SAGLEK–HEBRON–OKAK AREA

Effects of Late Archean Metamorphism and Migmatization on the Early Archean Gneiss Complex

Regional Background. Mapping from 1974 to 1976 (Bridgwater *et al.*, 1975, 1978; Collerson *et al.*, 1976) and 1982-1983 (Ryan *et al.*, 1983, 1984) in the Saglek–Hebron area, followed by petrological and isotopic studies (Hurst *et al.*, 1975; Hurst and Tilton, 1976; Bridgwater and Collerson, 1976, 1977; Baadsgaard *et al.*, 1979; Collerson *et al.*, 1981, 1982; Collerson and Campbell, 1989; Schiøtte *et al.*, 1986, 1989a,b; Schiøtte and Bridgwater, *in press*) have shown that the early Archean Uivak gneisses, which form over 60 percent of the area, were affected by differing degrees of late Archean migmatization and amphibolite- to granulite-facies metamorphism. The granulite-facies metamorphism is most extensive in the western part of the Saglek–Hebron region, but the eastern coastal zone exhibits a southward transition from amphibolite to granulite facies. The effects of late Archean metamorphism and migmatization on the early Archean gneisses in the transitional amphibolite- to granulite-facies terrane of the outer coastal zone vary markedly across the regional strike on a scale of tens to hundreds of metres (cf. Ryan, 1977). Some of these variations are addressed below, since they are important for the understanding of granulite-facies–amphibolite-facies transitions in general, and for the understanding of geochemical results from the Saglek–Hebron area in particular.

Variations in Metamorphic Grade. The Handy fault, a major lineament extending approximately north–south from the passage west of Big Island in Saglek Bay through St. John's Harbour and Hebron Fiord into the Okak area (Ermanovics *et al.*, 1988, 1989), forms a major metamorphic and tectonic break in northern Labrador (Figure 1). On the western side, all early Archean gneisses were affected by a series of events that took place under granulite facies conditions between 2.77 and 2.71 Ga (Schiøtte *et al.*, 1989a). Uivak gneisses from Torr Bay, Saglek Fiord, affected by this metamorphism show both severe depletion in LIL elements and exhibit partial melting phenomena. The latter feature also characterizes the gneisses west of the Handy fault at least as far south as Winnie Bay. East of the fault, the gneiss complex from Big Island to Tigigakyuk Inlet, 10 km south of Saglek Fiord, was affected by late Archean amphibolite-facies metamorphism. South of Tigigakyuk Inlet, the eastern gneiss block was at least in part affected by the 2.77 to 2.71 Ga regional granulite-facies event (Schiøtte *et al.*, 1989a). The gradual transition from amphibolite facies to granulite facies observed from north to south, is interpreted as due to scissor-like movement along the Handy fault, so that higher levels of the late Archean crust are exposed in the northern part of the fault block (Ryan *et al.*, 1983, 1984; Schiøtte *et al.*, 1986). Partial melting and the formation of granulite-facies pegmatites is not as common east of the Handy fault as it is to the west, and no examples of granulite-facies gneisses as severely geochemically depleted as those from Torr Bay, have been noted east of the fault. This may be interpreted to mean that the late Archean granulite-facies metamorphism did not reach the same intensity in the eastern block north of Hebron Fiord.

Variations in Migmatization. The gneisses both to the east and west of the Handy fault were intruded by widespread late Archean granitic and trondhjemitic sheets, concentrated in regional swarms, which vary from a few hundred metres up to 1 to 2 km in width. In severely migmatized zones, these intrusive rocks can make up 80 to 90 percent of the local gneiss complex. The sheets, informally referred to as 'the main migmatite sheet swarm', were emplaced during a period of deformation, which impressed the present regional north-northwest–south-southeast structural grain on the area. They are foliated and generally parallel to the regional gneissosity but are locally transgressive to late Archean mineral fabrics and minor folds in their country rocks. They are regarded as late syn- to post-kinematic with respect to the peak of regional deformation and high-grade metamorphism in the area. In the amphibolite-facies area at the mouth of Saglek Fiord, the sheets contain amphibolite-facies mineral assemblages. In the transitional area south of Tigigakyuk Inlet, most of the sheets similarly contain amphibolite-facies assemblages, but locally the margins of the main sheets and stringers in the gneisses contain orthopyroxene. In the western fault block and in the Okak area to the south, many of the sheets contain orthopyroxene or minerals derived from the retrogression of orthopyroxene. There is thus an overall coincidence between the areas affected by the regional 2.77 to 2.71 Ga granulite-facies event and the occurrence of orthopyroxene in 'the main migmatite sheet swarm'. On a local scale, there is no direct correlation between the development of granulite-facies mineralogy in the country rocks and in the sheets. In several outcrops, orthopyroxene-bearing migmatite sheets cut grey gneisses, in which textures and mineral assemblages developed during the late Archean regional granulite-facies event, have been deformed and retrogressed. In some cases, this retrogression was caused by the introduction of hydrous fluids from a slightly earlier sheet, intruded as part of 'the main migmatite sheet swarm'.

The contact relations between the sheet swarm and the country rocks are equally variable. In the granulite-facies areas, both east and west of the Handy fault, many of the sheets are surrounded by Uivak gneiss country rocks, which have developed diffuse leucocratic patches and pegmatitic stringers (the Kiyuktok gneisses of Kerr, 1980; Collerson *et al.*, 1981; Schiøtte *et al.*, 1986). Geochemical and isotopic studies (Bridgwater and Collerson, 1976, 1977; Bridgwater *et al.*, 1978; Collerson *et al.*, 1981, 1982; Schiøtte *et al.*, 1986) show that the granulite-facies or retrogressed granulite-facies country rocks that host the sheets were enriched in LIL and LRE elements at the time of migmatization. Our interpretation of Rb–Sr, Pb–Pb and Sm–Nd whole-rock data from samples collected by one of us (D.B.) in 1974 and 1975, and investigated isotopically by Collerson *et al.* (1981, 1982, 1989), is that there has been considerable interchange of Pb, Sr and Nd between the late Archean intrusive sheets (which contain a component that is isotopically more juvenile than that developed by the main gneisses at the time of migmatization) and their early Archean Uivak gneiss country rocks.

Multigrain U–Pb dating of the zircons from a major migmatite sheet located on eastern Fish Island has yielded a concordia intercept age of 2742 $^{+35}_{-34}$ (Schiøtte, 1988). The oldest ^{207}Pb–^{206}Pb ages measured on individual fractions are in the range 2660 to 2650 Ma. As the zircons are rather discordant the validity of the intercept age can be debated. The Fish Island sheet is intrusive into ortho- and para-gneisses, which have previously recrystallized under granulite facies, but which were partially retrogressed. Small apophyses from the sheet, which cut a Saglek dyke, contain orthopyroxene but the main sheet lacks orthopyroxene. The sheet thus occupies the same position in the local stratigraphy as the pegmatitic sheets associated with the Kiyuktok gneisses, and since these latter sheets postdate the 2.77 to 2.71 Ga granulite-facies events indicated by ion-probe U–Pb studies on single zircon crystals, it may be realistic to assign a ca. 2.7 Ga age to the emplacement of the whole swarm in this area.

Both the field relations and the available detailed U–Pb age determinations of zircons (Schiøtte *et al.*, 1989a,b), suggest therefore that granulite-facies conditions continued for an extended period of time in the area (50 to 100 Ma). The features seen in any one outcrop are the result of several different processes, including geochemical depletion, partial melting, and a slightly younger phase of migmatization that introduced leucocratic material from outside. The variations in mineralogy seen both within single sheets and between different phases of migmatization on the same outcrop, strongly suggest that local variations in fluid composition played an important role in controlling the development of granulite-facies mineral assemblages during the final stage of the granulite-facies metamorphism.

The emplacement of the 'main migmatite sheet swarm', ending at about 2.7 Ga, was followed by granitic activity in the period 2.7 to ca. 2.5 Ga (Baadsgaard *et al.*, 1979; Schiøtte, 1988). Many of these younger granites were emplaced as thin sheets under amphibolite-facies conditions. They postdate the foliated main swarm, but are themselves folded during late Archean deformation. The gneiss complex was affected by lower amphibolite to greenschist-facies retrogression associated with late Archean deformation concentrated in distinct shear belts, and shearing/faulting reflecting the easternmost effects of the major Proterozoic movements in the west of the area. In the area between the mouth of Saglek and Hebron fiords, most of the retrogression appears to be late Archean or very early Proterozoic, since the Proterozoic dykes cut gneisses having well-developed fabrics at amphbiolite to greenschist facies. On eastern Kingmirtok Island and throughout much of the Okak area, the early Proterozoic dykes (and their host gneisses) are affected by post-dyke, low-grade metamorphism assumed to be related to Proterozoic tectonic events seen in the west.

A range of U–Pb mineral ages (apatite and sphene) reported by Baadsgaard *et al.* (1979) from the Saglek–Hebron area, and the most metamict high-U zircons determined by Schiøtte *et al.* (1989a), show that this isotopic system remained partially open, well into the Proterozoic (between 2.4 and 2.3 Ga). Rb–Sr isochron ages in the 2.4–2.3 Ga range have also been obtained from 1- to 10-mm slabs of amphibolite collected at the contact to late Archean pegmatites, north of Lister Island (Figure 1; Schiøtte, unpublished data). In the Okak area, Barton (1977) has obtained Rb–Sr whole-rock age of about 2.3 Ga from the Okak granite (recalculated assuming a ^{87}Rb decay constant of 1.42×10^{-11}). This late intrusive body, which has a high initial Sr isotopic ratio, is interpreted to be largely derived from early Archean crust. Granitoid sheets in the Okak area also locally develop granulite-facies assemblages in their marginal zones.

Detailed Field Relations Around the Mouth of Hebron Fiord. Three main varieties of early Archean gneiss have been noted from the mouth of Hebron Fiord. All three show variable effects of late Archean granulite-facies metamorphism and subsequent retrogression, but they differ in overall field character. The gneiss types we have identified are, a) Uivak gneisses that show little imprint of late Archean structural and migmatizing events, b) Uivak gneisses that are structurally modified by late Archean ductile deformation, and c) Uivak gneisses that are both structurally refoliated and strongly migmatized by the introduction of a late Archean mobilizate. Types b) and c) were originally referred to collectively as Iterungnek gneiss by Ryan (1977). It is proposed here that the structural reworking of the early Archean Uivak gneisses was a distinct and separate event divorced from the migmatization (which is younger than the main tectonic overprint). The resultant gneiss types are, therefore, treated as separate units below. It is recognized that the boundaries between all three gneiss types defined above are transitional, reflecting the common inhomogeneity of tectonic processes at such crustal levels.

(A) Gneisses that show very little effect of the late Archean metamorphism/migmatization. These are best exposed on the 0.5-km-wide peninsula 7.5 km southwest of Hebron village, from which Barton (1975) collected a single slab of layered gneiss and obtained one of the first Rb–Sr isochrons showing the presence of early Archean rocks in the area. At this locality, there are many discordant, little deformed mid-Archean plagioclase phenocryst-bearing Saglek dykes. These are up to 3- to 5-m wide and intrude the early Archean Uivak gneisses, which at this locality comprise two main components, an early banded grey phase showing considerable variation in the content of mafic minerals from layer to layer, and a younger pegmatitic phase poor in mafic minerals. On the western side of the peninsula, the gneisses contain amphibolite-facies assemblages and show virtually no macroscopic effects of late Archean metamorphism. The Saglek dykes in this area likewise contain amphibolite-facies assemblages, but also exhibit very local garnet and orthopyroxene-bearing patches at their cores. By contrast, on the eastern side of the peninsula, the banded gneisses are overprinted by a deformation fabric and locally develop an indistinct recrystallization texture, in which the mafic minerals show signs of segregation. Both features postdate Saglek dyke emplacement and are earlier than the intrusion of the regional migmatite sheet swarm. The dykes on the eastern side of the peninsula are more deformed, generally coarser grained, contain larger amounts of orthopyroxene, and the plagioclase phenocrysts are frequently surrounded by rims of garnet. Late Archean pegmatite sheets of 'the main migmatite sheet swarm' are sharply discordant and show only very local interaction with their country rocks.

The well-preserved, early Archean gneisses outcropping on this peninsula in Hebron Fiord, pass laterally both to the west and east into layered grey gneisses, in which the Saglek dykes are folded and disrupted and in which the pre-dyke structures are strongly modified. No sharp boundaries or structural discontinuities between these gneiss types were observed, and if, as seems probable, the original distinction between well-preserved and less well-preserved parts of the early gneiss complex is structurally controlled, then these differences were developed before the main fabric, now seen in outcrop. Other areas of comparatively well-preserved early Archean Uivak gneisses cut by clearly discordant Saglek dykes occur in the Hebron area, e.g., eastern Dog Island just east of Hebron village, and on the north shore of Hebron Harbour. The boundaries between these well-preserved gneisses and those affected by subsequent deformation are gradational and are not easily recognized inland from the coast. Such areas of Uivak gneiss are presumed to be lacunae of low deformation a few-hundred-metres wide, elongated parallel to the late Archean regional gneissosity.

(B) Ductilely folded early gneisses without late Archean migmatization. The majority of early Archean banded gneisses between Tigigakyuk Inlet and Hebron Fiord were much more strongly modified during the late Archean thermal and tectonic events than the gneisses described above. Internal structures within the Uivak gneisses and the remnants of Saglek dykes are complexly folded under ductile conditions and earlier discordancies destroyed. Orthopyroxene or retrogressed relics of orthopyroxene are found at most localities. Field observations suggest that the units of well-preserved gneisses described above alternate across strike with the more abundant ductile deformed units. Geochemical data from the structurally reworked gneisses suggest that, in spite of clear evidence of ductile deformation and orthopyroxene growth during the late Archean, these gneisses were not so strongly depleted in LIL elements as the rocks from the Torr Bay granulites west of the Handy fault.

(C) Gneisses showing extensive late Archean migmatization. The regional, late Archean pegmatitic 'main migmatite sheet swarm' emplaced at approximately 2.7 Ga occurs throughout the Hebron Fiord area on both sides of the Handy fault. The sheets are particularly abundant in the parts of the gneiss complex that were compositionally inhomogeneous before injection of the pegmatitic material, e.g., where units of supracrustal rocks or Saglek dykes occur within the early orthogneisses. The break-up of basic rocks by the introduced material resulted in complex agmatitic mélanges, in which basic inclusions occur in a leucocratic pegmatitic matrix (e.g., at Hebron village).

On many outcrops in the southern part of the area, e.g., southern Kingmirtok Island and on the Harp Peninsula, the intrusion of pegmatites was accompanied by widespread introduction of leucocratic material into the adjacent gneisses. This migmatization took place both by the injection of veins and by the permeation of the country rocks. It was accompanied by recrystallization with the development of mafic mineral (garnet and orthopyroxene) aggregates ('blebby texture'). These migmatites are identical in the field to the Kiyuktok gneisses originally described by Kerr (1980) from Saglek Fiord west of the Handy fault (see Figure 2 of Schiøtte *et al.*, 1986).

Supracrustal Units in the Saglek–Hebron–Okak Area: The 'Upernavik' Supracrustal Problem

The original field work by Bridgwater *et al.* (1975) in the Saglek Fiord area distinguished two supracrustal sequences: inclusions in the regional Uivak gneiss suite (later known as the Nulliak assemblage, see Bridgwater and Collerson, 1977; Nutman *et al.*, 1989) and larger units interlayered with the gneisses known collectively as the Upernavik supracrustals. The Nulliak assemblage is clearly older than the regional Uivak gneisses and, like them, is cut by the mid-Archean Saglek dykes. An ion-probe U–Pb age of 3.78 Ga has been obtained from zircon within a clastic metasediment thought to be derived from an acid metavolcanic protolith in Saglek Fiord (Schiøtte *et al.*, 1989b); this paragneiss predates the intrusion of the main grey phase of Uivak gneiss. A similar Sm–Nd whole-rock isochron age has been reported by Collerson and Campbell (1989) from basic rocks in the type Nulliak suite. Zircons from a quartzite, identified as a Nulliak supracrustal remnant by Collerson *et al.* (1985) from inner Hebron Fiord, have yielded U–Pb ion-probe ages between 3.82 and 3.5 Ga.

The Upernavik supracrustals as first described (from Upernavik Island and Big Island, Saglek Fiord) were not seen to be cut by either the Uivak gneisses or the Saglek dykes and were therefore assumed to be younger than these units. Field work by two of us (D.B. and L.S.) in 1987 showed that supracrustal rocks from 1 km south of Hebron village and classified during regional compilations (e.g., Ryan *et al.*, 1983, 1984) as Upernavik supracrustal rocks are cut by metamorphosed porphyritic basic dykes comparable to the Saglek dykes. The sequence south of Hebron consists of basic and ultrabasic rocks interlayered with semipelitic garnet–biotite–cordierite–sillimanite metasedimentary gneisses. It is typical of the 'Upernavik' supracrustal suite found in the area around the mouth of Hebron Fiord. In contrast to the Nulliak supracrustal suite at the type locality, there are no major ironstone or calc-silicate units. There is a considerably smaller proportion of clastic sediments (particularly silicic rocks) than seen in the 'Upernavik' supracrustal suite found at outer St. John's Harbour and Big Island, Saglek Fiord. The differences in rock types could be explained as the result of tectonic separation of different parts of an original single sedimentary–volcanic sequence now preserved as a series of thrust slices (e.g., the original models of McGregor, 1973 and Bridgwater *et al.*, 1975). However, recent age determinations on the Malene supracrustal rocks in Greenland, (Schiøtte *et al.*, 1988) together with the discovery that tectonic intercalation between supracrustal units and their host gneisses occurred during more than one period in the late Archean development of the gneiss complex in West Greenland (Friend *et al.*, 1987), have suggested that the simple correlations between different supracrustal rock units cannot be accepted without isotopic support. Lu–Hf studies (Stevenson, personal commumication, 1988) on bulk zircons from outcrops of granulite-facies 'Upernavik' semipelitic gneisses from Torr Bay gave a CHUR model age of ca. 3.4 Ga, consistent with a dominantly early Archean source. Lu–Hf determinations on zircons from amphibolite-facies 'Upernavik' psammitic gneisses from outer St. John's Harbour yield a CHUR model age of 3.1 Ga. Collerson *et al.* (1985) report U–Pb upper intercept ages of ca. 3.1 Ga using the ion-probe on detrital zircons from an 'Upernavik' quartzitic unit from an unspecified locality in the Saglek area. These results strongly suggest that some of the 'Upernavik' quartzites contain zircons from a source that is younger than the Uivak gneiss, for example the 3.24 Ga Lister gneisses (Schiøtte *et al.*, 1989a). Whole-rock Sm–Nd studies of several 'Upernavik' supracrustal units in the Saglek–Okak area are now in progress (Schiøtte *et al.*, *in press*), but give equivocal results. Data obtained from the metasediments are consistent with the Lu–Hf results from the same units and suggest that at least some of the 'Upernavik' supracrustals could be deposited after the emplacement of the Lister gneisses. However, moderately well fitted isochrons obtained on associated basic supracrustals from all the units investigated agree within error and yield ages of 3.5 to 3.4 Ga. Whereas the status of the 'Upernavik' supracrustal suite as a single stratigraphic unit is doubtful and requires further detailed isotopic work, the Sm–Nd results are sufficiently distinct to suggest that the Nulliak assemplage from the type locality is older than any of the 'Upernavik' supracrustal units investigated.

FIELD WORK IN THE FORD HARBOUR AREA, EASTERN PAUL ISLAND, NAIN

Regional Setting

Outcrops of Archean gneiss occur as screens and roof pendants between the mid-Proterozoic anorthosites and granites forming the Nain Plutonic Suite, which separates the Archean Nain Province into halves. These gneisses have received very little detailed attention and their relationship to other Archean gneisses in Labrador is unknown. As pointed out above, the northern Archean block is dominated by early Archean gneisses throughout the area mapped in detail from Saglek to southern Okak Island. On the other hand, the southern block, centred around Hopedale, is dominated by the quartzofeldspathic Maggo gneisses (Ermanovics and Korstgärd, 1981; Ermanovics *et al.*, 1982; Korstgärd and Ermanovics, 1984), the main phase of which has given a 3.1 Ga U–Pb zircon concordia intercept age (Loveridge *et al.*, 1987). The earliest proven crustal components from the Hopedale area are detrital zircons yielding an age of 3.26 Ga (Schiøtte *et al.*, 1989b) from one of the rare outcrops of paragneiss classified as part of the mid to late Archean Weekes amphibolite supracrustal suite, which occurs as inclusions in the Maggo gneiss. The zircons are interpreted to be derived from an earlier igneous source, possibly a temporal equivalent of the Lister gneisses of the Saglek–Okak area (Schiøtte *et al.*, 1989b). The low U/Th ratios of the zircons are consistent with the parent orthogneiss being emplaced under granulite-facies conditions. Basic rocks from a second outcrop of the Weekes amphibolite have given a Sm–Nd isochron age of ca. 3.0 Ga (Stecher *et al.*, 1986) and thus differ from any basic supracrustal rocks of the Saglek–Hebron–Okak region. Finn (*in press*) reports a 4 point Rb–Sr whole-rock isochron age of ca. 3.3 Ga for orthogneisses from the same locality as the paragneisses studied by Schiøtte *et al.* (1989b).

The Maggo gneisses of the Hopedale block were affected by two major structural events in the period ca. 3.1 Ga to 2.8 Ga. Both the Hopedalian and the Fiordian deformation took place under amphibolite-facies conditions, but granulite-facies assemblages of pre-Fiordian age are preserved locally (Ermanovics *et al.*, 1982). Multigrain U–Pb dating of igneous zircons from intrusions emplaced during or immediately after the Fiordian event (Loveridge *et al.*, 1987) and ion-probe determinations of overgrowths on single zircon grains from the Weekes paragneisses (Schiøtte *et al.*, 1989b) both give ages of 2.84 Ga. Apart from the possible occurrence of zircons derived from a source equivalent in age to the Lister gneisses, there is no direct correlation between either major rock units or metamorphic events in the northern and southern sections of the Nain Province.

The foregoing framework demonstrates the critical need to understand the geological setting of the remnants of the Archean basement that occur between the Proterozoic intrusions of the Nain area, and occupy a geographically central area between Saglek–Okak and Hopedale. The largest of these remnants outcrops on easternmost Paul Island and adjacent islands, 35 km east of Nain (Figure 2). These have been briefly described previously by De Waard (1971) and Bridgwater *et al.* (1973), and were examined more closely during the 1989 field season in order to determine their salient features relative to the more extensive Archean rocks to the north and south. The results of this survey are presented below.

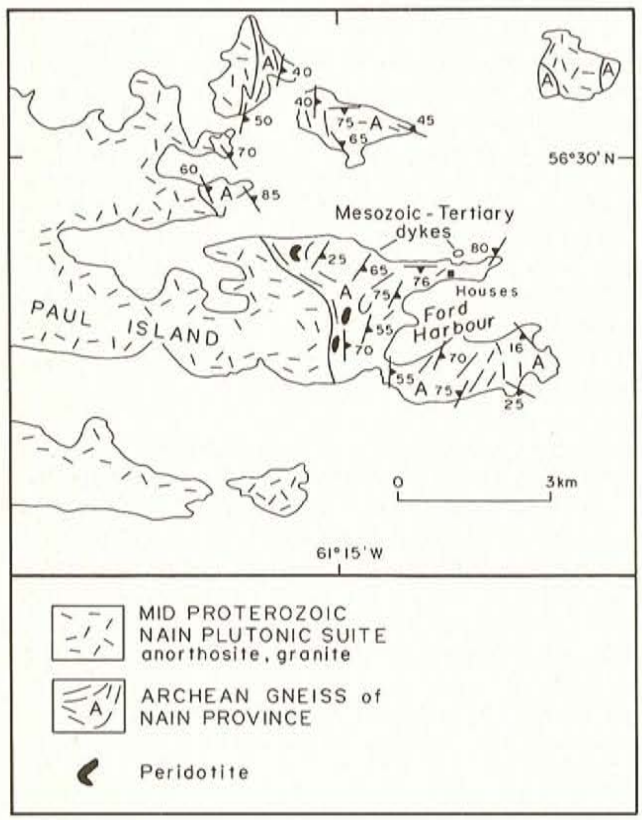

Figure 2. *Geological map of eastern Paul Island and adjacent islands showing distribution of Archean gneisses described in the text.*

The Ford Harbour Gneisses

The Ford Harbour gneisses are a suite of highly migmatized polymetamorphic and polygenetic rocks, which were intruded by early Proterozoic basic dykes (now containing amphibolite-facies assemblages) and partly recrystallized during the emplacement of the mid-Proterozoic igneous suite. The Archean gneisses developed Proterozoic granulite-facies assemblages in a zone extending for tens of metres adjacent to the main anorthosite body forming western Paul Island. Rare orthopyroxene-bearing mafic dykes, some of which form a matrix to intrusion breccias, cut the gneisses several kilometres away from the main intrusions but are thought to belong to the mid-Proterozoic igneous suite. Elsewhere, the overall effects of the Proterozoic intrusions has been to retrogress earlier regional granulite-facies and amphibolite-facies assemblages in the gneisses. Locally, the Archean gneisses have become partially mobile during the Proterozoic and it is not always possible to distinguish Archean and Proterozoic events.

The Ford Harbour gneisses contain three main components:

1) *Leucocratic-Layered Grey Gneisses.* These are assumed to be derived from a tonalitic or granodioritic parent and are best exposed on the extreme east of the island where they locally contain thin amphibolite layers interpreted to be basic dyke remnants. The gneisses are highly modified by late Archean and Proterozoic events and do not preserve any certain diagnostic field characters, which could help to determine possible correlatives to the north or south. Their layered nature is, however, more like typical Uivak gneisses rather than Maggo gneisses.

2) *Supracrustal Units.* Highly migmatized paragneisses form a larger component of the Archean gneiss complex from Ford Harbour than they do in either the Saglek–Okak area or the Hopedale area. They are interpreted as derived from dominantly semipelitic to impure psammitic parents, strongly migmatized during late Archean high-grade metamorphism. The paragneisses are associated with layered basic volcanic rocks affected by high-strain and granulite-facies metamorphism. The layered basic rocks contain subconcordant homogeneous layers having small plagioclase aggregates interpreted as metamorphosed dykes. Hornblende-rich-banded iron formation similar to that described from the Nulliak assemblage (Nutman *et al.*, 1989) was noted at one locality. Textures such as symplectic coronas of plagioclase and hypersthene around garnet in the basic rocks suggest that they recrystallized from garnet–orthopyroxene-bearing assemblages. Their present amphibolite-facies assemblages and the widespread development of symplectites thought to have replaced garnets are regarded as dominantly formed during the mid-Proterozoic lower pressure metamorphism caused by emplacement of the Nain Plutonic Suite. Whereas the compositional associations within the supracrustal rocks are not diagnostic, a high proportion of paragneisses derived from clastic sources is a more common feature of supracrustal units to the north of Nain than that seen in the Weeks amphibolites in the Hopedale district.

3) *Late Pegmatite Sheets.* Both the grey gneisses and the supracrustal rocks from Ford Harbour are very heavily migmatized both by the injection of widespread pegmatitic swarms and by intimate permeation of a leucosome identical in the field to that seen in the Kiyuktok gneisses. Many of the migmatite sheets contain orthopyroxene and garnet or their relics, comparable to that seen in the main pegmatite sheets of the Saglek–Okak area. The orthopyroxene is largely replaced by amphibole whereas the garnet is variably replaced by what appears to be an intricate cordierite-rich symplectite, interpreted as the result of a metamorphic overprint associated with the Proterozoic intrusions. The orthopyroxene- and garnet-bearing pegmatites are intruded by composite medium- to fine-grained granite sheets similar to the granitic sheets and plutons emplaced in the Saglek–Okak area in the latest Archean to very early Proterozoic.

Both the type of pegmatite injection and associated migmatization seen in the Ford Harbour gneisses and the remnants of granulite-facies metamorphism, which developed late in the Archean sequence of events, is similar to that seen north of Nain rather than in the Hopedale block. Therefore, we tentatively conclude that the Ford Harbour gneisses are a continuation of the Saglek–Hebron–Okak gneiss complex and based on present field evidence, suggest that they may contain a high proportion of early Archean crust, migmatized and severely modified during the late Archean, then metamorphosed and locally partly melted during the Proterozoic. There are no isotopic measurements available from Ford Harbour, but it can be noted that the initial Sr ratio of 0.745 at 1576 Ma obtained by Barton (1977) from granitic gneisses from Loon Island east of Nain is consistent with approximately 2 Ga of crustal residence prior to their emplacement (assuming an average Rb/Sr ratio of 0.5 or less), comparable to the average values of the gneiss complex both to the south and north of Nain. Pb and Nd isotopic compositions from the Nain anorthosites and associated dykes (Ashwal and Wooden, 1985; Ashwal *et al.*, 1985) also point to a high proportion of early Archean crust beneath the Nain Plutonic Suite.

POST-PROTEROZOIC DYKES

Rare kimberlitic or lamproitic blocks have been noted as float during previous mapping of the Saglek–Hebron area and have been assumed to be derived from deeply weathered dykes now hidden within gullies. One well-exposed body, approximately 2-m wide and striking northwest-southeast was discovered within Archean supracrustal rocks 1 km south of Hebron village. The matrix is dark-coloured and biotite-rich and contains scattered olivine-rich nodules. There are rare garnet-bearing inclusions.

A single east–west red-brown olivine diabase, which exhibits zeolite-filled vesicles, was noted from the north coast of Ford Harbour. This dyke, which is up to 2-m wide, is open jointed and intrudes the youngest fracture patterns seen in the gneisses. It is identical in the field to late Mesozoic to Tertiary dykes cutting the gneiss complexes of southern West Greenland (Watt, 1969). We suggest that this body could either represent crustal fracturing during the Mesozoic breakup of Greenland and Labrador or possible later (?Tertiary) movements along fractures parallel to transform faults in the Labrador Sea. Similar, rare Tertiary dykes (ca. 50 Ma) occur at high angles to the coast in West Greenland.

ACKNOWLEDGMENTS

The field work represents a continuation of cooperation between the Geological Museum, Copenhagen, Memorial University of Newfoundland and both the Newfoundland Department of Mines and Energy (A.B. Ryan and R.J. Wardle) and the Geological Survey of Canada, Ottawa (I. Ermanovics and E. Cameron). We are grateful for logistic and scientific support from both organizations. One of us (F.C.M.) has been supported while at Memorial University by operating grants to Dr. T. Rivers. Without his continued support this project would not have been possible. The Carlsberg Foundation, Copenhagen provided the main financial backing for the field work and is making a considerable contribution toward analytical expenses. One of us (L.S.) wishes to thank the isotope laboratories at DTM (S. Shirey and R. Carlson), Munster (B.T. Hansen), and ROM (S. Noble and T. Krogh) where he has worked in the last year.

REFERENCES

Ashwal, L.D. and Wooden, J.L.
1985: Sm–Nd isotopic studies of Proterozoic anorthosites: systematics and implications. *In* The Deep Proterozoic Crust in the North Atlantic Provinces. *Edited by* A.C. Tobi and J.L.R. Touret. Reidel Publishing Company, pages 61-73.

Ashwal, L.D., Wooden, J.L. and Emslie, F.R.
1985: Nd, Sr and Pb isotope systematics of mid-Proterozoic dikes from the Grenville and Nain Provinces of Labrador (abstract). EOS, Volume 66, page 414.

Baadsgaard, H., Collerson, K.D. and Bridgwater, D.
1979: The Archean gneiss complex of northern Labrador: 1. Preliminary U–Th–Pb geochronology. Canadian Journal of Earth Sciences, Volume 16, pages 951-961.

Barton, J.M., Jr.
1975: Rb-Sr isotopic characteristics and chemistry of the 3.6 B.Y. Hebron gneiss, Labrador. Earth and Planetary Science Letters, Volume 27, pages 427-435.

1977: Rb-Sr ages and tectonic setting of some granite intrusions, coastal Labrador. Canadian Journal of Earth Sciences, Volume 14, pages 1635-1645.

Bridgwater, D. and Collerson, K.D.
1976: The major petrological and geochemical characters of the 3600 m.y. Uivak gneiss from Labrador. Contributions to Mineralogy and Petrology, Volume 54, pages 43-59.

1977: On the origin of early Archean gneisses: A reply. Contributions to Mineralogy and Petrology, Volume 62, pages 179-191.

Bridgwater, D., Collerson, K.D., Hurst, R.W. and Jesseau, C.W.
1975: Field characters of the early Precambrian rocks from Saglek, coast of Labrador. *In* Current Research, Part A. Geological Survey of Canada, Paper 75-1A, pages 288-296.

Bridgwater, D., Collerson, K.D. and Myers, J.
1978: The development of the Archean gneiss complex of the North Atlantic region. *In* Evolution of the Earth's Crust. *Edited by* D.H. Tarling. London Academic Press, pages 19-69.

Bridgwater, D., Watson, J. and Windley, B.F.
1973: The Archean craton of the North Atlantic region. Philosophical Transactions of the Royal Society, London, A273, pages 493-512.

Collerson, K.D. and Campbell, L.M.
1989: Sm-Nd isotopic systematics of Early Archean ultramafic rocks in the North Atlantic craton: A sample of ancient depleted mantle? EOS, (abstract), October 1989, page 1390.

Collerson, K.D., Jesseau, C.W. and Bridgwater, D.
1976: Crustal development of the Archean gneiss complex, eastern Labrador. *In* The Early History of the Earth. *Edited by* B.F. Windley. Wiley, New York, pages 237-253.

Collerson, K.D., Kerr, A. and Compston, W.
1981: Geochronology and evolution of late Archean gneisses in Northern Labrador: An example of reworked sialic crust. Geological Society of Australia, Special Publication, Volume 7, pages 205-222.

Collerson, K.D., Kerr, A., Vocke, R.D. and Hanson, G.N.
1982: Reworking of sialic crust as represented in late Archean-age gneisses, northern Labrador. Geology, Volume 10, pages 202-208.

Collerson, K.D., McCulloch, M.T. and Nutmen, A.
1989: Sr and Nd isotope systematics of polymetamorphic Archean gneisses from southern West Greenland and northern Labrador. Canadian Journal of Earth Sciences, Volume 26, pages 446-466.

Collerson, K.D., Williams, I.S. and Ryan, A.B.
1985: Archean crustal evolution of northern Labrador: inferences from ion microprobe studies of zircons in metasedimentary units. Geological Association of Canada-Mineralogical Association of Canada, Annual Meeting, Program with Abstracts, Volume 10, page A11.

De Waard, D.
1971: Eastern Contact Zone: Country rock of the anorthosite massif and anorthosite contacts in the Ford Harbour region. *In* The Nain Anorthosite Project, Labrador. *Edited by* S.A. Morse. Geology Department, University of Massachusetts, Field report 1971, pages 15-26.

Ermanovics, I.F. and Korstgård, J.
1981: Geology of Hopedale Block and adjacent areas, Labrador: Report 3. *In* Current Research, Part A. Geological Survey of Canada, Paper 81-1A, pages 169-176.

Ermanovics, I., Korstgärd, J.A. and Bridgwater, D.
1982: Structural and lithological chronology of the Archean Hopedale Block and the adjacent Proterozoic Makkovik Subprovince, Labrador: Report 4. *In* Current Research, Part B. Geological Survey of Canada, Paper 82-1B, pages 153-165.

Ermanovics, I.F., van Kranendonk, M., Corriveau, L., Bridgwater, D., Mengel, F.C. and Schiøtte, L.
1988: Geology of the North River–Nutak map areas, Nain-Churchill provinces, Labrador. *In* Current Research, Part C. Geological Survey of Canada, Paper 88-1C, pages 19-26.

Ermanovics, I.F., van Kranendonk, M., Corriveau, L., Mengel, F., Bridgwater, D. and Sherlock, R.
1989: The boundary zone of the Nain-Churchill Provinces in the North River–Nutak areas, Labrador. *In* Current Research, Part C. Geological Survey of Canada, Paper 89-1C, pages 385-394.

Finn, G.
In press: Rb-Sr geochronology of the Archean Maggo gneiss from the Hopedale Block, Labrador. Canadian Journal of Earth Sciences.

Friend, C.R.L., Nutman, A.P. and McGregor, V.R.
1987: Late-Archean tectonics in the Faeringehavn-Tre Brødre area, south of Buksefjorden, southern West Greenland. Journal of Geological Society, London, Volume 144, pages 369-376.

Hurst, R.W. and Tilton, G.R.
1976: Isotopic investigations of the 3.62 b.y. old iron-rich Uivak gneiss, Saglek Bay, Labrador. *In* Geological Society of America, Program with Abstracts, page 933.

Hurst, R.W., Bridgwater, D., Collerson, K.D. and Wetherhill, G.W.
1975: 3600 m.y. Rb-Sr ages from very early Archean gneisses from Saglek Bay, Labrador. Earth and Planetary Science Letters, Volume 27, pages 393-403.

Kerr, A.
1980: Late Archean igneous, metamorphic and structural events in the Saglek area, northern Labrador. Unpublished M.Sc. thesis, Memorial University of Newfoundland.

Korstgärd, J.A. and Ermanovics, I.F.
1984: Archean and early Proterozoic tectonics of the Hopedale Block, Labrador, Canada. *In* Precambrian Tectonics Illustrated. *Edited by* A. Kroner. E. Schweizerbart'sche Verlagsbuchhandlung Stuttgart, pages 295-318.

Loveridge, W.D., Ermanovics, I.F. and Sullivan, R.W.
1987: U-Pb ages on zircon from the Maggo gneiss, the Kanairiktok plutonic suite and the Island Harbour plutonic suite, coast of Labrador, Newfoundland. *In* Radiogenic Age and Isotopic Studies: Report 1. Geological Survey of Canada, Paper 87-2, pages 59-65.

McGregor, V.R.
1973: The early Precambrian gneisses of the Godthaab district, West Greenland. Philosophical Transactions of the Royal Society, London, A273, pages 343-358.

Nutman, A.P., Fryer, B. and Bridgwater, D.
1989: The early Archean Nulliak (supracrustal) assemblage, northern Labrador. Canadian Journal of Earth Sciences, Volume 26, pages 2159-2168.

Ryan, A.B.
1977: Progressive structural reworking of the Uivak gneisses, Jerusalem Harbour, northern Labrador. Unpublished M.Sc. thesis, Memorial University of Newfoundland, 230 pages.

Ryan, A.B., Martineau, Y., Bridgwater, D., Schiøtte, L. and Lewry, J.
1983: The Archean-Proterozoic boundary in the Saglek Fiord area, Labrador: Report 1. *In* Current Research, Part A. Geological Survey of Canada, Paper 83-1A, pages 297-304.

Ryan, A.B., Martineau, Y., Korstgärd, J. and Lee, D.
1984: The Archean-Proterozoic boundary in northern Labrador: Report 2. *In* Current Research, Part A. Geological Survey of Canada, Paper 84-1A, pages 545-551.

Schiøtte, L.
1988: En undersgelse af metamorfe processers betydning for tidlig-Arkaeiske bjergarters geokemi og isotop-geologi i nordlige Labrador, Canada. Unpublished Lic. Scient.-thesis, Geological Museum, Copenhagen.

Schiøtte, L. and Bridgwater, D.
In press: Multistage late Archean granulite facies metamorphism in northern Labrador, Canada. *In* Granulites and Crustal Differentiation. *Edited by* D. Vielzeuf and Ph. Vidal. Nato ASI series C: Kluwer Academic press.

Schiøtte, L., Bridgwater, D., Collerson, K.D., Nutman, A.P. and Ryan, A.B.
1986: Chemical and isotopic effects of late Archean high-grade metamorphism and granite injection on early Archean gneisses, Saglek-Hebron, northern Labrador. *In* The Nature of the Lower Continental Crust. *Edited by* J.B. Dawson, D.A. Carswell, J. Hall and K.H. Wedepohl. Geological Society Special Publication, Volume 24, pages 261-273.

Schiøtte, L., Compston, W. and Bridgwater, D.
1988: Late Archean ages for the deposition of clastic sediments belonging to the Malene supracrustals, southern West Greenland: evidence from an ion probe U-Pb zircon study. Earth and Planetary Science Letters, Volume 87, pages 45-58.

1989a: Ion-probe U-Th-Pb zircon dating of polymetamorphic orthogneisses from northern Labrador, Canada. Canadian Journal of Earth Sciences, Volume 26, pages 1533-1556.

1989b: U-Th-Pb ages of single zircons in Archean supracrustals from Labrador, Canada. Canadian Journal of Earth Sciences, Volume 26, pages 2636-2644.

Schiøtte, L., Shirey, S.B., Carlson, R.W. and Bridgwater, D.
In press: Sm-Nd isotopic systematics of Archean Upernavik supracrustal rocks from the Saglek to Okak area, Labrador: relation to high-grade orthogneisses of the North Atlantic Craton. *In* Abstracts from the 3rd International Archean Symposium, Perth, 1990.

Stecher, O., Carlson, R.W., Shirey, S.B., Bridgwater, D. and Nielsen, T.F.D.
1986: Nd-isotope evidence for the evolution of metavolcanic rocks from the Archean block of Greenland and Labrador. Terra Cognita, Volume 6, page 236.

Watt, W.S.
1969: The coast parallel dyke swarm of southwest Greenland in relation to the opening of the Labrador sea. Canadian Journal of Earth Sciences, Volume 6, pages 1320-1321.