Investigations of Paleozoic geology, northern Axel Heiberg and northwestern Ellesmere islands

Project 860007

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Abstract

The Rens Fiord Complex of Axel Heiberg Island is divided into: 1. interstratified basalt and carbonate of Early Cambrian or Hadrynian age; 2. dolostone and minor limestone of probable Early Cambrian age (facies equivalent of Ella Bay Formation?); 3. the Grant Land Formation (Lower Cambrian); and 4. the Hazen Formation (Lower Cambrian to Lower Silurian). The Svartevaeg Formation probably is a thrust-faulted facies equivalent of the Silurian Lands Lokk Formation. The basal Carboniferous succession includes a thin volcanic unit.

Steeply inclined to subhorizontal thrusts in northern Axel Heiberg Island, directed both to the northeast and the southwest, are attributed to deformations of Late Silurian – Early Devonian, and post-Early Devonian to pre-Visean ages.

On northwestern Ellesmere Island, the sandy and argillaceous member C of the Lands Lokk Formation represents a submarine fan facies that ranges in age from latest Llandovery or Wenlock to Ludlow. The chert-rich sediments are comparable to formations of northeastern Greenland and may have been affected by sinistral strike slip.

Résumé

Le complexe de Rens Fiord dans l'île Axel Heiberg se subdivise de la façon suivante: 1) basaltes et carbonates interstratifiés d'âge Cambrien inférieur ou Hadrynien; 2) dolomie détritique et quantités mineures de calcaire, probablement d'âge Cambrien inférieur (faciès équivalent à la formation d'Ella Bay?); 3) formation de Grant Land (Cambrien inférieur); et 4) formation de Hazen (Cambrien inférieur à Silurien inférieur). La formation de Svartevaeg est probablement un faciès avec failles chevauchantes, équivalent à celui de la formation silurienne de Lands Lokk. La succession basale du Carbonifère comprend une mince unité volcanique.

On attribue des charriages fortement inclinés à subhorizontaux, présents dans le nord de l'île Axel Heiberg, dirigés vers le nord-est et le sud-ouest, à des déformations survenues du Silurien supérieur au Dévonien inférieur, et durant une autre préiode, ultérieure au Dévonien inférieur et antérieure au Viséen.

Dans le nord-ouest de l'île Ellesmere, le membre sableux et argileux de la formation de Lands Lokk correspond à un faciès de cône alluvial sous-marin, dont l'âge se situe entre le sommet du Llandovérien ou le Wenlockein, et le Ludlovien. Les sédiments cherteux sont comparables aux formations du nord-ouest du Groenland, et ont peut-être subi un décrochement sénestre.

INTRODUCTION

The purpose of fieldwork in 1986 was to update the information on the pre- Carboniferous geology of northern Axel Heiberg Island and northwestern Ellesmere Island obtained from 1955 through 1962 (in chronological order) by E.F. Roots, R. Thorsteinsson, P.E. Fricker, and the author (Trettin, 1969). Stratigraphic and structural studies in northern Axel Heiberg Island, from three camps south of Rens Fiord and from one camp northeast of Rens Fiord (Fig. 36.1), were concerned mainly with the lower Paleozoic rocks, but also included a newly discovered volcanic unit in the basal part of the Carboniferous succession. On Ellesmere Island, stratigraphic and sedimentological studies of the Silurian Lands Lokk Formation were made from two camps, south and southeast of Emma Fiord, respectively.

The writer is indebted to the officers and pilots of the Polar Continental Shelf Project for transport in the field and courtesies. Gordon Check, student assistant from Dalhousie University, is thanked for his excellent work and companionship. The graptolite identifications were made by R. Thorsteinsson and B.S. Norford and the chemical analyses of volcanic rocks collected earlier, were carried out by the Analytical Chemistry Section of the Geological Survey under the supervision of G.R. Lachance.

PRE-CARBONIFEROUS GEOLOGY, NORTHERN AXEL HEIBERG ISLAND

Stratigraphy

The unfosssiliferous and severely deformed Ordovician and/or older strata of northern Axel Heiberg Island were originally assigned to four lithological units of uncertain stratigraphic order, collectively referred to as the Rens Fiord Complex. They are now reassigned to two informal units of Early Cambrian and(?) older age (Jaeger Lake assemblage and Aurland Fiord beds), and to two formations of the Franklinian deep-water basin established on northern Ellesmere Island — the Lower Cambrian Grant Land Formation, and the Cambrian to Lower Silurian Hazen Formation.

The fossiliferous Silurian-Devonian succession was divided into three formal stratigraphic units: the Lands Lokk Formation, established on Ellesmere Island (see below); the Lower Devonian Stallworthy Formation; and the Svartevaeg Formation of presumed Early and/or Middle Devonian age. The last now is interpreted as Silurian in age and correlative, to some extent, with the Lands Lokk Formation. Only those parts of the Lands Lokk Formation exposed southwest of Aurland Fiord were restudied in 1986; the summaries of the other units are based on more detailed descriptions in Trettin (1969) with some reinterpretation.

Lower Cambrian and (?) older

The original volcanic and carbonate units of the Rens Fiord Complex now are regarded as informal units of formational rank, provisionally named Jaeger Lake assemblage and Aurland Fiord beds, respectively. Their age and stratigraphic order are uncertain because they are unfossiliferous, bounded by faults, and not in stratigraphic or structural contact with each other. However, the fact that both have been thrust over the Grant Land Formation suggests that they are older than that unit and hence Early Cambrian and/or Hadrynian in age. The Aurland Fiord beds are tentatively correlated with the Lower Cambrian Ella Bay Formation of central Eastern Ellesmere Island. If this correlation is correct, then the Aurland Fiord beds underlie the Grant Land Formation in a stratigraphic sense and the Jaeger Lake assemblage is the oldest exposed unit in this area.

The **Jaeger Lake assemblage** occurs as small fault blocks in the central part of the study area and as thrust sheets in a narrow belt extending from east of Rens Fiord to southeast of Cape Thomas Hubbard (Fig. 36.2A). A 426 m thick stratigraphic section east of Jaeger Lake (Trettin, 1969, p. 9) comprises nearly equal proportions of volcanic and carbonate rocks, occurring in three units each. The volcanic rocks are original flows and tuffs, metamorphosed in the greenschist facies and pervasively altered by calcite and quartz. The ratios of immobile trace elements ($Zr/TiO2^{fi}$vs. Nb/Y according to Winchester and Floyd [1977, Fig. 6]) in three specimens analyzed indicate that they are subalkaline basalts, probably of within-plate origin (Pearce and Cann, 1973, Fig. 3; and Holm, 1982). The carbonate rocks are dolostones and recrystallized limestones (marbles) that locally contain stromatolites.

The Jaeger Lake assemblage is comparable to the Yelverton assemblage of northwestern Ellesmere Island (south of Phillips Inlet to east of the head of Yelverton Inlet), which consists of interstratified, variably metamorphosed tholeiitic tuff, flows and sills, limestone, dolostone, mudrock, and chert, with an estimated total thickness of more than 1 km. This unit also has been thrust over the Grant Land Formation.

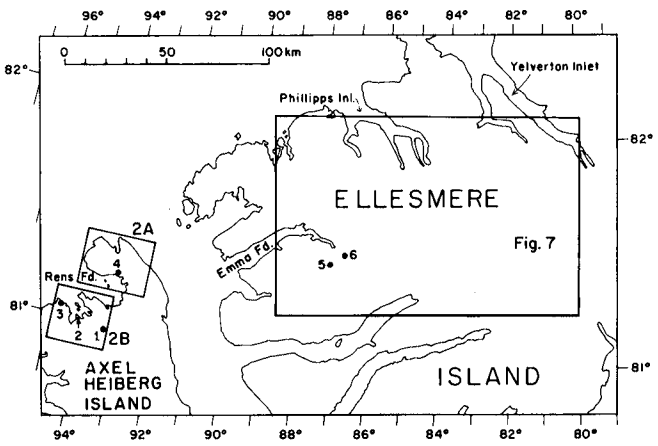


Figure 36.1. Index for Figures 36.2A, 36.2B and 36.7, and location of camp sites (numbered 1-6).

Both may be correlative with Hadrynian basalt on Victoria Island (Natkusiak Formation), which has yielded a K-Ar isochron age of 635 Ma (recalculated from Palmer and Hayatsu (1975) using present constants) and the related Franklin dyke swarms, but the possibility that they are Early Cambrian in age cannot be dismissed.

The **Aurland Fiord beds** are widely distributed in the vicinity of Aurland Fiord (Fig. 36.2B) and also occur north and east of Rens Fiord. The stratigraphic thickness of the various fault slices and blocks varies from a few metres to about 1.3 km, attained in a steeply dipping block west of Aurland Fiord. The unit consists mainly of flat- laminated dolostone and related dolomitic intraformational conglomerate with lesser proportions of nonlaminated dolostone, microcrystalline limestone, and dolomitic grainstone, pisolite, and solution (?) breccia. Recrystallized argillaceous and cherty sediments are interbedded with dolostone near the base of a major thrust sheet 8.4 km southeast of central Aurland Fiord. Quartz veins and chert replacement are ubiquitous.

The abundant laminated dolostone is tentatively interpreted as an original "peri-platform ooze" deposited in outer shelf – upper slope settings, but differs from typical sediments of this type by a lack of interstratified mudrock; the grainstones, accordingly, would represent high-energy shoals on the shelf margin. The unit may represent a facies intermediate in water depth between the shelf sediments of the Lower Cambrian Ella Bay Formation of central Ellesmere Island (Long, 1985; and unpublished manuscript), and the correlative deep-water carbonate sediments of the southern Grant Land Mountains (Nesmith beds, Trettin, unpublished manuscript) and northeastern Greenland (Paradisfjeld Formation, Friderichsen et al., 1982). If so, the Aurland Fiord beds, like the Nesmith beds, would underlie the Grant Land Formation stratigraphically. However, neither the Ella Bay Formation nor the Nesmith beds are exposed on Axel Heiberg Island and western Ellesmere Island, so that this assignment is speculative.

Grant Land Formation

The Grant Land Formation was established in the southern Grant Land Mountains of northern Ellesmere Island (Trettin, 1971, and unpublished manuscript) where it lies stratigraphically between resedimented carbonates of Early Cambrian age (Nesmith beds) and the Hazen Formation (see below). At this location, it comprises an estimated 2 km of clastic sediments, mainly variably feldspathic quartzite and multicoloured phyllite or slate with small proportions of pebble conglomerate and intraformational mudrock-clast conglomerate. The unfossiliferous formation is considered to be middle to late Early Cambrian in age on the basis of regional stratigraphic relationships. It is similar to the Polkorridoren Group of northeastern Greenland (Friderichsen et al., 1982) and correlative with the Ellesmere Group of central Ellesmere Island. It appears to be a submarine fan deposit, (although classical turbidites [Bouma sequences] are rare on Ellesmere Island) and evidently was derived from the North American craton (Trettin et al., in press).

The original sandstone unit of the Rens Fiord Complex, and a large proportion of the rocks originally designated as "argillaceous and cherty strata", now are assigned to the Grant Land Formation on the basis of lithological and petrographic similarity. On Axel Heiberg Island, the formation consists mainly of fine to coarse grained quartzite and dark grey, greenish grey or purplish red slate and phyllite with small amounts of granule conglomerate. The thickness of the formation cannot be established here because of complex folding and faulting but appears to be considerable (i.e. probably greater than 1 km) because of its wide distribution.

Hazen Formation

In the Hazen Plateau region of northern Ellesmere Island the Hazen Formation is a condensed succession of deep water carbonate, radiolarian chert, mudrock and minor sandstone of late Early Cambrian to Early Silurian age that lies stratigraphically between the Grant Land Formation and flysch of the Imina Formation (Trettin, 1971, and unpublished manuscript). Its thickness decreases from probably more than 1 km near the Franklinian shelf to about 250 m in the northwesternmost exposures. The lower part is dominated by resedimented carbonate and the upper part by radiolarian chert, but the contact between the carbonate and chert members is diachronous, ranging in age from Arenig in the northeast to middle Landovery in the southwest. In some areas, the carbonates and mudrocks have been replaced by chert.

On northern Axel Heiberg Island, three major and a few minor outcrop areas of this formation have been recognized south of Rens Fiord and east and west of Aurland Fiord. North of Rens Fiord, only a few small outcrop areas have been mapped, but others may be present within the northern part of the outcrop area of the Grant Land Formation, which was not traversed in 1986.

In a syncline south of central Aurland Fiord, the Grant Land Formation is overlain by more than 60 m of carbonate and minor mudrock that must represent the basal part of the formation if the concealed contact between the two units is not faulted. The carbonate rocks include: 1. laminated, variably argillaceous dolostone; 2. graded dolsiltite and dolarenite; and 3. dolomitic intraformational conglomerate that appears to have originated by sliding of carbonate boudins in a submarine slope environment. The carbonate member of the Hazen Formation is probably also represented by dolomitic strata associated with dark grey mudrock and chert in small outcrop areas southwest and southeast of Aurland Fiord.

Silurian sedimentary and volcanic strata

The Silurian sedimentary and volcanic rocks are discussed below in terms of the two units to which they were assigned originally – the Lands Lokk and Svartevaeg formations – but a revision of that usage is advisable. The stratigraphy of the

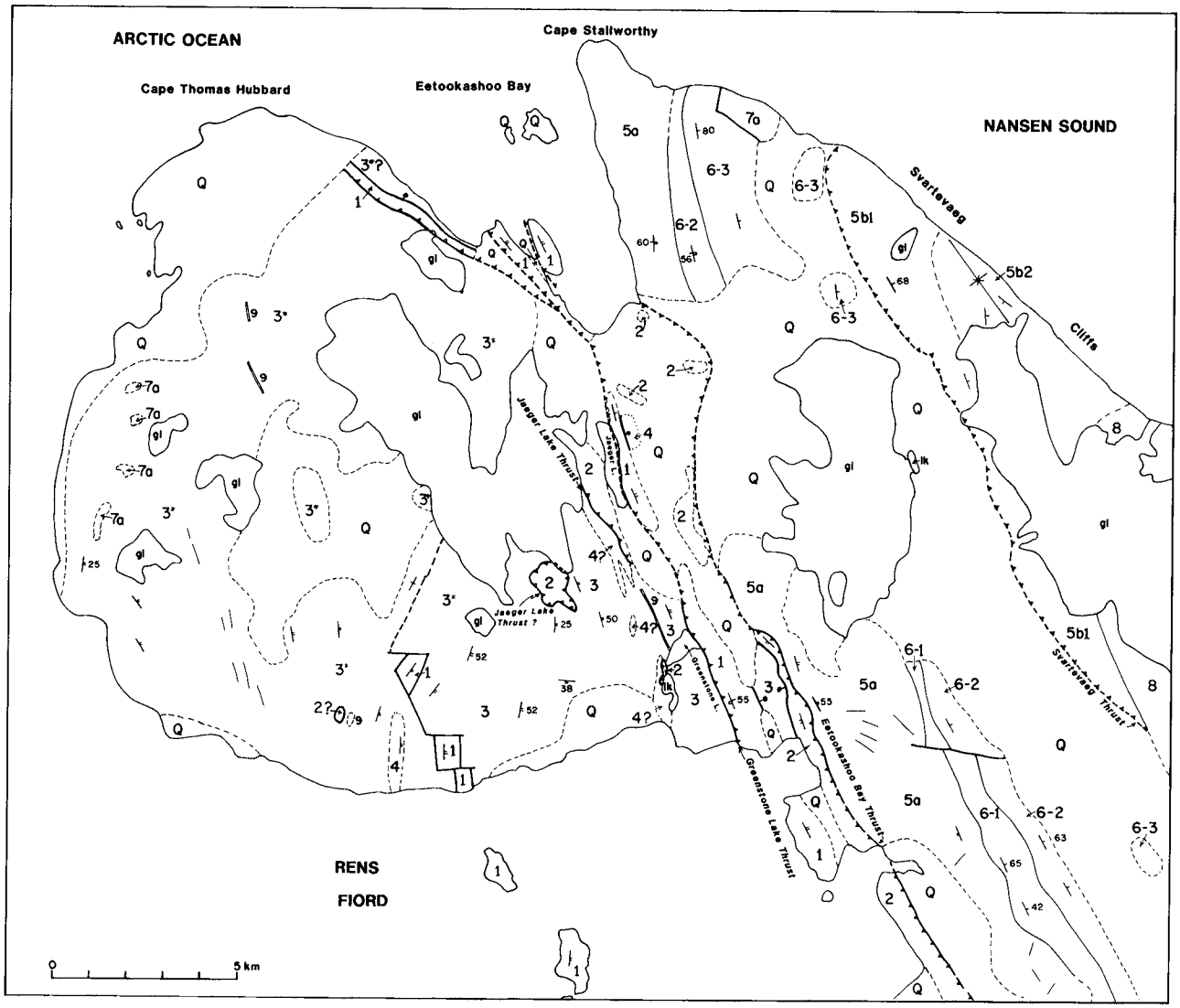


Figure 36.2. Geology of northern Axel Heiberg Island; 36.2A: area north of Rens Fiord; 36.2B: area south of Rens Fiord.

LEGEND, FIGURES 36.2A and 36.2B

Q — QUATERNARY
sand, gravel, mud

CRETACEOUS and/or OLDER

9 — diabase

CARBONIFEROUS and PERMIAN

8 — undifferentiated

8-3 — limestone, dolostone, minor sandstone

8-2 — volcanics

8-1 — sandstone etc.

DEVONIAN and (?) YOUNGER
felsic to intermediate intrusions

7a — quartz diorite, tonalite, granodiorite (Devonian)

7b — diorite (Devonian or Cretaceous)

7c — felsic porphyry (Devonian or Cretaceous)

LOWER DEVONIAN
Stallworthy Formation

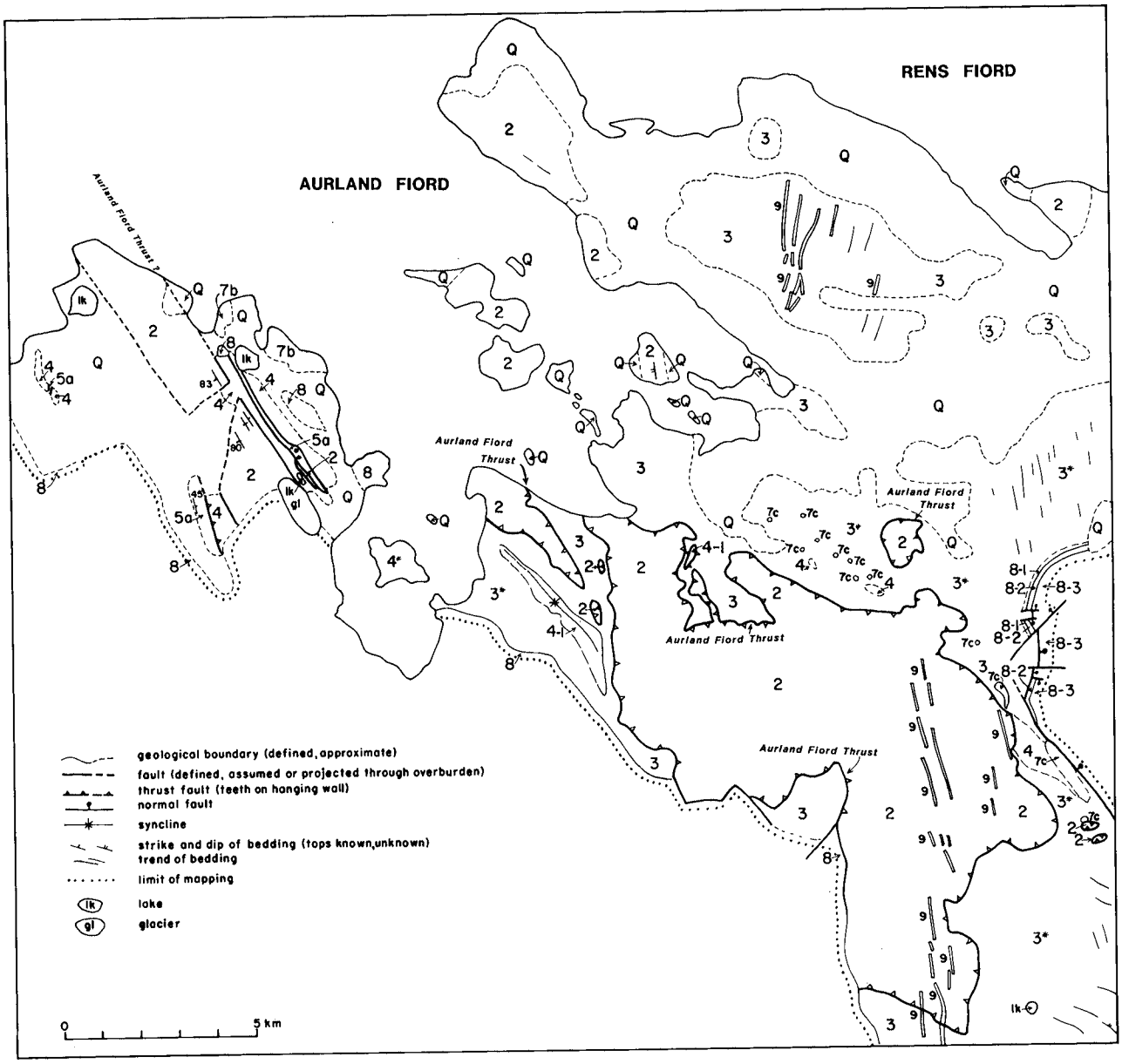
6-3 — Member C
multicoloured mudrock, minor sandstone, conglomerate

6-2 — Member B
sandstone, conglomerate, breccia, mudrock (mainly red)

6-1 — Member A
red mudrock, minor sandstone, conglomerate

SILURIAN
upper Llandovery (?), Wenlock, and (?) Ludlow

5a — **Lands Lokk Formation**
north of Rens Fiord:
slate, minor sandstone, volcanogenic sandstone, tuff, conglomerate
south of Aurland Fiord:
volcanogenic sandstone, slate, minor conglomerate



Svartevaeg Formation

5b-2 Member B
volcanogenic sandstone, minor slate, tuff, conglomerate, breccia, volcanic flows (including basalt)

5b-1 Member A
tuff, volcanic flows (including andesite), volcanogenic sandstone, minor slate

UPPER LOWER CAMBRIAN TO LOWER SILURIAN

4 **Hazen Formation (undifferentiated)**
chert, slate, phyllite, dolostone, limestone
4*: may include Grant Land and/or Lands Lokk formations

4-1 Carbonate Member
dolostone, minor slate

LOWER CAMBRIAN

3 **Grant Land Formation**
quartzite, slate, phyllite, very rare conglomerate
3*: may include minor outcrop areas of Hazen Formation and Aurland Fiord beds

LOWER CAMBRIAN (?)

2 **Aurland Fiord beds**
dolostone, minor limestone, rare phyllite

LOWER CAMBRIAN or HADRYNIAN

1 **Jaeger Lake assemblage**
metamorphosed basaltic flows and tuff, dolostone, limestone

Lands Lokk Formation in its type area on northwestern Ellesmere Island is reviewed in a later part of this report.

Lands Lokk Formation

The main outcrop belt of the Lands Lokk Formation extends from east of Rens Fiord to east of Eetookashoo Bay. This intensely deformed belt is overthrust on the southwest by the Aurland Fiord beds and unconformably overlain on the northeast by the Stallworthy Formation. The Lands Lokk Formation here consists mainly of medium to dark grey slaty mudrock, lesser proportions of lithic and tuffaceous sandstone and tuff, and of at least one carbonate conglomerate of pebble to cobble grade. The volcanic fraction in the tuffs and sandstones comprises rock fragments of intermediate to siliceous composition, feldspar, chlorite, and volcanic quartz; the sedimentary fraction of the sandstones consists mainly of nonvolcanic quartz, chert and carbonate fragments. The occurrence of graded bedding indicates that these rocks represent sediment gravity flows (including turbidites); the carbonate conglomerate appears to be a subaqueous debris flow.

Benthonic fossils in the carbonate clasts of the conglomerate are of Llandovery or Wenlock, perhaps late Llandovery age. Graptolites near the top of the unit are probably late Wenlock in age.

Outcrops of similar, but coarser grained rocks, in fault contact with the Hazen Formation, occur in three small areas southwest of Aurland Fiord. The strata consist mainly of sandstone with lesser proportions of slate and small proportions of pebble conglomerate. Both Bouma sequences, and thick massive beds deposited by concentrated sediment gravity flows, are present. The sandstones are composed of volcanic material of intermediate to siliceous composition and of sedimentary quartz and chert. The chert is reminiscent of that in the Hazen Formation because of the presence of lamination and "ghosts" of radiolarians.

Svartevaeg Formation

The name Svartevaeg Formation (originally Svartevaeg Group) was introduced by Fricker and Trettin (1962) for a thick succession of volcanogenic sediments and volcanic rocks that overlies the Stallworthy Formation in a structural sense; the contact between the two units is covered and its nature is subject to interpretation. The Svartevaeg is overlain by the Emma Fiord Formation of Visean (late Early Carboniferous) age with angular unconformity.

The Svartevaeg Formation consists primarily of sediment gravity flows that are composed mainly of volcanogenic (tuffaceous ?) sandstone with lesser amounts of siltstone and breccia or conglomerate; a minor proportion of the formation consists of tuff and volcanic flows. The proportion of volcanic rocks and mudrock versus sandstone is greater in the lower part (member A) than in the upper part (member B). The sandstones consist mostly of volcanic rock fragments of siliceous to mafic, predominantly intermediate (andesitic) composition, with lesser proportions of feldspar, carbonate and chlorite. A chemically analyzed tuff from member A is classified as calc-alkaline andesite and a flow from the upper part of member B as calc-alkaline basalt, both on the basis of major elements (cf. Trettin et al., 1972, p. 104, analyses 6 and 7). The plagioclase in the sedimentary rocks studied and in the andesitic tuff mentioned (but not in the basalt) has been altered to albite to a large extent.

The formation contains several limestone breccias with benthonic fossils. The most diagnostic faunule, from a slide block of limestone about 60 m above the base of the exposures, is late Llandovery or Wenlock in age. Basaltic breccia near the top of the formation contains Silurian pentamerids.

The age assignment for this unit depends on the interpretation of its stratigraphic-structural relationship with the Stallworthy Formation. In the 1960's, when the lower Paleozoic geology of the northern regions was poorly known, this boundary was cautiously interpreted as a normal stratigraphic contact. The following considerations, however, strongly suggest that it is a thrust fault:

1. Thrust faults are common in northern Axel Heiberg Island (see below).
2. The Svartevaeg Formation is comparable in lithology and origin to the volcanogenic components of the Lands Lokk Formation both in northern Axel Heiberg Island and northwestern Ellesmere Island. Differences in the proportion and clast size of the volcanic material can be explained by a facies change, telescoped by thrust faulting. On the other hand, no evidence has come to light indicating that deep-water and arc-type conditions existed in the region in late Early or Middle Devonian time.
3. On Ellesmere Island, as far as is known, the shelf-derived fossils in Ordovician to Devonian deep water sediments all are of about the same age as the enclosing strata. Inclusion of Silurian fossils in sediment gravity flows and volcanic rocks of Early or Middle Devonian age would be anomalous and difficult to explain.

If the present interpretation is true, then the formation must be, at least in part, late Llandovery in age. Considering the great thickness of these deposits, their overall age range could extend from late Llandovery to early Ludlow, the same age as volcanic member B of the Lands Lokk Formation in adjacent northwestern Ellesmere Island.

Stallworthy Formation

The Stallworthy Formation, divisible into three members, comprises 3 to 4 km of sandstone, multicoloured mudrock, and conglomerate that overlie the Lands Lokk Formation with angular unconformity. Its upper boundary, as mentioned, is now interpreted as a fault. The unit was not re-examined in 1986 and the reader is referred to Trettin (1969) for detailed information. Ostracoderms, found about 1 km below the top of the formation, now are regarded as mid-Early Devonian (late Lochkovian or early Pragian) in age (R. Thorsteinsson and H.P. Schultze, pers. comm., 1985). The formation is

interpreted as a syntectonic and post-tectonic deposit derived from uplands to the southwest, in which the Hazen and Grant Land formations were exposed, providing detrital chert and quartz, respectively. Its lower part (members A and B) was deposited in alluvial fan and braided river environments; its upper part (member C) mainly in brackish delta environments.

Granitic intrusions

Granitic intrusions north of Rens Fiord are in the compositional field of granodiorite - tonalite - quartz diorite. They include a fault-bounded pluton southeast of Cape Stallworthy, and four aligned plugs southwest of Cape Thomas Hubbard, one of which has yielded a K-Ar age of 367 ± 25 Ma (recalculated from Lowdon et al. (1963), according to present standards). These rocks are probably no younger than early Late Devonian and may be correlative with a granitic pluton in northwestern Ellesmere Island, which has yielded a U-Pb (sphene) age of 390 ± 10 Ma (Trettin et al., in press).

Granitic intrusions in the region south and southwest of Rens Fiord comprise: 1. felsic porphyry dykes and plugs, and 2. a diorite pluton. It is uncertain whether they also are Devonian in age or whether they belong to the Late Cretaceous bimodal suite reported recently from northern Ellesmere Island (Trettin and Parrish, in press). These intrusions were reinvestigated in 1986 and sampled for isotopic age determination.

Felsic porphyry

A linear, northwesterly trending belt of porphyritic felsite dykes and plugs, more than 11 km long and up to about 0.7 km wide, occurs within the Grant Land Formation south of central Rens Fiord. The intrusions range in length from a few metres to about 2 km. The rocks are uniform in composition and appearance. Phenocrysts, mainly of plagioclase (zoned from sodic andesine to sodic labradorite or altered to albite) with small proportions of K-feldspar and biotite, variably replaced by chlorite, are set in a pale brown to pale red groundmass of feldspar with minor biotite, chlorite and quartz.

Diorite southwest of Aurland Fiord

This intrusion, exposed in two areas, probably has an overall extent of 3 by 2 km and appears to intrude the Hazen Formation although its contacts are covered. It consists of feldspar (mainly zoned andesine, a little K-feldspar), pyroxene, hornblende, and biotite (partly replaced by chlorite), and minor quartz.

STRUCTURAL GEOLOGY

Structural trends are northwest, almost at right angles to those in northwestern Ellesmere Island, but parallel or subparallel to trends in central and southern Axel Heiberg Island. The area lies at the northwestern end of the southeast-plunging Princess Margaret Arch of Tertiary age and represents a structural high, named Rens Fiord Uplift, that is marked by extensive outcrops of Lower Cambrian strata. The margins of the high are characterized by complex thrust faults, some of which were investigated in 1986.

Thrust faults at the northeastern margin of Rens Fiord Uplift

The Aurland Fiord beds have been displaced northeastward onto the Lands Lokk formation along the Eetookashoo Bay Thrust. The dip of this fault is apparent only in the area immediately north of Rens Fiord. A short distance to the southwest, the Jaeger Lake assemblage has been thrust southwestward over the Grant Land Formation along the Greenstone Lake Thrust, which splays into three thrusts southeast of Cape Thomas Hubbard. The area of poor exposure between the Aurland Fiord beds and the Jaeger Lake assemblage, underlain by the Grant Land and Hazen formations, is interpreted as a graben.

Farther west, the Jaeger Lake Thrust places the Aurland Fiord beds onto dark grey chert that is tentatively assigned to the Hazen Formation but could represent older strata. A subhorizontal thrust sheet of the Aurland Fiord beds lying on the Grant Land Formation about 2 km to the west is interpreted as a klippe related to the Jaeger Lake Thrust.

Southwestern Margin of Rens Fiord Uplift

South of central Rens Fiord and southeast of Aurland Fiord, subhorizontal sheets of the Aurland Fiord beds lie on tightly folded, generally steeply dipping strata of the Grant Land Formation and, locally, the Hazen Formation. This relationship was recognized earlier but it was uncertain whether it indicated an angular unconformity or a flat thrust fault. The absence of clastic sediments and presence of tectonic breccia at the base of the dolomitic Aurland Fiord beds support the

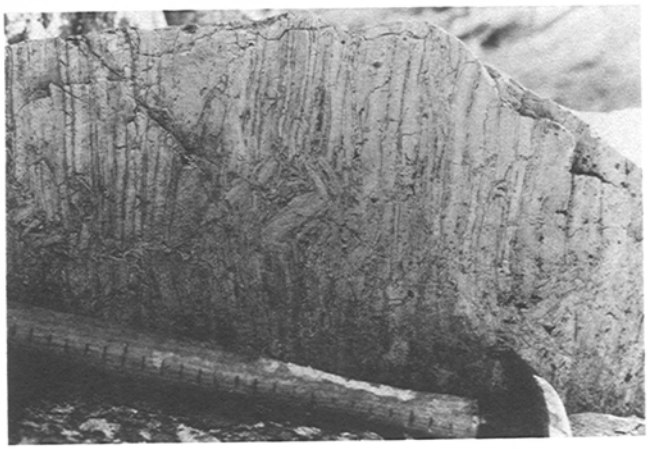


Figure 36.3. Aurland Fiord beds, southwest of Aurland Fiord: laminated dolostone showing intraformational deformation.

second alternative. The various subhorizontal outcrops of the Aurland Fiord beds evidently are erosional remnants (klippen) of a single thrust sheet no less than 20 km long and 10 km wide. About 1.75 km southeast of Aurland Fiord, the Aurland Fiord thrust sheet lies on a parallel thrust sheet of the Grant Land Formation, which, in turn, overlies the carbonate member of the Hazen Formation (Fig. 36.4). Minor folds in the Hazen Formation suggest relative motion of the Grant Land strata toward the northeast.

West of Aurland Fiord, two steeply dipping blocks of the Aurland Fiord beds are in fault contact with the Hazen Formation. The northeastern fault bounding these blocks may represent the root of the Aurland Fiord Thrust but appears to have been affected by a later (Tertiary ?) event of block faulting. If it is the root, then the thrust had no less than 12 km of northeastward horizontal displacement.

Age of structures

The regional stratigraphic-structural record indicates that northern Axel Heiberg Island was affected by three major periods of deformation:

1. The oldest event is indicated by the angular unconformity between the Lands Lokk and Stallworthy formations. Its age range is bracketed by fossils of late Wenlock age below the unconformity and of late Lochkovian – early Pragian age some distance above it, but it must have been more restricted. It now is thought to have occurred in latest Silurian (Pridoli) – earliest Devonian time, probably simultaneously with compressive deformation of the Boothia Uplift (Thorsteinsson, 1980; Okulitch et al., 1986) and northern Ellesmere Island (Trettin, in press).
2. The second deformational period is indicated by the angular unconformity between the Stallworthy and Emma Fiord formations of Early Devonian and Visean age, respectively. This interval includes the main phase of the Ellesmerian Orogeny of latest Devonian and/or earliest Carboniferous age.
3. The third event is the Eurekan Orogeny of latest Cretaceous to early Tertiary age.

The tight and complex folds in the Silurian and older rocks differ markedly in style from the open folds in the Carboniferous and younger strata, and therefore are almost certainly related to the two earlier phases of deformation. The same probably applies to major faults such as the Svartevaeg, Eetookashoo Bay and Jaeger Lake thrusts, the southeastward projections of which (under Quaternary cover) do not seem to have affected the Carboniferous and younger rocks (cf. Thorsteinsson and Trettin, 1972). The Aurland Fiord thrust sheet and the structurally underlying Grant Land Formation are both cut by mafic dykes (Fig. 36.2B) that are Late Cretaceous or older in age (younger swarms are not known in the region); the Aurland Fiord Thrust, therefore, is also older than the Eurekan Orogeny.

Figure 36.4. Stacked thrust sheets of carbonate member of Hazen Formation (4-1), Grant Land Formation (3), and Aurland Fiord beds (2) about 1.75 km southeast of central Aurland Fiord. Minor folds in Hazen Formation (lower left) suggest northeastward motion of overlying sheet.

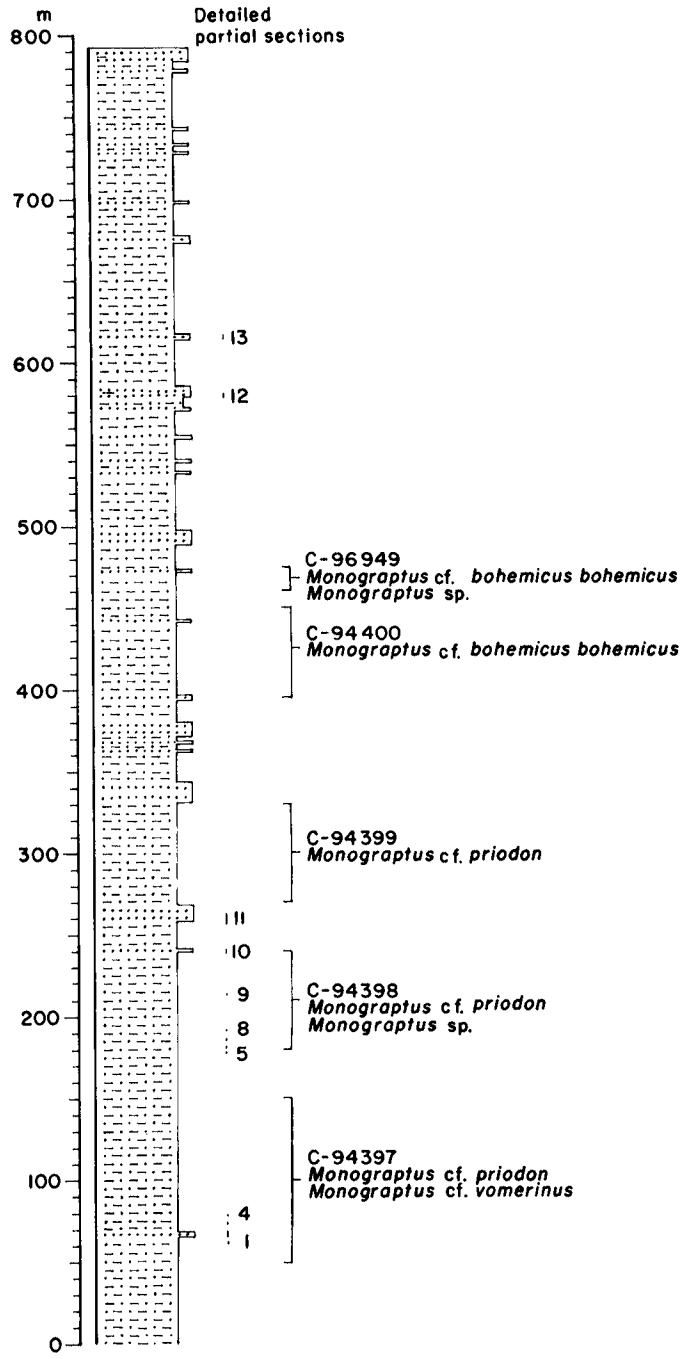


Figure 36.5. Generalized stratigraphy of member C of the Lands Lokk Formation south of Emma Fiord (locality 5 of Figure 36.1).

The postulated Svartevaeg Thrust is the only structure that can be attributed with some assurance to the Middle Devonian – Early Carboniferous deformation; elsewhere, distinction between the first and second phases is impossible at present. However, differences in structural style between the Stallworthy Formation on the one hand and the Lands Lokk Formation and older units on the other hand, suggest that the Late Silurian – Early Devonian deformation was a major compressional event, characterized by tight and complex folding and thrust faulting in spite of the fact that the angular discordance is relatively small where best exposed (Trettin, 1962, Fig. 3.).

MEMBER C OF THE LANDS LOKK FORMATION IN NORTHWESTERN ELLESMERE ISLAND

In northwestern Ellesmere Island, the Lands Lokk Formation conformably overlies a tongue of the lower Imina Formation, and is overlain by the Upper Carboniferous Borup Fiord Formation with angular unconformity. Three members have been distinguished in this region (Trettin, 1969). Member A, probably more than 1.5 km thick locally, consists mainly of mudrock with small proportions of quartzose and tuffaceous sandstone and small amounts of tuff. Graptolites indicate a late Llandovery to early Ludlow age range. Member B, restricted to the immediate vicinity of Emma Fiord, consists of mudrock, tuff and volcanic flows of siliceous to intermediate, calc-alkaline composition (Trettin et al., 1972, p. 104, analysis #5) and small amounts of limestone. At Fire Bay, Emma Fiord, member B seems to overlie strata of member A containing graptolites of early Ludlow age. Member C is exposed south and southeast of Emma Fiord, where it overlies member A. The latter exposures, examined only very briefly in 1962, were re-investigated in 1986.

Member C has a minimum thickness of 1 km southeast of Emma Fiord (east of locality 6, Figure 36.1) and the lower 800 m are well exposed on the northern limb of a syncline south of Emma Fiord (locality 5, Fig. 36.1). There it can be divided into two assemblages: 1. thinly interstratified mudrock and sandstone, commonly forming Bouma sequences a few centimetres to a few decimetres in thickness; and 2. units composed of sandstone, with or without small proportions of mudrock and very small proportions of pebble conglomerate (Fig. 36.5). The sandstone units are 0.8 to 13.5 m thick (mean: 3.6 m) and constitute about 11 per cent of the succession. The sandstones occur in Bouma sequences (Fig. 36.6) and as thick, structureless beds that show an upward decrease in grain size only in the uppermost part. Individual sandstone beds commonly have convex parting surfaces at the base that indicate shallow minor channels, probably within broader channels of the mid-fan environment.

Graptolites of undifferentiated latest Llandovery-Wenlock age (*Monograptus* ex gr. *priodon* (Bronn) and *Monograptus* sp. cf. *M. vomerinus* (Nicholson)) occur about 50 to 330 m above the base of the formation, and graptolites of Ludlow age (*Monograptus* sp. cf. *M. bohemicus bohemicus* Barrande) 395 to 473 m above the base of the formation at locality 5 (Fig. 36.1). The contact between members A and C is probably a highly diachronous facies boundary, member C representing submarine fan environments and member A basin plain environments.

The provenance and paleocurrent directions of these strata are important for interpretation of the regional tectonic history. The sandstone consists mainly of chert and quartz with smaller amounts of carbonate, feldspar, chlorite and white mica. The chert was evidently derived from deep water sediments (Hazen Formation or equivalents in Greenland) because it contains "ghosts" of radiolarians.

It had earlier been inferred (Trettin, 1969) that the sediments were derived from northern Axel Heiberg Island because they are comparable in composition to those of the Stallworthy Formation, and this conclusion seemed to be supported by northeastward paleocurrent determinations from the Kulutingwak Fiord - Yelverton Inlet area (Trettin, 1976). However, a total of 129 paleocurrent determinations at two localities south and southeast of Emma Fiord indicate northwestward transport in this area (Fig. 36.7). The determinations are based on the angle between paleocurrent indicators (mainly flute casts, minor tool marks) and local strike measured on the underside of beds. Structural plunge, established on local folds, has been taken into consideration in the conversion of these angles to azimuths. Sediment derivation from Axel Heiberg Island also is contradicted by the fact that the Wenlock strata of member C on Ellesmere Island are older than the uplift of northern Axel Heiberg Island, which probably did not occur before Ludlow time (see above). The significance of the paleocurrent directions is difficult to evaluate. Compositionally, the sediments of the Lands Lokk Formation are more closely related to the chert-rich Lauge Koch and Nordkronen formations of northeastern Greenland (Hurst and Surlyk, 1982) than to the correlative, carbonate-rich Imina Formation of central Ellesmere Island (Trettin, 1979), and it is possible that the Lands Lokk Formation has been affected by the sinistral strike slip inferred for the Pearya Terrrane of northernmost Ellesmere Island, (Trettin, in press). The anomalous directions may have been inherited from that region (Hurst and Surlyk, 1982, Fig. 124) and may also have been affected by counterclockwise rotation during the postulated transcurrent motion.

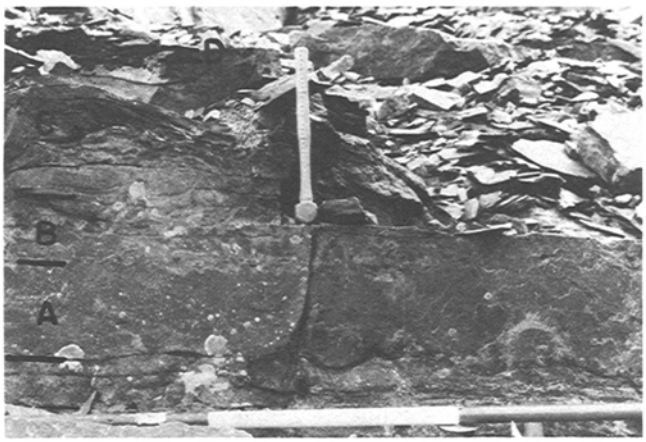


Figure 36.6. Bouma sequence (divisions A-D) in member C of Lands Lokk Formation with undulating lower surface (detailed interval 12 of Figure 36.4; scale in cm on hammer handle).

CARBONIFEROUS VOLCANICS, NORTHERN AXEL HEIBERG ISLAND

Carboniferous volcanics are exposed south of central Rens Fiord in a narrow belt about 5 km long (Fig. 36.2B). The outcrop belt is terminated by a fault in the south and by overburden in the northeast. The volcanic rocks are flows of

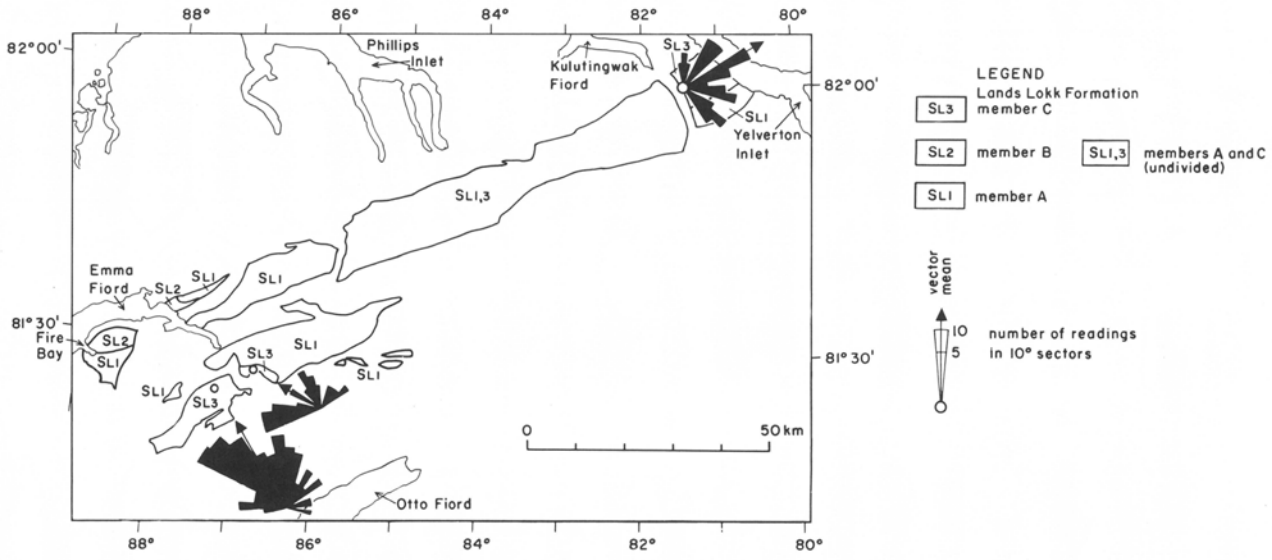


Figure 36.7. Paleocurrent directions in member C of Lands Lokk Formation.

basaltic aspect, and occur 26.8 to 48.5 m above the angular unconformity that separates red sandstone of the Borup Fiord Formation from quartzite of the Grant Land Formation, but only the lowermost 5 m of the Borup Fiord Formation are exposed. The volcanics are separated from overlying sandstone, dolostone and limestone, presumably of the Nansen Formation, by a covered interval 15.5 m thick. They either represent the Audhild Formation, so far known only from northwestern Ellesmere Island (Thorsteinsson, 1974), or are part of the Borup Fiord Formation.

REFERENCES

Fricker, P.E. and Trettin, H.P.
1962: Pre-Mississippian succession of northernmost Axel Heiberg Island, District of Franklin; Geological Survey of Canada, Paper 62-18.

Friderichsen, J.D., Higgins, A.K., Hurst, J.M., Pedersen, S.A.S., Soper, N.J. and Surlyk, F.
1982: Lithostratigraphic framework of the Upper Proterozoic and Lower Paleozoic deep water clastic deposits of North Greenland; The Geological Survey of Greenland, Report No. 107.

Holm, P.E.
1982: Non-recognition of continental tholeiites using the Ti-Y-Zr diagram; Contributions to Mineralogy and Petrology; v. 79, p. 308-310.

Hurst, J.M. and Surlyk, F.
1982: Stratigraphy of the Silurian turbidite sequence of North Greenland; Grønlands Geologiske Undersøgelse, Bulletin No. 145.

Long, D.G.F.
1985: Early evolution of a lower Paleozoic passive margin: the lower Lower Cambrian history of the Franklinian sequence, northeast Ellesmere Island, Arctic Canada; Geological Association of Canada, Mineralogical Association of Canada, Annual Meeting, Program with Abstracts, v. 10, p. A35.

Lowdon, J.A., Stockwell, C.H., Tipper, H.W., and Wanless, R.K.
1963: Age determinations and geological studies; Geological Survey of Canada, Paper 62-17.

Okulitch, A.V., Packard, J.J., and Zolnai, A.I.
1986: Evolution of the Boothia Uplift, arctic Canada; Canadian Journal of Earth Sciences, v. 23, p. 350-358.

Palmer, H.C. and Hayatsu, A.
1975: Paleomagnetism and K-Ar dating of some Franklin lavas and diabases, Victoria Island; Canadian Journal of Earth Sciences, vol. 12, p. 1439-1447.

Pearce, J.A. and Cann, J.R.
1973: Petrogenetic implications of Ti, Zr, Y and Nb variations in volcanic rocks; Contributions to Mineralogy and Petrology, v. 69, p. 33-47.

Thorsteinsson, R.
1974: Carboniferous and Permian stratigraphy of Axel Heiberg Island and western Ellesmere Island, Canadian Arctic Archipelago; Geological Survey of Canada, Bulletin 224.
1980: Part I. Contributions to stratigraphy (with contributions by T.T. Uyeno); in Stratigraphy and conodonts of Upper Silurian and Lower Devonian rocks in the environs of the Boothia Uplift, Canadian Arctic Archipelago; Geological Survey of Canada, Bulletin 282, p. 1-38.

Thorsteinsson, R. and Trettin, H.P.
1972: Geology, Cape Stallworthy, District of Franklin (scale 1:250 000); Geological Survey of Canada, Map 1305 A.

Trettin, H.P.
1969: Pre-Mississippian geology of northern Axel Heiberg and northwestern Ellesmere islands, Arctic Archipelago; Geological Survey of Canada, Bulletin 171.
1971: Geology of lower Paleozoic formations, Hazen Plateau and southern Grant Land Mountains, Ellesmere Island, Arctic Archipelago; Geological Survey of Canada, Bulletin 203.

Trettin, H.P.
1976: Reconnaissance of lower Paleozoic geology, Agassiz Ice Cap to Yelverton Bay, northern Ellesmere Island; in Current Research, Part A, Geological Survey of Canada, Paper 76-1A, p. 431-444.
1979: Middle Ordovician to Lower Devonian deep-water succession at southeastern margin of Hazen Trough, Canon Fiord, Ellesmere Island; Geological Survey of Canada, Bulletin 272.
in press: Pearya: a composite terrane with Caledonian affinities in northern Ellesmere Island; Canadian Journal of Earth Sciences.

Trettin, H.P., Frisch, T.O., Sobczak, L.W., Weber, J.R., Niblett, E.R., Law, L.K., DeLaurier, J.M., and Witham, K.
1972: The Innuitian Province; in Variations in tectonic styles in Canada, R.A. Price and R.J.W. Douglas (eds.), Geological Association of Canada, Special Paper 11, p. 83-179.

Trettin, H.P. and Parrish, R.
in press: Late Cretaceous bimodal magmatism, northern Ellesmere Island: isotopic age and origin; Canadian Journal of Earth Sciences.

Trettin, H.P., Parrish, R. and Loveridge, W.D.
in press: U-Pb age determinations on Proterozoic to Devonian rocks from northern Ellesmere Island, Arctic Canada; Canadian Journal of Earth Sciences.

Winchester, J.A. and Floyd, P.A.
1977: Geochemical discrimination of different magma series and their products using immobile elements; Chemical Geology, vol. 20, p. 325-343.