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BULLETIN 224

CARBONIFEROUS AND PERMIAN STRATIGRAPHY OF AXEL HEIBERG ISLAND AND WESTERN ELLESMERE ISLAND, CANADIAN ARCTIC ARCHIPELAGO

R. Thorsteinsson

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By

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PREFACE

One of the principal aims of the Geological Survey is the estimation of the potential abundance and probable distribution of mineral and fuel resources available to Canada. Such estimates depend on the availability of information concerning the geological framework. This report describes the stratigraphy and structural relationships of Carboniferous and Permian Rocks on Axel Heiberg Island and western Ellesmere Island. The region is part of the Sverdrup Basin, a major geological province within the Canadian Arctic Archipelago that is currently being explored for oil and gas. The stratigraphic framework presented in this report provides a model for Carboniferous and Permian rocks throughout the greater part of the basin where they are largely covered by younger formations.

Y. O. FORTIER,

Director, Geological Survey of Canada

OTTAWA, December 17, 1971

CONTENTS

Illustrations

PAGE

CARBONIFEROUS AND PERMIAN STRATIGRAPHY OF AXEL HEIBERG ISLAND AND WESTERN ELLESMERE ISLAND, CANADIAN ARCTIC ARCHIPELAGO

Abstract

This bulletin records primarily the results of a study of the stratigraphy of Carboniferous and Permian rocks in Axel Heiberg Island and in western regions of Ellesmere Island. These rocks constitute basal deposits of the Sverdrup Basin, a major geological province within the Canadian Arctic Archipelago that contains an essentially concordant succession of formations ranging in age from Early Carboniferous to about mid-Cenozoic. The Carboniferous and Permian rocks, composed predominantly of carbonate, quartzose clastics and anhydrite, are mainly of marine origin; however, nonmarine quartzose clastic, and volcanic rocks are present locally. Much of the quartzose clastic sediment appears to have had a south-easterly provenance.

Résumé

L'auteur a consigné dans ce bulletin les résultats d'une étude stratigraphique des roches du Permien et du Carbonifère de l'île Axel Heiberg et du secteur ouest de l'île Ellesmere. Il s'agit de dépôts de fond du bassin de Sverdrup, province géologique importante de l'archipel arctique canadien formée d'une suite essentiellement concordante de formations dont l'âge varie entre le Carbonifère inférieur et le milieu de l'ère cénozoïque. Les strates du Permien et du Carbonifère, composées principalement de carbonates, de dépôts clastiques quartzeur et d'anhydrites, sont surtout d'origine marine; il y a cependant, des dépôts clastiques quartzeux non-marins et des roches volcaniques en certains endroits. Une bonne partie des sédiments clastiques quartzeux semble être venue du sud-est.

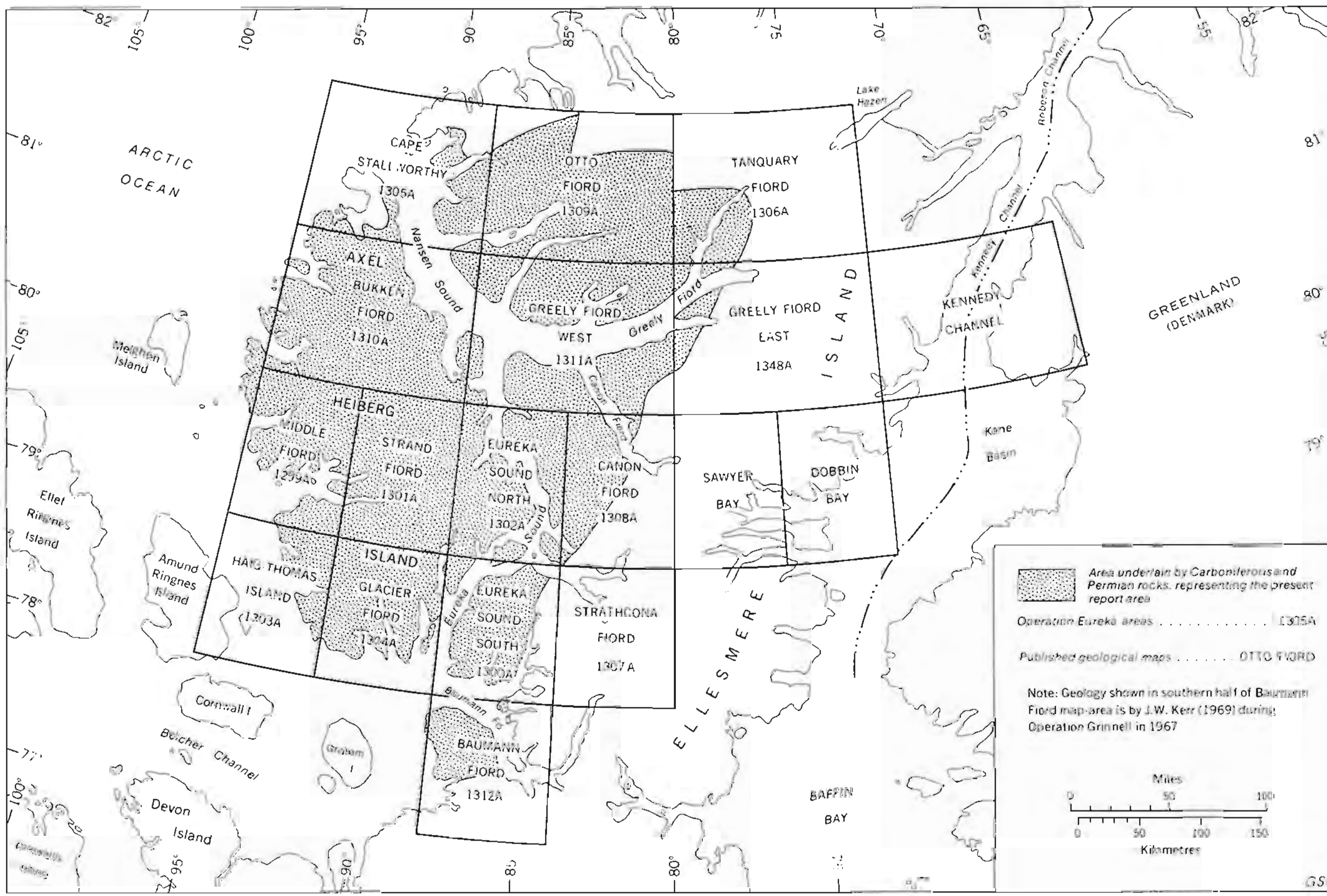

FIGURE 1. Index map showing area covered by geological maps listed on page 3.

INTRODUCTION

Location and Scope of Study

This bulletin records the results of a study of the stratigraphy of Carboniferous and Permian rocks of Axel Heiberg and Ellesmere Islands, the most northerly islands of the Canadian Arctic Archipelago. It is based primarily on thirty-five critically chosen sections that were studied in considerable detail and measured by means of a five-foot rule equipped with a clinometer. The measured sections are widely distributed over an area of about 30,000 square miles. The report area includes all exposures of Carboniferous and Permian rocks on Axel Heiberg Island and in western regions of Ellesmere Island (*see* Fig. 1). It does not include rocks of these systems that are exposed in northeastern regions of Ellesmere Island which were studied in 1964 by Nassichuk and Christie (1969), and by members of Operation Grant Land directed by R. L. Christie in 1965 and 1966. The thirty-five stratigraphic sections are illustrated graphically on Figures 7, 8, 9, and 10 (*in pocket*). Besides these sections, numerous other exposures of Carboniferous and Permian rocks were examined within the report area.

Carboniferous and Permian rocks have been known to occur in the Canadian Arctic Archipelago for more than a century, and have been studied and reported on by many geologists. Most studies have dealt with marginal facies of these systems that outcrop in a narrow belt along the southern (Melville Island, Bathurst Island group, and Grinnell Peninsula; *see* Fig. 6) and southeastern margins (western Ellesmere Island) of the Sverdrup Basin, with the result that the stratigraphy of these areas is moderately well known. Nevertheless, the Carboniferous and Permian have remained the least known of Phanerozoic systems in the archipelago. Two principal reasons for this circumstance are: (1) By far the greater volume of Carboniferous and Permian rocks in the Sverdrup Basin is represented by shelf and basinal facies north and northwest of the marginal deposits. Rocks of the shelf and basinal facies are exposed, for the most part, only in northern and eastern Axel Heiberg Island and northwestern Ellesmere Island, regions which until recently have constituted some of the more inaccessible parts of the archipelago. These rocks have, therefore, received little attention and are poorly understood. (2) The shelf and basinal facies, like the marginal facies, are notable for abrupt changes from one rock type to another within short distances, and for stratigraphic relationships that are further complicated by disconformities and transgressive units. Mainly because of these complexities, the limited studies made at isolated localities in these regions prior to the present investigations, failed to elucidate the regional relationships of Carboniferous and Permian rocks.

The principal aim of the present study is to establish the classification, age, and correlation of Carboniferous and Permian rocks across the various facies belts on Axel Heiberg and Ellesmere Islands.

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Ellesmere and Axel Heiberg Islands have areas of about 82,000 and 16,000 square miles respectively. The only permanent settlement within the report area is the Eureka weather station on the west coast of Ellesmere Island at latitude 79°59′N and longitude 85°57′W. This station was established in 1947 by airlift from Thule, Greenland, and for many years was operated jointly by the Canadian Department of Transport and the United States Weather Bureau. Now operated by Canada alone, it is resupplied each year by icebreaker and has an airstrip that is normally serviceable the year round.

Field Work

This report is one of several resulting from reconnaissance mapping and stratigraphic studies carried out over a period of five field seasons, during which time the Eureka weather station served as base camp. In 1956 E. T. Tozer and the writer investigated parts of eastern Axel Heiberg Island and western Ellesmere Island by means of dog teams and canoe (Thorsteinsson and Tozer, 1957). In 1957 the writer, using the same methods of travel, worked in the same general regions of these islands, including a trip to the west coast of Axel Heiberg Island and Meighen Island (Thorsteinsson, 1961). In 1961 and 1962 personnel engaged in a Geological Survey project known as Operation Eureka mapped and studied the geology of previously unstudied parts of Axel Heiberg Island and western Ellesmere Island (*see* Fig. 1). This project was directed by the writer, and included staff geologists, J. Wm. Kerr, E. T. Tozer, and H. P. Trettin. J. G. Fyles was a member of the project in 1961 when he studied the Pleistocene geology of the region. Field transportation in 1961 was provided by three Piper Super Cub aircraft that were supplied by Bradley Air Services Limited of Carp, Ontario. The aircraft were equipped with large, low-pressure tires for landing on unprepared terrain. Two aircraft were used in 1962: a G2A Bell helicopter contracted from Atlantic Helicopters Limited of Montreal, and a Piper Super Cub aircraft supplied by Bradley Air Services. Non-contract service on Operation Eureka in 1961 included a DC-4 flight from Churchill to Eureka at the start of the field season and a DC-6 flight from Eureka to Montreal at the close of the season. In 1962 the party moved from Yellowknife to Eureka, and returned by means of a Bristol Freighter aircraft. The writer, accompanied by P. Harker, devoted the field season of 1963 to further stratigraphic studies and mapping on Axel Heiberg Island and Ellesmere Island. Field transportation was by Super Cub aircraft once again contracted from Bradley Air Services.

Much of the early work by Tozer and the writer using dog teams and canoe consisted of three-to-eight-week journeys made from Eureka. Both methods of travel limited geological investigations to coastal areas, and much time was devoted to studying excellent exposures that commonly characterize the sides of fiords on these islands. Even under winter conditions, which persist until about June in these latitudes, the steeper fiord walls are commonly free of snow by early April, owing partly to strong winds but mainly to the insolating effect of the sun[1]. Temperatures in the Eureka district in April are generally about minus 40°F; during this time the field parties lived mainly in igloos. With the progressively moderating temperatures of May and June, double-walled tents provided more practical living quarters than snow houses. Ring seal, abundant in the fiords of these islands, provided food for the dogs. Although July is generally the best month of the year for field work on Axel Heiberg and Ellesmere Islands, sledging is impractical because of widening shore leads, and the

[1] At the latitude of Eureka, the sun remains above the horizon from April 15 to August 29. Insolation is especially effective in the dark coloured rocks. On May 29, 1956, the author observed running water and live flies on dark grey rocks of the Triassic Blaa Mountain Formation about 1,000 feet above sea-level in Hare Fiord. At the same time the temperature on the surface of the fiord was 5°F below zero.

development of long cracks in the sea ice, up to about 40 feet wide, that trend across the fiords. Moreover, the disappearance of the snow from the surface of the fiord ice, generally in late June, produced a condition that cut the feet of dogs. Consequently, July was spent in traversing on foot and conducting detailed geological studies in the environs of Eureka. It was in such circumstances that Tozer and the writer made a detailed geologic map of the Slidre Fiord area (Map 1298A). By early August the ice in the fiords is sufficiently broken to permit the use of a canoe, but in late August this method of travel comes to an end with the onset of winter and freezing conditions.

In most years at Eureka, the land is free of snow and conditions are optimum for geologic investigations from about mid-June until August 25. Extreme conditions prevailed during the two years of Operation Eureka. In 1961 the snow-free period lasted from about July 1 to August 25 and in 1962 from June 1 to August 26.

The main base of operation during 1961, 1962, and 1963, was established in tent quarters about a quarter of a mile west of Eureka. Throughout each field season this camp was occupied by a cook, a radio operator, and varying numbers of staff geologists and geological assistants. The hours flown by each contract aircraft during the three field seasons averaged about 225. The aircraft served three main functions: (1) They were used in setting out small parties of one or two geologists in subsidiary base camps where these men remained for periods generally from two days to a week before being flown back to Eureka or to another locality. (2) Aircraft were used also in day-long traverses out of the main base camp for mapping and stratigraphic studies. The average day traverse entailed about eight landings. (3) At various times flights were made to set out caches of aviation gasoline, both as a safety measure and to extend the range of aircraft into more distant parts of the area of study.

Geological Maps, Responsibilities, and Reports

The geology of the report area is illustrated by 15 maps at 1:250,000 scale and one map at 1:50,000 scale as follows: Slidre Fiord (1298A; scale 1:50,000); Middle Fiord (1299A); Eureka Sound South (1300A); Strand Fiord (1301A); Eureka Sound North (1302A); Haig-Thomas Island (1303A); Glacier Fiord (1304A); Cape Stallworthy (1305A); Tanquary Fiord (1306A); Strathcona Fiord (1307A); Cañon Fiord (1308A); Otto Fiord (1309A); Bukken Fiord (1310A); Greely Fiord West (1311A); Baumann Fiord (1312A); Greely Fiord East (1348A).

These maps may be purchased from the Publications Distribution Offices of the Geological Survey of Canada in Ottawa or Calgary, either as a packaged set at $10.00 per set, or as separates.

The greater part of the information presented on the geological maps listed above was obtained from work carried out on Operation Eureka when field responsibilities were divided as follows: Kerr was responsible principally for studying and mapping early Paleozoic miogeosynclinal rocks, Trettin for the early Paleozoic eugeosynclinal rocks, Tozer for the stratigraphy of Mesozoic and Cenozoic rocks in the Sverdrup Basin, and the author for the late Paleozoic rocks of the Sverdrup Basin. Tozer and the writer jointly mapped rocks of the Sverdrup Basin.

A list of selected reports that are particularly useful to a fuller understanding of the geological maps follows:

Christie, R. L.
1967: Bache Peninsula, Ellesmere Island, Arctic Archipelago; Geol. Surv. Can., Mem. 347.

Frebold, Hans
1964: The Jurassic faunas of the Canadian Arctic, Cadoceratinae; Geol. Surv. Can., Bull. 119.

Fricker, P. E. and Trettin, H. P.
1962: Pre-Mississippian succession of northernmost Axel Heiberg Island, District of Franklin; Axel Heiberg Island Res. Repts., McGill Univ., Montreal, Geology, No. 3.

Kerr, J. Wm.
1967: New nomenclature for Ordovician rock units of the eastern and southern Queen Elizabeth Islands, Arctic Canada; Bull. Can. Petrol. Geol., v. 15, No. 1, p. 91–113.
1967: Vendom Fiord Formation—a new red-bed unit of probable early Middle Devonian (Eifelian) age, Ellesmere Island, Arctic Canada; Geol. Surv. Can., Paper 67-43.
1967: Stratigraphy of central and eastern Ellesmere Island, Arctic Canada: Part I, Proterozoic and Cambrian; Geol. Surv. Can., Paper 67–27.
1967: Devonian of Franklinian Miogeosyncline and adjacent Central Stable Region, Arctic Canada *in* D. H. Oswald, ed. International Symposium on the Devonian System, v. 1, p. 677–692; Alberta Soc. Petrol. Geol., Calgary, Alberta.
1968: Stratigraphy of central and eastern Ellesmere Island, Arctic Canada; Part II, Ordovician; Geol. Surv. Can., Paper 67–27.

Thorsteinsson, R. and Tozer, E. T.
1970: Arctic Lowlands, Franklinian System, Sverdrup Basin, and Arctic Coastal Plain; *in* R. J. W. Douglas, ed. Geology and Economic Minerals of Canada; Econ. Geol. Report No. 1, Geol. Surv. Can.

Tozer, E. T.
1961: Triassic stratigraphy and faunas, Queen Elizabeth Islands, Arctic Archipelago; Geol. Surv. Can., Mem. 316.
1963: Mesozoic and Tertiary stratigraphy, western Ellesmere Island and Axel Heiberg Island, District of Franklin; Geol. Surv. Can. (prelim. acct.), Paper 63-30.
1965: Latest Lower Triassic ammonoids from Ellesmere Island and northeastern British Columbia; Geol. Surv. Can., Bull. 123.
1967: A standard for Triassic time; Geol. Surv. Can., Bull. 156.

Trettin, H. P.
1963: Caledonian movements in the Canadian Arctic Archipelago; Bull. Can. Petrol. Geol., v. 11, p. 107–115.
1967: Devonian of the Franklinian Eugeosyncline *in* D. H. Oswald, ed. International Symposium on the Devonian System, v. 1, p. 693–670; Alberta Soc. Petrol. Geol., Calgary, Alberta.
1969a: Pre-Mississippian geology of northern Axel Heiberg and northwestern Ellesmere Islands, Arctic Archipelago; Geol. Surv. Can., Bull. 171.
1969b: Geology of Ordovician to Pennsylvanian rocks, M'Clintock Inlet, north coast of Ellesmere Island, Canadian Arctic Archipelago; Geol. Surv. Can., Bull. 183.
1970: Ordovician–Silurian flysch sedimentation in the axial trough of the Franklinian Geosyncline, northeastern Ellesmere Island, Arctic Canada *in* Flysch sedimentology in North America, *in* J. Lajoie, ed.; Geol. Assoc. Can., Spec. Paper 7, p. 13–35.
1971a: Stratigraphy and sedimentology of lower Paleozoic clastic units, Tanquary and Cañon Fiord regions, Ellesmere Island *in* Report of Activities, Part A: April to October, 1970; Geol. Surv. Can., Paper 71-1, p. 236–241.
1971b: Geology of lower Paleozoic formations, Hazen Plateau and southern Grant Land Mountains, Ellesmere Island, Arctic Archipelago; Geol. Surv. Can., Bull. 203.

Physiography

The diverse physiographic regions making up Axel Heiberg and Ellesmere Islands include high mountain belts, valley and ridge systems, and dissected plateaux, all impressive alike for magnitude and ruggedness, as well as lesser regions of lowlands. Moreover, all systems of Phanerozoic time including rocks of the Canadian Shield occur in these islands and the variety and number of rock formations are great. Each of these formations has impressed its own specific characteristics on the landscape. Indeed, for variety and interest of topographic forms, no part of the Canadian Arctic Archipelago offers more attractions than Axel Heiberg and Ellesmere Islands.

Large areas of Axel Heiberg and Ellesmere Islands are now ice capped, and certain ice caps are of sufficient size to constitute, in themselves, distinctive physiographic regions. All parts of both islands appear to have been glaciated, and many topographic features relate to the time of more extensive ice cover and to submergence during and following deglaciation. The most notable of such features are knife-edge crests, cirques, U-shaped valleys, and fiords that cut deeply into the islands forming numerous and characteristic peninsulas. A system of interconnecting fiords is undoubtedly responsible for the separate existence of Axel Heiberg and Ellesmere Islands. Ice tongues occupy many valleys, and in places these and the ice caps reach tidewater.

The most extensive mountain belts are: the United States Range, which overlooks the Arctic Ocean in northern Ellesmere; the Victoria and Albert Mountains between Greely Fiord and the east coast of Ellesmere Island; and the Princess Margaret Range, which occupies much of central Axel Heiberg Island. Each of these mountain belts carries an extensive ice cap. Barbeau Peak, a nunatak in the United States Range with an elevation of 8,760 feet some 19 miles northeast of the head of Tanquary Fiord (*Tanquary Fiord*[1]), represents the highest mountain in North America east of the Rocky Mountains (Hattersley-Smith, 1970). The highest point on Axel Heiberg Island, also a nunatak, is 6,720 feet; it is in the northeastern part of the *Middle Fiord* map-area.

To explain fully the present physiography of Axel Heiberg and Ellesmere Islands, it would be necessary to consider the long succession of stratigraphic and structural events that are responsible for the character and distribution of the various formations, as well as the processes of subaerial erosion, particularly glaciation, that have in the recent geological past shaped the landscape. Such a study is beyond the scope of this report. For a detailed and well-illustrated description of the topography of these islands, based mainly on the study of aerial photographs, the reader is referred to Dunbar and Greenaway (1956).

Geological Setting

Carboniferous and Permian rocks constitute a small, albeit important, part of the unusually extensive and inclusive geological record of Axel Heiberg and Ellesmere Islands. It seems desirable, therefore, to present a brief summary of the structural and stratigraphic history of these islands as a background against which the record of Carboniferous and Permian times may be seen in perspective.

Two structural provinces are included in the combined areas of these islands—the Central Stable Region and the Innuitian Orogen (*see* Fig. 11, *in pocket*)—each of which is divisible into two major geological regions as follows: Central Stable Region including the Canadian Shield and Arctic Platform; and Innuitian Orogen comprising the Franklinian Geosyncline and Sverdrup Basin.

Canadian Shield

The Precambrian rocks of the Canadian Shield constitute the basement in the Central Stable Region and are exposed on southeastern Ellesmere Island where they occupy an area a little less than one quarter of the island. The Shield is there composed mainly of gneissic and granitoid rocks, including small areas of Proterozoic-type sediments (Christie, 1962a, b, 1967).

[1] Italicized names in parentheses refer to the geological maps listed on page 3.

Arctic Platform

The Arctic Platform forms the outer part of the Central Stable Region, and consists of a narrow belt of relatively thin sediments that range in age from Early Cambrian to Early Devonian (Christie, 1967; Kerr, 1967d, 1968). To the north and northwest, rocks of the Arctic Platform are continuous with, and thicken into, rocks of the Franklinian Geosyncline (*see* Fig. 12, *in pocket*). The contact of platform and geosynclinal deposits is arbitrarily shown in Figure 11 at the outer limit of folded and faulted geosynclinal rocks. Rocks of the platform are broken by numerous normal faults, most of which cannot be more closely dated than post-early Paleozoic. However, a few faults displace the early Cenozoic, Eureka Sound Formation, that is preserved as outliers lying disconformably on early Paleozoic rocks, and it is possible that most faults in the Arctic Platform are related to widespread, mid-Cenozoic crustal movements in the archipelago that are discussed later.

Rocks of proved Late Cambrian age have not been found in the Arctic Platform, or for that matter in the entire archipelago. Nevertheless, it is difficult to believe that rocks of this age were not deposited in this region, and it seems likely that they will ultimately be found, probably in some of the as yet unexplored part of the Franklinian Geosyncline.

Franklinian Miogeosyncline

Rocks of the Franklinian Geosyncline adjacent to the Arctic Platform are miogeosynclinal in character, and record nearly continuous and thick sedimentation from late Precambrian to Late Devonian (*see* Figs. 12, 13, *in pocket*). The miogeosyncline, like the Arctic Platform, is confined to Ellesmere Island and is sigmoidal in plan. It trends southwestward in southwestern parts of the island, north-south in central parts, and then northeastward to Kennedy Channel on the east coast. Miogeosynclinal rocks consist mainly of carbonate and quartzose sandstone, with lesser amounts of siltstone, shale, and anhydrite (Kerr, 1967a, b, c, 1968). The maximum thickness of late Precambrian to Late Devonian formations is about 50,000 feet. The two youngest formations in the conformable succession of the miogeosyncline constitute a thick clastic wedge of late Middle to Late Devonian age and are clearly related to the climactic orogeny (Acadian) of the eugeosyncline. They are the Bird Fiord Formation of late Eifelian and Givetian ages that attains a thickness of about 3,000 feet, and the Okse Bay Formation of Frasnian and Famennian age that reaches a thickness of at least 10,000 feet (McLaren, 1963). The clastic wedge provides the lower age limit of the principal orogeny that deformed the miogeosyncline—the Ellesmerian Orogeny of latest Devonian or Early Carboniferous inception. The upper age limit is obtained from the Early Carboniferous age (Viséan) of the oldest rocks in the Sverdrup Basin, that unconformably overlie rocks of the Franklinian Geosyncline.

Rocks of the miogeosynclinal belt have been folded and faulted along trends aligned with the sinuous course of the belt itself. Northeasterly parts of the miogeosyncline in the environs of Kennedy Channel on the east coast of Ellesmere Island are characterized by long, nearly parallel, northeasterly trending folds that are generally asymmetrical towards the southeast. A few high-angle faults show thrust movement in the same direction. In central parts of the miogeosyncline, meridionally trending folds and faults are common (*see* for example *Cañon Fiord*). Faults are the dominant structural features here, and they include both normal and high-angle thrusts, the latter displaced relatively eastward. The outstanding structures in southwestern parts of the miogeosyncline are a series of widely spaced, apparently strike-slip faults arranged diagonally across the miogeosynclinal belt (*Baumann Fiord*). Many thrust and normal faults are demonstrably related to the mid-Cenozoic Eurekan Orogeny, in that they displace outliers of the early Cenozoic Eureka Sound Formation. While the relative effects of the two orogenies cannot be fully assessed on the basis of available evidence, it seems probable that simple folds were the principal structures of Ellesmerian Orogeny (as in the Franklinian miogeosynclinal belt on Bathurst and Melville Islands) and that faulting was effected mainly during the Eurekan Orogeny.

Franklinian Eugeosyncline

Northwestern Ellesmere Island and a relatively small area in northern Axel Heiberg Island are characterized by rocks of eugeosynclinal aspect. Much of this region is rugged and ice covered. It is difficult of access, and large areas have not been investigated in detail. Although the eugeosyncline is less well understood than the miogeosyncline, the broader outlines of its sedimentary and structural history are beginning to emerge, mainly through the work of H. P. Trettin (1967, 1968, 1969a, b, 1970, 1971a, b).

The boundary between the miogeosyncline and eugeosyncline is shown in Figure 11 as a northeasterly trending line that joins the heads of Greely Fiord and Archer Fiord in northern Ellesmere Island. It marks approximately the northwestern limit of significant volumes of miogeosynclinal carbonate rocks, and in particular it represents the approximate line of facies change along which Lower and Middle Ordovician carbonates grade northwesterly into predominantly clastic rocks of the eugeosyncline. There is, moreover, evidence that this boundary may coincide also with the northwesterly transition of Lower and Middle Cambrian carbonates to clastics. Nevertheless the boundary is admittedly arbitrary as the eugeosynclinal environment, of various times, advanced southeastward over miogeosynclinal sediments. A noteworthy example is represented by Upper Ordovician to Lower Devonian graptolitic shale and siltstone that grades southeasterly into carbonate rocks along a northeasterly trending facies zone some 80 miles southeast of the miogeosyncline-eugeosyncline boundary as shown in Figure 12.

Typical eugeosynclinal terrane is confined to northern Axel Heiberg Island and northwestern parts of Ellesmere Island that are characterized by acidic and basic plutons, low to high rank metamorphic rocks, and sedimentary rocks dominated by rapidly deposited sandstone and siltstone, and associated shale, greywacke, arkose, and chert. In some place, notably in the environs of M'Clintock Inlet (Trettin, 1969b), thick carbonate units occur, but they appear to be mainly of local extent. Ordovician and Silurian volcanic rocks are common in Ellesmere Island, and Silurian and Devonian volcanic rocks occur in Axel Heiberg Island. The volcanic flows are commonly keratophyric. The aggregate thickness of layered rocks is known to be several thousand feet, but thicknesses are generally difficult to estimate because of structural complexity and alteration.

Although it is probable that sedimentary rocks of the eugeosyncline range from late Precambrian to about Early Devonian, it should be noted that the presence of Ordovician, Silurian, and Lower Devonian rocks only is substantiated by paleontological evidence. Moreover, Lower Devonian sediments are known only in northern Axel Heiberg Island, although in northwestern Ellesmere Island, a unit of apparently unfossiliferous clastic rocks that lies conformably on Upper Silurian carbonate rocks (Marvin Formation; Trettin, 1969b), may be in part at least Early Devonian. That late Precambrian and Cambrian sediments, or their metamorphosed equivalents, are present seems likely in view of the occurrence of thick deposits of these ages in the miogeosyncline (Kerr, 1967c). Furthermore, a thick, widespread clastic unit that lies stratigraphically below rocks of Early Ordovician age in northwestern Ellesmere Island may well include rocks of Cambrian age (Grant Land Formation; Trettin, 1971b). Trettin has tentatively assigned this unit to the Early Ordovician and/or Cambrian.

In northwestern Ellesmere Island clastic units that were presumably derived from tectonic lands beyond the present-day coast of the Arctic Ocean indicate that eugeosynclinal terrane probably underlies a considerable area of the continental shelf and slope.

A remarkable succession of deep water, clastic sediments ranging from Early Ordovician to about Middle Silurian and probably into Early Devonian was deposited in a linear, northeasterly trending trough in southeastern regions of the eugeosyncline. The trough has been named the Hazen Trough (Trettin, 1971a; *see also* 1970, 1971b). Rocks of the Hazen Trough are characterized by a sedimentary and structural history that sets them apart from contemporaneous deposits in the adjoining miogeosyncline, as well as from remaining parts of the eugeosyncline. The Hazen Trough lies conformably on clastic rocks of the Grant Land Formation of Early Ordovician and/or Cambrian age. Incipient deposits in the trough are represented by the Hazen Formation, a unit of graptolitic shale, chert, redeposited carbonate, and minor amounts of breccia (*see* Fig. 12). It is about 1,300 feet thick, and ranges from Early to early Middle Ordovician. Conformably overlying the graptolitic rocks is a uniform succession of flysch deposits, about 3,000 feet thick and consisting of calcareous greywacke, calcareous siltstone, calcareous shale, and minor amounts of conglomerate and breccia. These deposits are assigned to the Imina Formation. The Imina is the youngest formation preserved in the Hazen Trough as shown in Figures 12 and 13, and in this region the formation ranges from late Middle Ordovician to late Early or Middle Silurian.

On the basis of extensive studies of directional features, Trettin (op. cit.) has demonstrated that the great bulk of flysch deposits entered the trough, probably as turbid flows from the northwest, and were deflected to the southwest along the axis of the trough. He has shown also that the flysch deposits were flanked to the southeast by correlative graptolitic shales and that they advanced both to northwest and southeast as the Hazen Trough widened progressively (*see* Fig. 13). The most southeasterly exposures occur in the environs of Cañon Fiord, deep within areas previously characterized by miogeosynclinal sediments, and some 40 miles southeast of the generalized boundary of the trough depicted in Figure 11. In Cañon Fiord the flysch deposits have been dated as Late Silurian to Early Devonian. Thus the Imina Formation in the Hazen Trough may be considered to range from late Middle Ordovician to about Early Devonian.

Although the Hazen Trough includes neither volcanic nor plutonic rocks, and is therefore genuinely neither eugeosynclinal nor miogeosynclinal, the predominantly clastic nature of its sediments and the absence of shelf-type carbonate rocks suggest relationship with the eugeosyncline rather than the miogeosyncline. Presumably the Hazen Trough is what it seems to be—a region of transitional deposits between typical miogeosynclinal and typical eugeosynclinal deposits.

Significant differences in degree of deformation characterize different regions of the Franklinian Eugeosyncline, which is thereby divisible into three parts. (1) The dominant structural pattern of rocks in the Hazen Trough is a uniform series of relatively short, tightly compressed folds with well-developed axial plane cleavage. The folds are commonly asymmetric to overturned, with northwesterly dipping axial planes. Faulting appears to have played a minor role in this part of the eugeosyncline. (2) A crystalline area made up largely of gneissic and schistose rocks and plutonic bodies occupies a narrow strip of territory along the northwest coast of Ellesmere Island between Phillips Inlet and Cape Columbia. Both basic and acidic plutons are represented, the latter including diorite, quartz diorite, quartz monzonite and related rocks. The known rank of metamorphic rocks ranges from the chlorite zone to the kyanite zone (Frisch, 1967). (3) The main part of the eugeosynclinal belt lies between the crystalline area and the Hazen Trough, and includes northern Axel Heiberg Island and the greater part of northwestern Ellesmere Island. This region is intensely deformed into dominantly northeasterly striking folds and faults, although marked deviations from the regional trend characterize northern Axel Heiberg Island where structures generally strike somewhat west of north, and an area west of M'Clintock Inlet in northwestern Ellesmere Island in which northerly trending folds and faults are conspicuously developed. As in the Hazen Trough, many of the folds are represented as similar folds with well-developed axial plane cleavage. Both high- and low-angle faults are common. Scattered along northwestern parts of this region are acidic and basic plutons.

In general, metamorphic rank decreases markedly southeastward from the crystalline belt into the sedimentary and volcanic terrane of the eugeosyncline where rank above the greenschist facies is rare.

The exact age of the metamorphic rocks in the crystalline area and their relationship to rocks of known Lower Ordovician to Lower Devonian age in other parts of the eugeosyncline are uncertain. In the environs of M'Clintock Inlet, an angular unconformity separates slightly altered Middle Ordovician rocks from older quartz–muscovite–chlorite schist rocks that may be correlative with the metamorphic rocks in the crystalline area (Trettin, 1969). Therefore, the age of the rocks in the crystalline area is presumably Middle Ordovician and/or older.

The eugeosyncline has been studied in detail at widely separated localities; large intervening areas have not been studied except for interpretations from aerial photographs. On the tectonic map (Fig. 11) most folds and faults in the eugeosynclinal belt are indicated by trend lines.

The eugeosyncline was a region of considerably greater crustal mobility than the miogeosyncline. Various considerations including the sedimentary record, angular unconformities at various levels, and radiometric dates indicate the occurrences of four and possibly five pulses of orogeny in the eugeosyncline (Trettin, 1969b): (1) Cambrian or earlier orogeny indicated by the widely distributed Grant Land Formation, consisting mainly of fine- to coarse-grained sandstone, and dated as Early Ordovician and/or Cambrian. According to Trettin (1971b), the Grant Land Formation was derived from the north, presumably from the metamorphic terranes around Cape Columbia. (2) Middle Ordovician or earlier orogeny based on an angular unconformity separating Middle Ordovician rocks from metamorphic rocks in the M'Clintock Inlet region in northwestern Ellesmere Island. It is possible that this unconformity and the Grant Land Formation point to one and the same orogeny. (3) Caledonian Orogeny based mainly on an angular unconformity between Middle Silurian and Lower Devonian rocks in northern Axel Heiberg Island, and partly on radiometric determinations that cluster about 390 million years for several plutons in northern regions of Ellesmere Island. The extent and magnitude of the Middle Ordovician or earlier orogeny and the Caledonian Orogeny are not clearly defined as these events have been masked by later events. (4) Acadian Orogeny represented principally by an angular unconformity between rocks as young as Early Devonian in eugeosynclinal rocks of northern Axel Heiberg Island, and the Early Carboniferous (Viséan) age of basal deposits in the overlying Sverdrup Basin. The limiting dates of this unconformity are admittedly too far apart to be able to specify the Acadian Orogeny as the climactic orogeny of the eugeosyncline in northwestern Ellesmere Island where the youngest dated rocks beneath the unconformity are Late Silurian, particularly because of Caledonian movements in northern Axel Heiberg Island. However, the following other lines of evidence all but confirm it: (a) The thick and widespread, clastic wedge of late Middle to Late Devonian age in the miogeosyncline indicates that an uplift, probably of unprecedented magnitude and intensity, occurred in the eugeosyncline at about late Middle Devonian time. (b) Sediments of Middle and Late Devonian ages are apparently absent throughout the eugeosyncline suggesting that northern Axel Heiberg Island and northwestern Ellesmere Island were above sea level during this interval of time and were being actively eroded. (c) Radiometric determinations of several plutons in northern Axel Heiberg Island and northwestern Ellesmere Island have indicated ages of about 360 million years. [With regard to Caledonian versus Acadian crustal movements in the eugeosyncline it seems reasonable to regard the long, northerly extension of Blue Fiord carbonates (Emsian and Givetian) in the miogeosyncline, as shown in Figure 13, as indicating a period of quiescence between the two movements.] (5) Eurekan Orogeny of mid-Cenozoic age. The effects of this orogeny are deferred for later discussion, but it is of interest to note at this time that whereas much or all of the eugeosyncline was deformed by Eurekan deformation, the Hazen Trough was unaffected by this event.

The precise limits of regions affected by Acadian and Ellesmerian Orogenies are not clearly defined. It is possible that deformation of the Hazen Trough was effected by one or the other orogeny, or by both.

Sverdrup Basin

Strata of the Sverdrup Basin lie with angular unconformity on rocks of the Franklinian Geosyncline. They consist of a thick and little interrupted sequence of largely marine sediments that range from Early Carboniferous to mid-Cenozoic age. Rocks of the basin underlie nearly all of Axel Heiberg Island, with the exception of the small area of exposed eugeosyncline around the northern extremity of the island, and they form a belt of exposures that trend northeasterly through western and northwestern regions of Ellesmere Island. There are, thus, fairly well defined southeastern and northwestern boundaries to Sverdrup Basin rocks on these islands (*see* Fig. 11). The axis of the basin, which is marked by the position of greatest subsidence and generally thickest deposits, extends northeasterly through central regions of Axel Heiberg Island and across northwestern Ellesmere Island. The aggregate maximum thickness of formations in the axial regions of the basin as inferred from isopach studies is more than 50,000 feet, but the maximum thickness of sediments to accumulate at any one point is probably nowhere greater than about 40,000 feet. Towards the southeastern boundary of the Sverdrup Basin the sedimentary section thins markedly owing mainly to disconformities, thinning and pinch-outs of individual rock units, and overstepping relations. It is therefore apparent that the present-day boundary corresponds more or less to the original depositional margin of the basin[1] (*see* Fig. 2; and Thorsteinsson and Tozer, 1970). Although thinning of certain rock units of the basin in the direction of the northwestern boundary is evident it is obvious that the northwestern depositional margin or threshold with the Arctic Ocean was farther to the northwest, probably along the continental shelf, and Sverdrup Basin rocks have been stripped back to their present-day northwestern boundary.

Strata of the Sverdrup Basin lie mainly on rocks of the Franklinian Eugeosyncline, and to a lesser extent on adjacent parts of the miogeosyncline. Presumably a considerable area of the miogeosyncline was exposed to erosion during the growth of the basin, and contributed to deposits laid down in the basin.

[1] It is of some interest to note that the southeastern margin of the Sverdrup Basin in Ellesmere Island was sufficiently fixed through time to suggest a hinge line of deep-seated structural origin; moreover that this hinge line strikes diagonally across the Franklinian miogeosynclinal and eugeosynclinal belts which also must have reflected deep-seated structural trends.

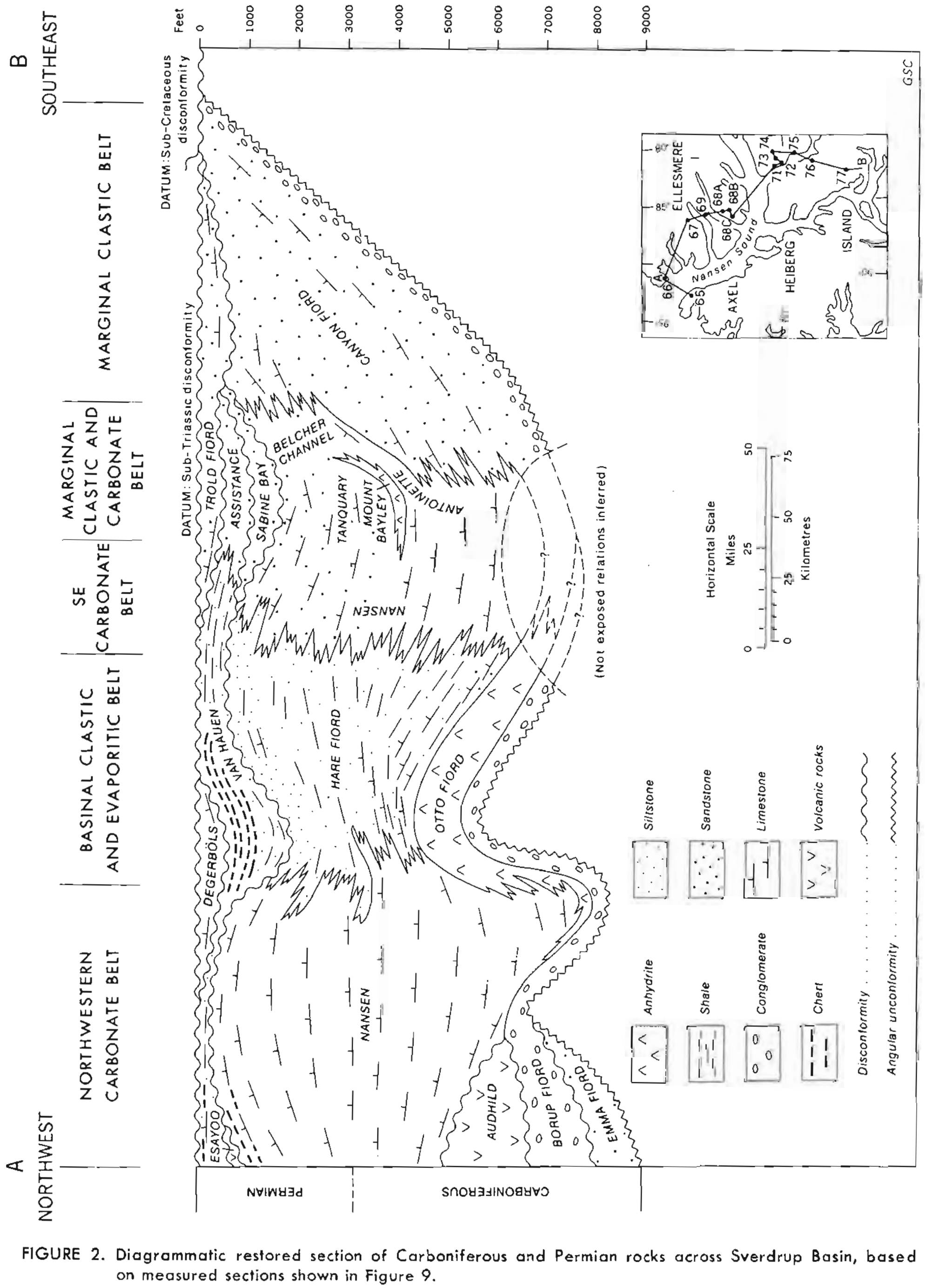

FIGURE 2. Diagrammatic restored section of Carboniferous and Permian rocks across Sverdrup Basin, based on measured sections shown in Figure 9.

The Sverdrup Basin was deformed by the Eurekan Orogeny, whose main pulse was about mid-Cenozoic. The age of this deformation is bracketed by two widely distributed, nonmarine, clastic units: the Eureka Sound Formation, which is dated as Paleocene to about Miocene and occurs at the top of the conformable succession of Sverdrup Basin rocks; and the Beaufort Formation of Pliocene and/or early Pleistocene age, which lies with angular unconformity on rocks of the Sverdrup Basin in islands of the archipelago southwest of Axel Heiberg Island (Thorsteinsson and Tozer, 1970). An early pulse of Eurekan Orogeny is indicated locally in eastern Axel Heiberg Island and neighbouring regions of northwestern Ellesmere Island by an angular unconformity between the Eureka Sound Formation and various rock units as young as Early Cretaceous (*Eureka Sound North*).

The Eureka Sound Formation is widely transgressive in regions of the archipelago beyond the limits of the Sverdrup Basin, and undoubtedly overspread much, if not all, of Ellesmere Island. As noted in previous discussion, this formation is commonly preserved as widely separated outliers, lying either disconformably on rocks of the Arctic Platform or with angular unconformity on the eroded edges of deformed rocks in the Franklinian Geosyncline (*see* for example *Strathcona Fiord*). In places in the geosyncline the formation is nearly flat lying, but in others it is folded and thrust faulted. These outliers of Eureka Sound rocks are of importance, not only in demonstrating that Eurekan deformation occurred beyond the confines of the Sverdrup Basin, but also in determining the extent of the region affected.

Rocks of the Sverdrup Basin are folded and faulted along trends that are more or less aligned with those of underlying Ellesmerian or older structures. Eurekan deformation was not intense, and the intensely deformed rocks of the Franklinian Geosyncline, particularly those of the eugeosyncline, present a marked contrast to the much less deformed rocks of the basin. So far as is known, Eurekan Orogeny was not accompanied by plutonism or metamorphism. Most folds in Sverdrup Basin rocks are symmetrical with gently dipping limbs; overturning of beds is rare indeed.

Significant changes in the style of deformations characterize different parts of the Sverdrup Basin, as well as regions of the Franklinian Geosyncline that underwent Eurekan Orogeny.

Large areas of the Sverdrup Basin including the northern half or more of Axel Heiberg Island and adjacent regions of northwestern Ellesmere Island appear to have been only mildly flexed by compressive forces, but are disrupted by block faulting, or are tilted and broken by normal faults, many of which have erratic trends (*Bukken Fiord, Cape Stallworthy, Otto Fiord*). In fact, normal faults represent the most common deformational features in regions affected by Eurekan Orogeny. It is seemingly reasonable to attribute these faults to crustal distention that followed the main episode of Eurekan compression, and many normal faults are demonstrably post-orogenic. Nevertheless, several normal faults in Sverdrup Basin rocks are known to be occupied by basic dykes, and available evidence suggests that most of these are Late Cretaceous (*see* p. 80). The problem is unresolved. Possibly some normal faults are related to the Late Cretaceous or early Cenozoic pulse of Eurekan Orogeny, but it is possible that certain dykes may have been emplaced following the climactic pulse of that orogeny in mid-Cenozoic time.

Folds and thrust faults increase in numbers and magnitude towards the southeastern margin of the Sverdrup Basin. Southern Axel Heiberg Island is of particular interest because of a belt of well-displayed, long, subparallel folds of low amplitude and long wave lengths (*Glacier Fiord*). To the north in central parts of the island, these folds give place to a number of shorter and less regular, closely folded anticlines, and complementary, broader and open synclines (*Strand Fiord*). The latter folds are broken by numerous normal faults and are characterized by the largest concentration of anhydrite diapirs in the Sverdrup Basin. It is probable that the folds in southern and central Axel Heiberg Island formed over a décollement at the level of the anhydritic Otto Fiord Formation of Carboniferous age. It is probable also that the large, westerly dipping Stolz thrust (*Eureka Sound North*) that marks the eastern boundary of the above described structures originates at this décollement. If the north-trending structures of southern Axel Heiberg Island were developed above a décollement, the underlying early Paleozoic rocks may have a different regional trend.

Most Eurekan thrusts are high-angle faults that dip to the west or northwest, indicating that, as in the earlier orogenies in these islands, the deformative forces were exerted from the oceanic side of the continent towards the Central Stable Region.

Although thrust faults are not especially numerous in the Sverdrup Basin as a whole, much of the southeastern marginal region of the basin is marked by a series of generally high-angle thrust faults, commonly arranged *en echelon* (*Eureka Sound South*, *Cañon Fiord*, *Greely Fiord West*, *Tanquary Fiord*). Presumably the margin of the Sverdrup Basin acted as a buttress reflecting the hinge line that developed with the growth of the basin. However, it is of interest that the continuity of these thrusts is broken where the margin of the basin crosses the Hazen Trough.

The gross structural configuration of the Sverdrup Basin in Axel Heiberg and Ellesmere Islands is that of a southwesterly plunging synclinorium, the principal axis of which coincides approximately with the axis of maximum deposition discussed earlier. It is this synclinorial character that causes all but the marginal belts of Carboniferous and Permian rocks to pass beneath the cover of Mesozoic and Cenozoic sediments in southwestern Axel Heiberg Island (*see* Fig. 3). Probably the synclinorium was affected largely by differential uplift during Eurekan Orogeny. However, differential isostatic adjustment post-dating the orogeny, and the possibility that a southwesterly plunge may have characterized the depositional Sverdrup Basin in these islands prior to orogeny, cannot be ruled out as contributing factors.

No practical distinction can be made between terrane of Sverdrup Basin and that of the Franklinian Geosyncline. The greater part of the combined areas of these diverse geologic provinces has undergone two or more tectonic adjustments that produced superimposed structures with similar regional trends. Consequently the various orogenic and epeirogenic events have merged through time to form a single orogenic region—the Innuitian Orogen.

Relationships of Sverdrup Basin and Gulf Coast Basin

Several interesting comparisons are possible between the development of the Sverdrup Basin and that of the Gulf Coast Basin on the opposite side of the North American continent: (1) Both basins are successor basins superposed on ancient orogenic systems. An angular unconformity marks the surface of separation between the Sverdrup Basin and the underlying Franklinian system, whereas the Gulf Coast Basin overlies with angular unconformity the Appalachian and Ouachita orogens of the United States, and their counterparts in Mexico and the Antilles. (2) Both basins developed as roughly oval-shaped depressions, the central and greater areas of which subsided more or less continuously with sedimentation and therefore include the thickest and most complete columns of rock. Along the margins of both basins the sediments are thinner and less complete. There also, the sequence of formations varies from place to place because of the wedging in and out of various units. (3) The sediments of both basins are genetically similar to, and belong with, miogeosynclinal and platform suites of rocks. (4) In neither basin is there a eugeosynclinal counterpart. Volcanic rocks of Carboniferous, Permian, and Cretaceous ages occur in the Sverdrup Basin, whereas

Cretaceous and Tertiary volcanic rocks occur in the Gulf Coast Basin. These rocks constitute only an incidental part of the total volume of rock in each basin and their distributions in these basins are not according to a eugeosynclinal plan. (5) Comparable maximum thicknesses of sediments, estimated to be 40,000 to 50,000 feet, accumulated in both the Sverdrup and Gulf Coast Basins. (6) By far the greater amounts of sediments in both basins are of clastic origin. These sediments were derived from the continental side of each basin, in contrast to the respective underlying geosynclines in which the preponderance of clastic sediments was derived from offshore tectonic lands. (7) In both the Sverdrup and Gulf Coast Basins the aggregate maximum thickness of formations as inferred from isopach studies is considerably greater than the thickness of the column of sediments at any one locality, mainly because the axes of maximum deposition shifted in the directions of the bordering oceans with the passage of time. In the Sverdrup Basin, for example, the axis of greatest deposition in Carboniferous and Permian times appears to have been approximately parallel to the central west coast of Ellesmere Island. In the Triassic it extended northeasterly through the eastern regions of Axel Heiberg Island, whereas in the Cretaceous it extended northeasterly through western Axel Heiberg Island. (8) Thick and widely distributed units of evaporites occur near the base of the sedimentary sequences in the Sverdrup Basin (Otto Fiord anhydrite) and the Gulf Coast Basin (Louann salt). These evaporitic sequences have been responsible for the numerous diapirs in their respective basins.

There are two principal differences in the development of these two basins: (1) The Sverdrup Basin contains an essentially conformable sequence of Carboniferous, Permian, Triassic, Jurassic, Cretaceous, and early Cenozoic (Paleocene to Miocene) rocks, whereas the Gulf Coast Basin comprises an essentially conformable sequence of Triassic, Jurassic, Cretaceous, Tertiary, and Quaternary rocks. (2) The Sverdrup Basin has gone through the full cycle from sedimentary basin to deformed belt; in contrast, the Gulf Coast Basin has not undergone orogeny but continues to receive sediments at present.

On the basis of the many similarities in the development of the Sverdrup and Gulf Coast Basins, it is probable that they are genetically similar geological provinces, and difference in neither age nor structural history militates against this conclusion. Furthermore, it would seem that neither basin represents a true geosyncline, at least not in the sense of an orthogeosyncline as defined by Stille (1940) and elaborated by Kay (1951).

Acknowledgments

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Students who assisted in the field were R. H. Janes in 1957, and D. Morris, T. O. Frisch, and A. R. Minty in 1962. Morris and Frisch are alone responsible for describing and measuring the section of Carboniferous and Permian rocks that is illustrated graphically in this report as section 78 on Figure 10.

Eskimo residents at Resolute, N.W.T., employed as dog drivers included Amagualik and Jebbardi in 1956 and Jebbardi and Jackoosie in 1957. Pilots of the Piper Super Cub aircraft

in 1961 were V. Andreason, J. Jamieson (chief pilot and flight engineer), and J. Kershaw. In 1962, M. Olson served as helicopter pilot with A. G. Hisock as flight engineer. J. Jamieson piloted the Piper Super Cub aircraft contracted during the 1962 and 1963 seasons. In 1961, J. Kyer served as cook, while J. Siddon operated the radio. In 1962 and 1963, J. Siddon served as both cook and radio operator. All these persons performed their duties very satisfactorily.

Acknowledgment is also made to the following persons who assisted in fossil identifications[1] and in supplying information on age and correlation: Dr. R. E. Grant, U.S. Geological Survey; Drs. W. M. Furnish and B. F. Glenister, Department of Geology, University of Iowa; Dr. B. L. Mamet, Department de Géologie, Université de Montréal; Dr. J. B. Waterhouse, Department of Geology, University of Toronto; and to Drs. E. W. Bamber, M. S. Barss, and W. W. Nassichuk of the Geological Survey of Canada.

Thanks are extended also to Dr. Nassichuk for useful information concerning Carboniferous and Permian biostratigraphy, and to H. P. Trettin for informative discussions concerning the geology of northern regions of Axel Heiberg and Ellesmere Islands. Dr. Trettin discovered and drew the writer's attention to the exposures herein erected as type sections of the Audhild and Emma Fiord Formations.

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[1] The ages of most formations described in this report are based directly or indirectly on fusulinaceans and ammonoids. The writer is responsible for identifications of the fusulinaceans; the ammonoids were identified by Furnish, Glenister, and Nassichuk. For the most part, fusulinacean and ammonoid identifications are listed opposite their respective stratigraphic levels in the sections that are illustrated graphically on Figures 7 to 10.

STRATIGRAPHY

Carboniferous and Permian rocks of the Sverdrup Basin constitute a natural grouping of structurally conformable formations, in which the lower and upper boundaries of the combined systems are represented everywhere by clearly marked regional unconformities. Carboniferous rocks lie with angular unconformity on bevelled and truncated structures of the lower Paleozoic Franklinian Geosyncline. The top of the Permian is invariably a disconformity, and throughout the greater part of the basin the Lower Triassic Blind Fiord Formation or correlative strata of the Bjorne Formation lies on Permian rocks. Although Carboniferous and Permian rocks are separated by an unconformity along southern margins of the Sverdrup Basin in Melville Island (Tozer and Thorsteinsson, 1964) and Grinnell Peninsula (Nassichuk, 1965), throughout the greater and principal part of the basin the intersystemic boundary is not represented by a physical break. Sedimentation in the basin was apparently continuous across the Mississippian–Pennsylvanian boundary.

The preponderance of Carboniferous and Permian sediments are of marine origin. Arranged in decreasing order of abundance, the principal lithologic types include carbonates, quartzose clastics, and evaporites. Nonmarine quartzose clastic rocks with coal, and volcanic rocks are present locally. Permian carbonates and evaporites constitute the youngest deposits of their kind in the Canadian Archipelago, because Mesozoic and Cenozoic deposits consist almost exclusively of quartzose sandstone, siltstone. and shale. It seems probable, therefore, that the close of the Permian marked the end of warm-water conditions in this region.

Carboniferous and Permian rocks within the report area range in age from Early Carboniferous to Late Permian. Represented within this span of geologic time are the stages, Viséan, Namurian, Bashkirian, Moscovian, Zhigulevian, Orenburgian, Asselian, Sakmarian, Artinskian, and Guadalupian. The lowermost stage of the Carboniferous (Tournaisian), and uppermost stage of the Permian (Dzhulfian) are apparently unrepresented in the Sverdrup Basin.

The nomenclature and correlation of Carboniferous and Permian formations in the report area are summarized in Table 1.

For purposes of description and correlation it is convenient to divide Carboniferous and Permian formations of the report area into five stratigraphic sequences, the boundaries between which are marked by disconformities. Many of the complex lateral and vertical relationships that characterize these sequences, as worked out by the present study, are represented diagrammatically in a cross-section of the Sverdrup Basin illustrated as Figure 2. Two and possibly three volcanic formations occur within the Carboniferous and Permian succession, but because they are of limited distribution and constitute such a minor part of the total thickness of rocks representing these systems, their consideration is deferred to later pages. The salient features of the five stratigraphic sequences outlined below include only those of the sedimentary rocks.

1. *Lower Carboniferous (Viséan) nonmarine sequence.* The sequence is represented by a single formation, the Emma Fiord, which consists principally of quartzose clastic sediments. The formation occurs sporadically at the base of the Carboniferous and Permian succession in northern Axel Heiberg and neighbouring parts of northwestern Ellesmere Island.

2. *Upper Carboniferous (Namurian) to Lower Permian (Artinskian) marine sequence.* This sequence includes the preponderance of Carboniferous and Permian rocks in the Sverdrup Basin (*see* Fig. 2).

The Borup Fiord Formation represents the oldest deposits of this sequence. Outcrops of the formation are limited to northern Axel Heiberg Island and northwestern Ellesmere Island, and where Emma Fiord rocks are absent the Borup Fiord constitutes the basal deposits of the Sverdrup Basin. The formation is composed mainly of red quartzose sandstone and conglomerate. It is of Namurian age, and retains relatively uniform characters throughout its areal extent.

In contrast to the Borup Fiord, formations stratigraphically higher in the sequence (early Bashkirian to early Artinskian) change radically in character across the Sverdrup Basin. Five facies belts are developed in these rocks, and they trend southwest to northeast, paralleling the axis of the basin (*see* Fig. 3). From northwest to southeast the belts are characterized as follows: (a) The northwestern carbonate belt is underlain by the Nansen Formation, a thick unit of relatively pure, light coloured limestone; (b) the basinal evaporitic and clastic belt includes, in order upwards, the Otto Fiord Formation consisting mainly of anhydrite, and the Hare Fiord Formation made up mainly of dark coloured siltstone, shale, and limestone; (c) southeastern carbonate belt underlain by the Nansen Formation; this facies belt unites with the northwestern carbonate belt in northwestern Ellesmere Island; (d) marginal clastic and carbonate belt. The border of the southeastern carbonate belt and the marginal clastic and carbonate belt marks the approximate line along which the Nansen Formation passes southeastward into combinations of either two or four formations. The twofold combination is most common and includes redbeds of the Canyon Fiord Formation, overlain by carbonate and clastic rocks of the Belcher Channel Formation. The combination of four formations includes in ascending stratigraphic order: Canyon Fiord (redbeds), Antoinette (mainly limestone), Mount Bayley (anhydrite), and Tanquary (carbonate and clastic rocks). In general the formations, Antoinette, Mount Bayley, and Tanquary are lateral equivalents of the Belcher Channel Formation which ranges from Late Carboniferous to Early Permian. Where the Canyon Fiord Formation is overlain by either the Belcher Channel or the Antoinette, its age is mainly Moscovian. (e) The marginal clastic belt occupies a limited area along the southeast side of the marginal clastic and carbonate belt, in the environs of Cañon Fiord. This belt is underlain by the Canyon Fiord Formation only, which there ranges in age from Bashkirian to Early Permian, and includes strata correlative with the Belcher Channel Formation.

3. *Lower Permian (Artinskian) nonmarine sequence.* This sequence is represented by a thin unit of light coloured, quartzose sandstone that is referred to the Sabine Bay Formation. The formation is confined to the margin of the Sverdrup Basin where it forms a narrow belt of exposures extending from a short distance south of Cañon Fiord to the north side of Greely Fiord. Rocks of the Sabine Bay Formation have no known correlatives in deeper parts of the Sverdrup Basin.

4. *Lower Permian (Artinskian) marine sequence.* Strata of this interval include the Assistance and van Hauen Formations, two relatively thin, correlative rock units that represent marginal and basinal facies, respectively (*see* Fig. 2). The Assistance is composed mainly of quartzose

TABLE 1 *Correlation table of representative sections in report area. Vertically ruled areas denote absence of deposits owing to unconformities in section. Diagonally ruled areas denote strata not exposed, or unrepresented because of faulting.*

SYSTEM	SERIES	STAGE	North coast of Axel Heiberg Island Section 65; in Figure 9	Near northwestern extremity of Ellesmere Island Section 66; in Figure 9	Head of Hare Fiord, Ellesmere Island Section 68; in Figure 9	Central regions of Hare Fiord, Ellesmere Island Section 69; in Figure 9	Near East Cape in Cañon Fiord, Ellesmere Island Section 71; in Figure 9	Near junction of Tanquary Fiord and Greely Fiord, Ellesmere Island Sections 80, 81 and 82; in Figure 10
PERMIAN	UPPER	DZHULFIAN						
		KAZANIAN			TROLD FIORD FORMATION 390+	DEGERBÖLS FORMATION 600	TROLD FIORD FORMATION 550	
	LOWER	ARTINSKIAN	VAN HAUEN FORMATION 700 ESAYOO VOL 130	VAN HAUEN FORMATION 360+	ESAYOO VOL 240	VAN HAUEN FORMATION 1335	ASSISTANCE FORMATION 570 SABINE BAY FM 635	
		SAKMARIAN	NANSEN FORMATION 4000+	NANSEN FORMATION 4000	NANSEN FORMATION 7780	HARE FIORD FORMATION 2480	TANQUARY FORMATION 2180	TANQUARY FORMATION 700
		ASSELIAN					MOUNT BAYLEY FORMATION 250	MOUNT BAYLEY FORMATION 500
CARBONIFEROUS	UPPER	ORENBURGIAN					ANTOINETTE FORMATION 2650	ANTOINETTE FORMATION 1550
		ZHIGULEVIAN						
		MOSCOVIAN						CANYON FIORD FORMATION 1255
		BASHKIRIAN	? OTTO FIORD FM 50± ?	AUDHILD VOL 1840	?	OTTO FIORD FORMATION 1000 ?		
		"NAMURIAN"	BORUP FIORD FORMATION 400±	BORUP FIORD FORMATION 1240	BORUP FIORD FORMATION 1290			
	LOWER	VISÉAN	EMMA FIORD FORMATION 400±	EMMA FIORD FORMATION 1140				
		TOURNAISIAN						

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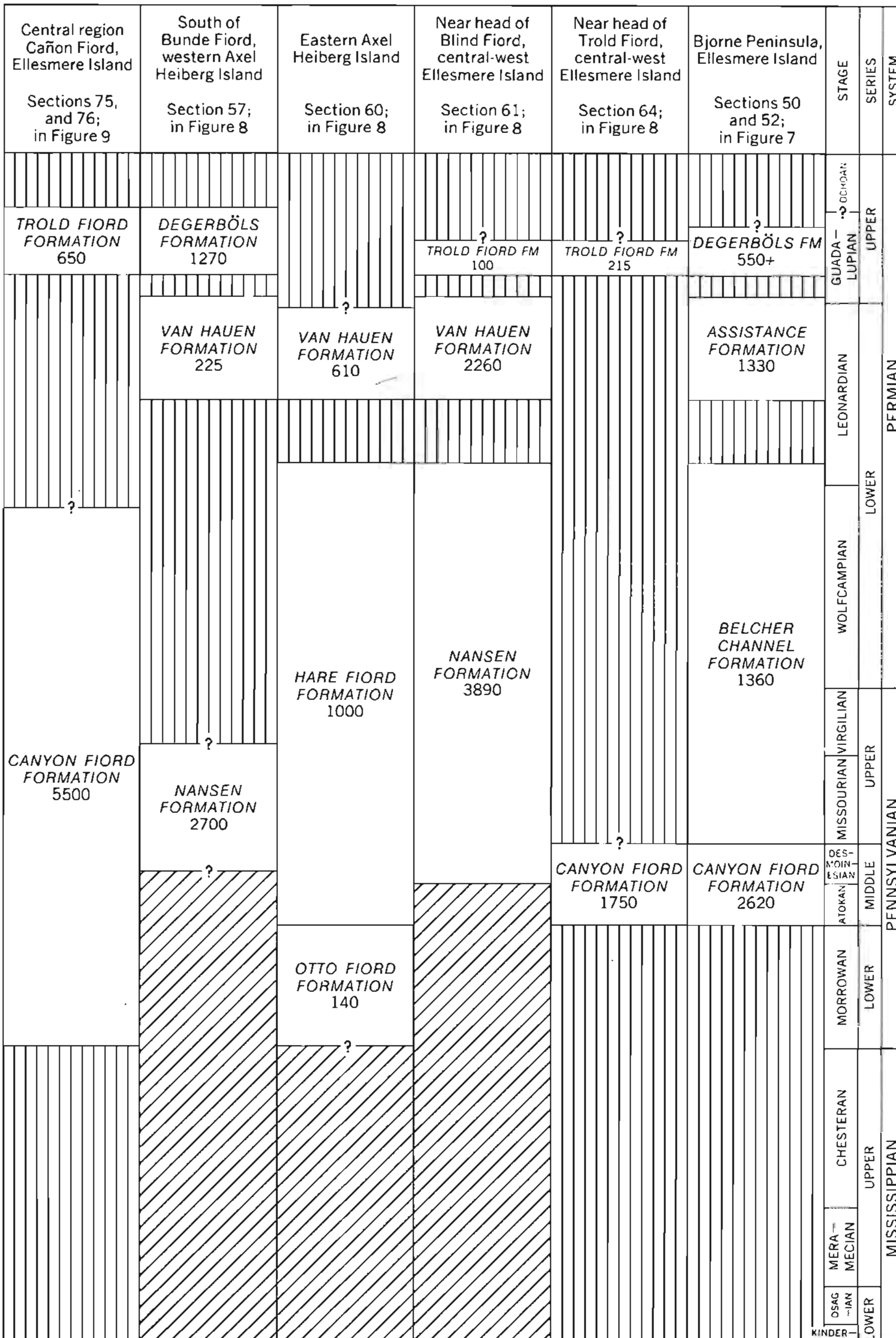
TABLE 1


Central region Cañon Fiord, Ellesmere Island
Sections 75, and 76; in Figure 9
South of Bunde Fiord, western Axel Heiberg Island
Section 57; in Figure 8
Eastern Axel Heiberg Island
Section 60; in Figure 8
Near head of Blind Fiord, central-west Ellesmere Island
Section 61; in Figure 8
Near head of Trold Fiord, central-west Ellesmere Island
Section 64; in Figure 8
Bjorne Peninsula, Ellesmere Island
Sections 50 and 52; in Figure 7
STAGE
SERIES
SYSTEM
TROLD FIORD FORMATION 650
CANYON FIORD FORMATION 5500
DEGERBÖLS FORMATION 1270
VAN HAUEN FORMATION 225
NANSEN FORMATION 2700
VAN HAUEN FORMATION 610
HARE FIORD FORMATION 1000
OTTO FIORD FORMATION 140
TROLD FIORD FM 100
VAN HAUEN FORMATION 2260
NANSEN FORMATION 3890
TROLD FIORD FM 215
CANYON FIORD FORMATION 1750
DEGERBÖLS FM 550+
ASSISTANCE FORMATION 1330
BELCHER CHANNEL FORMATION 1360
CANYON FIORD FORMATION 2620
OCHOAN
GUADA-LUPIAN
LEONARDIAN
WOLFCAMPIAN
VIRGILIAN
MISSOURIAN
DES-MOIN-ESIAN
ATOKAN
MORROWAN
CHESTERAN
MERA-MECIAN
OSAG-IAN
KINDER-HOOKIAN
UPPER
LOWER
UPPER
MIDDLE
LOWER
UPPER
LOWER
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
GSC

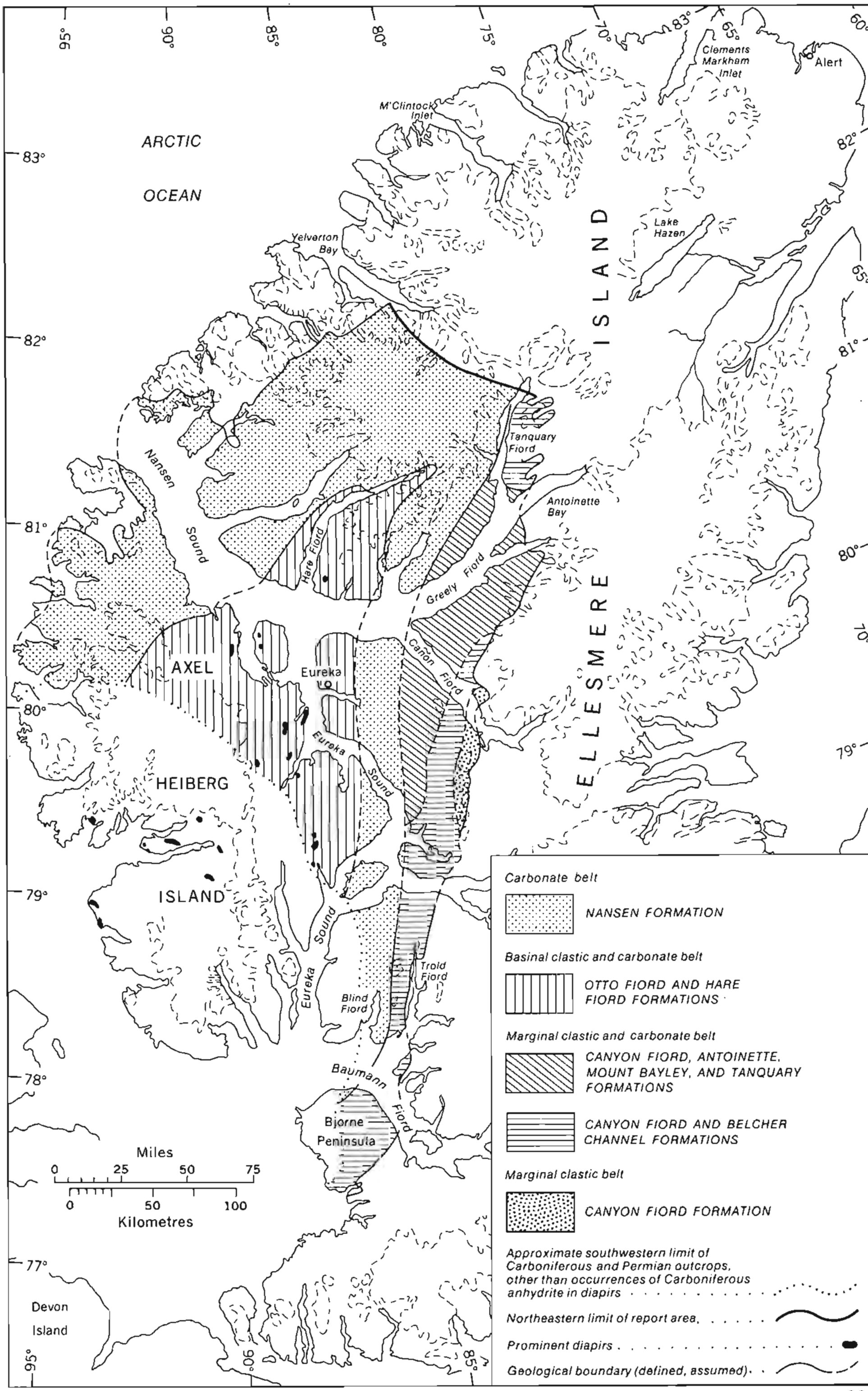


FIGURE 3. Facies belts of lower Bashkirian to lower Artinskian strata on Axel Heiberg and Ellesmere Islands.

sandstone and is distributed along the southeastern margin of the Sverdrup Basin in western Ellesmere Island. The van Hauen consists largely of dark coloured shale, siltstone and chert, and outcrops sporadically over large areas of southwestern and northwestern Ellesmere Island and eastern and northern Axel Heiberg Island.

5. *Upper Permian (Guadalupian) marine sequence.* Upper Permian rocks have several features in common with the Artinskian marine sequence. The Upper Permian sequence includes two, relatively thin, contrasting types of correlative deposits: The Trold Fiord Formation consists mainly of green glauconitic sandstone, and is exposed along the southeastern margin of the Sverdrup Basin in western regions of Ellesmere Island; correlative rocks are represented by the Degerböls Formation, which consists mainly of light coloured limestone and chert and is exposed over widely separated regions of northern Axel Heiberg, southwestern and northwestern Ellesmere Island. The Trold Fiord and Degerböls Formations are the youngest Paleozoic strata in the Canadian Arctic Archipelago.

Description of Formations

Lower Carboniferous (Viséan) Nonmarine Sequence

Emma Fiord Formation

Definition, Structural Relationships, and Distribution

The oldest rocks in the Sverdrup Basin are made up of nonmarine quartzose clastic sediments that are here designated the Emma Fiord Formation. The type section is on Kleybolte Peninsula, which forms the northwestern extremity of Ellesmere Island (*see* Pl. I). The formation is named after a prominent fiord about 18 miles southeast of the type section. Rocks herein referred to this formation were described from exposures in Svartevaeg Cliffs on northern Axel Heiberg Island (*see* locality 162, *Cape Stallworthy*) by Kerr and Trettin (1962). Their paper was the first to demonstrate the presence of Lower Carboniferous deposits in the Sverdrup Basin. The age of these rocks was based on a microflora determined by Playford and Barss (1963).

Emma Fiord rocks lie with angular unconformity on various formations of the Franklinian Geosyncline, and they are overlain disconformably by redbeds of the Borup Fiord Formation. The Emma Fiord is of limited distribution. Outcrops of the formation are confined to three general localities: several small areas of exposures on Kleybolte Peninsula; Svartevaeg Cliffs; and, outside of the report area, on a nunatak about 8 miles northwest of the terminus of Clements Markham Glacier in northeastern Ellesmere Island (reported by R. L. Christie, 1964, p. 34).

Lithology and Thickness

The Emma Fiord is a rather uniform sequence of strata with subdued topographic expression. It consists mainly of siltstone that is variably argillaceous, micaceous and carbonaceous, dark grey to black, and thin to medium bedded. Minor constituents include shale that is variably silty and carbonaceous, light grey quartzose sandstone, quartzite pebble conglomerate, and thin coal seams. The type section of the formation is 1,140 feet thick, and is illustrated graphically in section 66 on Figure 9. The thickness of Emma Fiord strata at Svartevaeg Cliffs has not been accurately determined, but it is probably about 400 feet. In these exposures three coal seams, each about 3 feet thick, occur in the basal 100 feet or so of the formation.

Age

The late W. A. Bell identified the plant fossil *Cardiopteris abbensis* Read, from a collection made 130 feet stratigraphically above the base of the type section of the Emma Fiord (GSC Cat. No. 6826). Bell comments as follows:

> A single identifiable species is hardly sufficient for refined age reference. The genus *Cardiopteris*, however, is a characteristic element in late Mississippian and early Namurian floras, and the types of *C. abbensis* were derived from a late Mississippian formation (Bluefield Shale, Virginia U.S.A.). A Viséan age is considered most likely.

M. S. Barss had identified a spore assemblage from the same locality and horizon, and his report is given below:

> *Convolutispora tuberculata* (Waltz) Hoffmeister, Staplin and Malloy
> *Convolutispora clavata* (Ishchenko) Hughes and Playford
> *Reticulatisporites cancellatus* (Waltz) Playford
> *Reticulatisporites peltatus* Playford
> *Reticulatisporites* cf. *R. rudus* Staplin
> *Microreticulatisporites lunatus* Staplin
> *Murospora aurita* (Waltz) Playford
> *Murospora sublobata* (Waltz) Playford
> *Anulatisporites anulatus* (Loose) Potonie and Kremp
> *Densosporites bialatus* (Waltz) Potonie and Kremp
> *Densosporites rarispinosus* Playford
> *Lycospora uber* (Hoffmeister, Staplin and Malloy) Staplin
> *Lophozonotriletes appendices* (Hacquebard and Barss) Playford
>
> In addition, specifically indeterminable representatives of the following genera occur: *Leiotriletes*, *Punctatisporites*, *Convolutispora*, *Murospora*, *Densosporites*, and *Reticulatisporites*.
>
> The spore assemblage detailed above is almost identical to the Mississippian microfloras recorded on Axel Heiberg Island by Playford and Barss (1963). These assemblages are considered to be of Viséan age because of their close similarity to Viséan floras of the U.S.S.R. and Spitsbergen.

Upper Carboniferous (Namurian) to Lower Permian (Artinskian) Marine Sequence

Borup Fiord Formation

Definition and Distribution

Emma Fiord strata are succeeded disconformably by a formation of redbeds on Kleybolte Peninsula in northwestern Ellesmere Island and at Svartevaeg Cliffs on the north coast of Axel Heiberg Island (*Cape Stallworthy*). The redbeds are more extensively distributed than the Emma Fiord, and constitute basal deposits of the Carboniferous and Permian succession over large areas of northern Ellesmere Island and northern Axel Heiberg Island, where Emma Fiord strata are absent (*see Tanquary Fiord*, *Otto Fiord*, *Cape Stallworthy*, *Bukken Fiord*). In such circumstances the redbeds lie with angular unconformity on lower Paleozoic rocks. The redbeds are here named Borup Fiord Formation. This formation is best exposed in the spectacular mountains that border the north side of Hare Fiord, northeast of van Hauen Pass; outcrops that occur near the headwaters of Stepanow Creek are chosen as the type section (*see* loc. 106, *Otto Fiord*). The formation is named after a prominent fiord in northern Ellesmere Island, some 47 miles south of the type locality.

Lithology and Thickness

Although locally variable in lithology, the Borup Fiord is uniform in gross aspect. The formation consists predominantly of alternating units of dusky red quartzose sandstone and conglomerate, with very small amounts of siltstone, shale, dolomite, and limestone. Probably the most distinctive features of the Borup Fiord are its well-bedded character and prevailing dusky red weathering colours.

The environment represented by the Borup Fiord is not definitely known. The single collection of fossils found in the type section indicates that the formation is, at least in part, marine. Characters suggesting that the formation is mainly, if not entirely, marine are: the apparent absence of plant remains; the rather common occurrence of calcareous cement; the scarcity of shallow water sedimentary structures; and the well-developed bedding.

The type section of the Borup Fiord Formation on Stepanow Creek is described as follows:

Unit No.	Lithologic Character	Thickness (feet)
	Overlying strata, Nansen Formation, limestone	unmeasured
	Covered interval, probably tongue of Otto Fiord Formation, anhydrite	100.0
5	Sandstone, quartzose, dusky red, in part greenish grey, fine- to coarse-grained, thin- to medium-bedded, variably calcareous	115.0
4	Sandstone, quartzose, dusky red, fine- to coarse-grained, thin- to mainly thick-bedded; in part conglomeratic with clasts of quartzite and chert pebbles; minor red siltstone; bed of hematite 10 inches thick occurs at base of unit	35.0
3	Limestone, bioclastic, in part sublithographic, greenish grey and medium grey, weathering grey and red, thin- to medium-bedded; dark grey shale and medium grey siltstone alternate in basal 5 feet of unit	25.0
2	Sandstone, quartzose, red, fine- to coarse-grained, thin- to generally thick-bedded; in part conglomeratic; clasts formed of granules and pebbles of chert and quartzite	90.0
1	Conglomerate, dusky red, thin- to mainly thick-bedded; clasts angular to subrounded, varying from granules to cobbles and formed of multi-coloured chert, quartzite, quartz and siltstone	275.0
	Total thickness of Borup Fiord Formation	540.0
	Underlying strata, Grant Land Formation, Lower Ordovician and/or Cambrian	

The maximum recorded thickness of the Borup Fiord is 1,290 feet on Girty Creek near the head of Hare Fiord (*see* Pls. II and VI). The rocks there are summarized as section 68 on Figure 9. They consist mainly of alternating sandstone, conglomerate and lesser amounts of siltstone, but a single stratum of mottled pink and yellow, aphanitic limestone, 2 feet thick, occurs 610 feet above the base. The sandstone is dusky red to greyish green, thin to generally medium and thick bedded, fine to coarse grained, partly calcareous and variably resistant. Conglomerate comprises about 25 per cent of this section and consists of granules, pebbles and cobbles of mainly chert and quartzite embedded in a groundmass of sandstone.

The phenoclasts vary from angular and subangular to forms that are well rounded. A unit of conglomerate 40 feet thick forms the base of the formation.

The Borup Fiord is 1,240 feet thick on Kleybolte Peninsula (*see* Pl. 1; sec. 66, Fig. 9), and it is estimated to be 400 feet thick at Svartevaeg Cliffs. The thickness of the Borup Fiord is highly variable, a characteristic that probably results from the fact that the formation was deposited on an unevenly eroded pre-Carboniferous surface of considerable local relief. The minimum measured thickness of the formation (330 feet) was obtained by H. P. Trettin south-southeast of the head of Fire Bay, a small indentation on the southeast side of Emma Fiord (*see* loc. 111, *Cape Stallworthy*). Trettin has contributed the following description and comments of the section at Fire Bay.

Unit No.	Lithologic Character	Thickness (feet)
	Overlying strata: Nansen Sound Formation	
4	Mainly dolomite, lesser amounts of sandstone, conglomerate and siltstone as below, reddish weathering; poorly exposed, mostly recessive interval	98
3	Pebble-conglomerate, pale olive-grey, pale red weathering; fragments of chert, shale, etc. in dolomitic, calcareous and quartzose matrix; fragments observed range up to about 35 mm; poorly sorted and poorly bedded	90
2	Conglomeratic sandstone, greyish red, greyish red to pale red weathering, laminated to thinly laminated; fragments observed range up to a few millimetres; fragments of chert, shale, etc. in dolomitic, calcareous, and quartzose matrix	33
1	Dolomite, greyish red, greyish red to pale red weathering, calcareous, argillaceous, quartzose, very thin bedded; minor conglomerate with pebbles of chert, shale, etc. in dolomitic, calcareous, quartzose and chloritic matrix	110
	Total thickness of Borup Fiord Formation	331
	Underlying strata, member A of the Lands Lokk Formation (Silurian)	

Trettin's remarks concerning the section are as follows:

The conglomerates are poorly sorted and the phenoclasts (fragments more than 2 mm in diameter) in them are subangular to subrounded and of irregular, elongate shapes.

The fragments consist of pure chert, shaly chert, dolomitic and calcareous chert, cherty shale, shale, vein quartz, and carbonate rock in about that order of abundance.

Relatively clear nodules, about 0.08 to 0.2 mm in diameter that may represent radiolarian remains were observed in several chert fragments, and remains of a sponge spicule was (sic) seen in one fragment. Most shale fragments are coated with red-weathering hematite.

The sandstone, siltstones, and the sandy and silty matrix of the conglomerates consist of subequal proportions of carbonate and silicate materials. Euhedral to subhedral dolomite of silt to fine sand grade is the predominant carbonate mineral, but anhedral calcite is invariably associated with it. The most abundant silicate is quartz; chert, muscovite, feldspar, and fragments of quartzite and phyllite are present in lesser amounts. A specimen from unit 1 contains sand-sized aggregates of microcrystalline chlorite or glauconite. The sand grains are mostly subangular to subrounded. They are mostly cemented by carbonates, but by quartz where siliceous grains are in contact with each other.

Statistical analysis of 100 points in a thin section established the following approximate composition for a dolomite specimen from unit 1.

Carbonates	60%
Quartz	5%
Phanerocrystalline muscovite	2%
Chert (?)	1%
Feldspar (?)	1%
Opaque and semiopaque materials	30%

The carbonate consists mainly of euhedral to subhedral dolomite of silt grade with interstitial anhedral calcite. An X-ray analysis by A. E. Foscolos indicates that the dolomite: calcite ratio is about 2.5:1, and that small amounts of siderite are also present.

The opaque to semiopaque materials include hematite and clay minerals, identified by Foscolos as muscovite, iron rich chlorites, and kaolinite. The red colour of the rock is due to the hematite.

The rock fragments and silicate minerals in the Borup Fiord Formation at Fire Bay appear to have been derived from relatively close terrestrial sources, and they appear to have been deposited rapidly, without much reworking; this is inferred from the coarse grade of part of the sediments, and from their poor sphericity and roundness. Bedded chert is common in the Ordovician succession of the Hazen Plateau (Trettin, 1968), and in the Ordovician or older Rens Fiord Complex of northern Axel Heiberg Island (Trettin, 1969), and early Paleozoic units such as these may have been the source of the cherty materials.

The dolomite, on the other hand, is probably not terrigenous, but originated contemporaneously with the strata in the depositional environment; this conclusion is based on the commonly euhedral habit of the mineral, and on the scarcity of dolomite in the pre-Pennsylvanian succession of the region.

Features characteristic of open marine environments on the one hand, and of unequivocally nonmarine, fluvial environments, on the other hand, are lacking in these sediments. Shallow marine, intertidal environments are suggested by the combination of the following criteria: coarse grade of part of the clastic sediments; red colour; association of clastic sediments and carbonates, with dolomite as the predominant carbonate mineral; apparent absence of marine fossils at this locality. Oxidizing conditions are indicated by the hematite content and red colour of the sediments and by the absence of carbonaceous matter.

Age and Correlation

The Borup Fiord has yielded only one collection of fossils, an assemblage of Foraminifera (GSC Cat. No. C-266), obtained from unit 3 of the type section. The fauna is reported by B. L. Mamet (*see* Appendix). Mamet dates this fauna as early Namurian, and as such it represents the oldest marine fauna in the Sverdrup Basin.

Audhild Formation

A sequence of volcanic rocks interposed between the underlying Borup Fiord Formation and overlying Nansen Formation is here named the Audhild Formation. The formation is named after Audhild Bay which forms the southeastern limits of Kleybolte Peninsula. Outcrops of the Audhild are confined to Kleybolte Peninsula, where the formation occurs in several isolated fault blocks. The best exposures occur near the southwestern extremity of the peninsula and are chosen as the type section (*see* loc. 66, *Cape Stallworthy*). The type section is 1,840 feet thick and is illustrated in Plate I, and in section 66 on Figure 9. It is made up of dark coloured basaltic and spilitic flows and lesser amounts of pyroclastic sediments. The age of the Audhild, as judged from its stratigraphic position, is late Namurian or early Bashkirian.

Otto Fiord Formation

Definition

Overlying the Borup Fiord Formation is a succession of strata as much as 1,100 feet thick and consisting largely of anhydrite, herein named Otto Fiord Formation after one of the major fiords in northwestern Ellesmere Island. The type section of the Otto Fiord Formation is on the north side of Hare Fiord, about 3 miles northeast of van Hauen Pass. It is illustrated graphically in section 69 on Figure 9 and shown in Plates III and IV.

Lithology

The type section of the Otto Fiord is composed mainly of anhydrite that varies from medium to very thick bedded and massive. At the surface, the formation consists largely of gypsum, an alteration product of anhydrite, but fresh exposures in rapidly eroding streams reveal that the rock is, in fact, anhydrite. Anhydrite constitutes about 80 per cent of the total thickness of strata; the remaining 20 per cent consists of eight interbedded units of dark grey limestone varying from 2 to 50 feet, including a bed of shale about 3 feet thick.

The Otto Fiord maintains relatively uniform lithologic characters throughout its areal extent. Consequently the description of the type section serves well for all exposures observed in normal stratigraphic position, including the core rocks in all diapirs in the Sverdrup Basin for which the Otto Fiord has almost certainly provided most of the source materials.

The striking white colour of the Otto Fiord as a whole is a useful criterion for identifying the formation from a distance, or on aerial photographs.

Thickness

The greatest known thickness of the Otto Fiord is 1,100 feet, which was obtained for an incomplete section outcropping immediately above the Blue Mountain thrust on the east side of Hare Fiord (*see* section 68A, Fig. 9). Although the type section of the Otto Fiord, underlain by a thrust fault, does not represent the complete formation, it is nevertheless 1,000 feet thick and very probably represents the greater part of the formation. Support for this conclusion comes from outcrops of the Otto Fiord on Stepanow Creek, some 17 miles northeast of van Hauen Pass, where a full section of the formation has been measured as 700 feet thick (*see* Pl. VII).

Stratigraphic Relationships

The Otto Fiord, throughout much of its areal extent, is overlain by the Hare Fiord Formation, which consists largely of dark coloured siltstone, shale, and limestone. This contact of the Otto Fiord has been observed at a number of places where it appears to be relatively sharp. The basal contact of the Otto Fiord with the Borup Fiord Formation has been observed only on Stepanow Creek, where the contact of the Otto Fiord and Hare Fiord is exposed also. At this locality both contacts appear gradational, suggesting that sedimentation was continuous across these boundaries. Locally, the Otto Fiord is overlain by the Nansen Formation, a thick unit of light coloured limestone.

The facies relationship of the Otto Fiord is well exhibited in the mountains on the north side of Hare Fiord, east of Stepanow Creek. There, on the basis of physical continuity of strata, it is evident that the Otto Fiord is a facies equivalent of the lower part of the Nansen

Formation, the upper and greater part of which is a facies equivalent of the Hare Fiord Formation. In places, what appear to be completely developed sequences of the Otto Fiord are overlain by the Nansen Formation. In other places, however, partial developments of the Otto Fiord in the form of anhydrite, a few tens of feet thick, are interbedded with limestone in the lower part of the Nansen (*see* sec. 68, Fig. 9).

Distribution

Outcrops of the Otto Fiord occurring in normal stratigraphic position, are shown on geologic maps *Eureka Sound South*, *Greely Fiord West*, and *Otto Fiord*.

The Otto Fiord comprises a relatively wide belt of sediments along the axis of the Sverdrup Basin, extending northeasterly across central Axel Heiberg Island into northwestern Ellesmere Island, and terminating northeast of the head of Hare Fiord. The areal distribution of the Otto Fiord including that of the overlying Hare Fiord Formation are shown as the basinal clastic and evaporitic belt in Figure 3. Although the areal extent of the Hare Fiord Formation is believed to be fairly accurately portrayed in this figure, that of the Otto Fiord is only an approximation. That the Otto Fiord, particularly partial developments of the formation, has a somewhat greater distribution than the Hare Fiord Formation has been noted in previous discussions concerning the relationships of the Otto Fiord and Nansen Formations around the head of Hare Fiord. Further support for this conclusion is found in the occurrence of sporadic, small anhydrite diapirs, obviously derived from Otto Fiord rocks, that intrude the Nansen Formation in widely separated parts of Axel Heiberg and Ellesmere Islands outside of the boundaries of the basinal facies belt in Figure 3 (*see* for example *Bukken Fiord*).

Age

With the exception of diapirs that are judged to have been derived from the Otto Fiord, outcrops of the formation in normal stratigraphic position have not yielded datable fossils. Nevertheless the Otto Fiord can be dated within fairly narrow limits on the basis of its stratigraphic position above the Borup Fiord Formation of Namurian age, and below the Hare Fiord Formation, basal beds of which contain ammonoids of early Moscovian age. On this basis it is reasonable to conclude that although the Otto Fiord may include strata of Namurian and/or Moscovian ages, the formation is probably mainly Bashkirian. Evidence that the Otto Fiord is, in part at least, Bashkirian comes also from the study of ammonoids obtained from interbedded limestone and shale in two widely separated diapirs in the Sverdrup Basin. Ernst W. Hoen (1964, p. 8), geologist to the "Jacobsen–McGill Arctic Research Expedition, 1959–1962", collected the following ammonoids from limestone interbedded with anhydrite and gypsum in the centre of the South Fiord Diapir in western Axel Heiberg Island.

Locality 181; GSC Cat. No. 47996
cf. "*Eumorphoceras carinatum*" Schmidt
Bisatoceras sp.
Reticuloceras reticulatum Phillips

Identifications are by W. M. Furnish and B. F. Glenister who regard the ammonoids as Namurian in terms of the European standard, an age that equates with the Bashkirian as used in this report. W. W. Nassichuk (1968, p. 205) has collected ammonoids from limestone and shale interbeds in the Barrow Diapir in northeastern Melville Island. One collection included species of *Reticuloceras* Bisat, and *Bisatoceras* Miller and Owen. A stratigraphically higher bed yielded representatives of *Gastrioceras* Hyatt and *Branneroceras* Plummer and Scott. Nassichuk considers that these collections indicate a Bashkirian age.

Hare Fiord Formation

Definition

This formation consists mainly of dark coloured siltstone, shale, and limestone. It is named after Hare Fiord in northwestern Ellesmere Island where the formation is splendidly displayed in a series of outcrops along the north side of the fiord, northeast of van Hauen Pass. The type section is about 3 miles northeast of the pass and is shown on Plates III and IV. Throughout its areal extent the Hare Fiord Formation lies conformably on evaporitic rocks of the Otto Fiord Formation and is overlain by the van Hauen Formation. A disconformity marks the surface of separation between the Hare Fiord and van Hauen, a rock unit that the Hare Fiord more closely resembles than any other within the Carboniferous and Permian succession in the area of this report.

Distribution

The Hare Fiord Formation outcrops in the environs of Hare Fiord and Nansen Sound in northwestern Ellesmere Island, and in eastern Axel Heiberg Island (*see Otto Fiord, Greely Fiord West, Bukken Fiord,* and *Eureka Sound North*). Its areal distribution, as well as that of the underlying Otto Fiord Formation, is shown also in Figure 3 as the basinal clastic and evaporitic belt. The northeastern extent of the formation is limited northeast of the head of Hare Fiord by the coalescence of the flanking belts formed by contemporaneous sediments of the Nansen Formation. The Hare Fiord Formation appears to represent deposits laid down along the axis of the Sverdrup Basin as it existed in Carboniferous and Permian times.

Thickness and Facies Equivalent

The formation is shown graphically in section 69, 68B and 68C on Figure 9, and in sections 59 and 60 on Figure 8. These sections indicate a range in thickness from 1,000 to about 4,100 feet.

The Hare Fiord is a facies equivalent of the generally thicker Nansen Formation, which is characterized by relatively pure carbonate rocks (*see* Fig. 2). The facies boundary of the Hare Fiord and the Nansen is arbitrarily established at the change from dark coloured, dominantly clastic rocks, to light coloured, dominantly carbonate rocks, respectively. Transitional rocks of the two formations are prominently displayed in the territory between the heads of Otto Fiord and Hare Fiord in northwestern Ellesmere Island.

Although little information is available on regional variations in thickness of the Hare Fiord, the formation appears to be thickest near the region of facies change into the Nansen Formation. It is there also that limestone constitutes a significant percentage of Hare Fiord rocks. The Hare Fiord is thinnest in central regions of its outcrop area where siltstone and shale make up most of the formation.

Lithology

The Hare Fiord Formation consists of quartzose siltstone, shale, and limestone, with lesser amounts of chert and quartzose sandstone; the proportions of lithologic types represented in the formation vary from place to place. A broad two-part subdivision appears to characterize virtually all complete sections of the Hare Fiord. It includes a basal unit that consists mainly of bedded limestone, and an upper, thicker unit that is made up largely of noncalcareous siltstone and shale.

The limestone is of three main types: The predominant type is an aphanitic to finely crystalline rock that is variably argillaceous or silty, and more rarely cherty. This rock occurs as beds that are ordinarily thin to medium bedded (*see* Pl. VII), but includes some that are very thin, thick, and very thick bedded. A less common type consists of thin to thick beds of bioclastic limestone, or as coquinas consisting of varying combinations of fusulinaceans, brachiopods, solitary corals, bryozoans, and crinoid columnals. The third type of limestone occurs as massive reefs.

The siltstone is variably argillaceous and siliceous, and typically medium to thick bedded. It is mainly noncalcareous and hard, but is represented also by beds that are noticeably calcareous and others that are soft. Carbonaceous impressions suggesting fossil algae are commonly observed on bedding planes in the siltstone.

The shale occurs generally as thin intercalated beds or as bedding plane partings in the limestone and siltstone, but in places it forms units varying in thickness from a few feet to several tens of feet. There is nothing especially distinctive about this rock type except that it is commonly noncalcareous and variably silty.

The sandstone is generally very fine to fine grained, and thin to medium bedded.

The chert occurs as bedded deposits and as nodules and irregular masses distributed in the limestone. The principal colours include shades of grey, blue, and purple.

Two outstanding characteristics of the Hare Fiord Formation are: (1) The prevailing colours of these rocks which, on a fresh surface, are medium grey to dark grey and, when weathered, are normally medium grey to dark grey but include also various shades of brown. The brown shades apply especially to the siltstone and bedded limestone. (2) The massive, light coloured reefs that occur in the region of facies change with the Nansen Formation in the vicinity of Hare Fiord. The reefs are distributed sporadically in the lower and middle parts of the formation and vary in thickness from a few feet to as much as 200 feet (*see* Pl. VII). They occur as lens-shaped masses and mounds that are generally surrounded by thin- to medium-stratified, impure limestone and siltstone, which dip outward from the reefs in such a manner as to indicate that the latter developed as topographic prominences on the sea floor. The reefs are made up of limestone that is light grey to medium light grey, and yellowish grey, and weather to yellowish grey and greyish yellow. The limestone is commonly characterized by a granular texture and is variably porous or vuggy. It contains many grains identifiable as fossils, and in rare instances yields well-preserved forms such as ammonoids, brachiopods, fusulinaceans, ostracodes, and algae. Fusulinaceans and ammonoids collected from various reefs indicate a range in age from Moscovian to about Zhigulevian.

Despite the prevailing dark colour of Hare Fiord rocks they are nowhere markedly bituminous. When struck or broken, however, they commonly yield a slight fetid odour.

Composed mainly of relatively hard, dark siltstone and limestone, the Hare Fiord Formation is only moderately resistant to erosion. The formation presents a characteristic dark appearance on aerial photographs.

The type section of the Hare Fiord is represented graphically in section 69 on Figure 9. It consists of four, broadly defined lithologic units of local extent. The unusually high percentage of limestone in this section reflects proximity to correlative rocks of the Nansen Formation. Details of the section are given below.

Unit No.	Lithologic Character	Thickness (feet)
	Overlying strata, van Hauen Formation	
4	Limestone, siltstone, shale and chert; limestone and siltstone are of about equal proportions and interbedded with lesser amounts of shale; limestone, variably argillaceous or silty, medium dark grey to dark grey; aphanitic to very fine grained, thin- to medium-bedded, weathering to various shades of grey and brown; siltstone, variably calcareous or variably argillaceous, medium dark grey to dark grey, thin- to medium-bedded, weathering to various shades of grey and brown; shale, noncalcareous, variably silty, dark grey to black; a 10-foot unit of thin-bedded, dark grey chert forms base of unit	1,000
3	Shale, and lesser amounts of siltstone; shale, noncalcareous, dark grey to black; siltstone, variably argillaceous dark grey to black	240
2	Limestone, shale and subordinate chert; unit is similar in most respects to unit 1, with the exception that shale constitutes about $\frac{1}{4}$ of unit and the amount of chert is very small. Fauna collected 100 feet above base of unit; *Fusulinella* sp., *Fusulina* sp., and *Triticites* sp. Fauna collected 220 feet above base of unit; *Fusulinella* sp., and *Triticites* sp	800
1	Limestone, subordinate shale and chert; limestone constitutes about $\frac{4}{5}$ of unit; it is typically argillaceous or cherty, medium grey to black, aphanitic, thin- to thick-bedded, hard and dense; shale comprises about $\frac{1}{10}$ of unit; it is dark grey to black and commonly sooty; chert, various shades of grey, blue and purple, occurs in beds up to 5 feet thick and as irregular intergrowth in limestone. Reef knolls up to 40 feet thick occur in this unit and unit 2, along the mountain front on either side of type section. Fauna collected 90 feet above base of unit; *Stenopronorites* cf. *S. arkansasensis*, *Diaboloceras* cf. *D. varicostatum*, *Pseudoparalegoceras* cf. *P. kesslerense*, *Eoasianites* cf. *E. smithwickensis*. Fauna collected 150 feet above base of unit; *Fusulinella* sp	440
	Total thickness of Hare Fiord Formation	2,480
	Underlying strata, Otto Fiord Formation	

Blue Mountains, Northwestern Ellesmere Island

An unusual lithological development of the Hare Fiord is exposed in the Blue Mountains between Hare Fiord and Greely Fiord (*Greely Fiord West*). There the formation outcrops in a series of excellent exposures above the southeast-dipping Blue Mountains thrust fault, which is exposed either within evaporitic rocks of the Otto Fiord Formation, or near the base of the Hare Fiord (*see* Pls. VIII and IX). Two sections of the Hare Fiord in this area are illustrated graphically in sections 68A and 68C of Figure 9.

Section 68C was studied about a mile northeast of Hare Fiord Diapir. At this locality basal beds of the Hare Fiord are represented by a unit of alternating siltstone and fine-grained sandstone, about 160 feet thick. The siltstone and sandstone are variable calcareous, light grey to greenish grey, and occur in thin to thick beds. This siltstone–sandstone unit is surmounted by about 5 feet of dark grey, thin-bedded limestone, above which follows a covered interval of some 40 feet. The covered interval is in turn overlain by strata that is similar lithologically to the basal part of section 68B discussed below. The basal siltstone–

sandstone unit lies with sharp, yet conformable contact on the Otto Fiord Formation, and is of interest in that it represents the only known occurrence of significant amounts of quartzose clastic rocks at the base of the Hare Fiord Formation.

A broad twofold subdivision is evident in section 68B which was measured in a ravine about 3 miles northeast of section 68C. The upper division underlies the van Hauen Formation, and is 3,300 feet thick. It consists largely of dark coloured siltstone, limestone and shale, and minor amounts of sandstone, all of which exhibit typical Hare Fiord characteristics. Fossils in these rocks indicate a range in age from about Zhigulevian or Orenburgian to Early Permian. The lower unit is 650 feet thick, and though the base is marked by the Blue Mountain thrust this thickness is judged to represent a nearly complete sequence of the unit along the line of section. This unit is composed mainly of limestone that is massive to poorly bedded, and weathers to medium light grey and greyish yellow colours. The thickness of the lower unit is extremely variable and ranges from about 400 to 1,800 feet over short distances along the fault line scarp. About 7 miles northeast of section 68B the lower unit grades laterally into dark coloured limestone and clastic rocks that are indistinguishable from the upper member. In most places the upper surface of the lower unit is moderately level and appears to be overlain conformably by beds of the upper unit. In other places, however, beds of the upper unit abut against irregular protuberances of the upper surface of the lower unit suggesting disconformable relations (*see* Pls. VIII and IX). Fusulinaceans collected in the lower unit indicate that these rocks are mainly of Moscovian age. Hare Fiord rocks in this region are the subject of a detailed study by G. F. Bonham-Carter (1966, 1967), who interprets the lower, light coloured limestone to be a "back-reef" deposit.

Age

The Hare Fiord Formation is considered to range in age from early Moscovian to early Artinskian. Evidence for this conclusion is based partly on the study of ammonoids and fusulinaceans obtained from the Hare Fiord, and partly on the age of correlative formations within the report area.

The ammonoids, *Stenopronorites* cf. *S. arkansasensis*, *Diaboloceras* cf. *D. varicostatum*, *Pseudoparalegoceras* cf. *P. kesslerense*, and *Eoasianites* cf. *E. smithwickensis* which were collected 90 feet above the base of the type section were identified by W. M. Furnish and B. F. Glenister who date the fauna as early Atokan (=early Moscovian).

A correlative but larger fauna of early Moscovian ammonoids was collected by R. L. Christie and W. W. Nassichuk from a bioherm in the lower part of the Hare Fiord, some 12 miles northeast of the type section (*see* Pl. VII). Nassichuk and Furnish (1965) have identified this fauna, as including species of the following genera: *Maximites* Miller and Furnish, *Proshumardites* Rauser, *Bisatoceras* Miller and Owen, *Eoasianites* Ruzhencev, *Syngastrioceras* Librovitch, *Pseudoparalegoceras* Miller, *Neoicoceras* Hyatt, *Winslowoceras* Miller and Downs, *Neodimorphoceras* Schmidt, *Boesites* Miller and Furnish, *Stenopronorites* Schindewolf, *Metapronorites* Librovitch, and *Christioceras* Nassichuk and Furnish.

The fusulinaceans *Fusulinella* sp., *Fusulina* sp., and *Triticites* sp., in unit 2 of the type section suggest correlation with the Zhigulevian Stage.

The ammonoid, *Paragastrioceras* n. sp. identified by Nassichuk, Furnish and Glenister (1965) from Hare Fiord rocks east of Hare Fiord (*see* Pl. VIII) is dated by these authors as Early Permian.

Environment of Deposition

With the exception of the reefoid masses described earlier, there is evidence to indicate that the dark coloured, bedded rocks of the Hare Fiord Formation were deposited in stagnant, and possibly deep, water. The formation is nearly unfossiliferous, and it is evident that normal bottom-living organisms were unable to live in the environment represented by these sediments. The scarce fossils, represented principally by brachiopods, corals, and bryozoans, are commonly broken and abraded suggesting that they may have been transported from neighbouring shelf areas, and pelagic forms such as the ammonoids provide no indication as to depth of water. In contrast, it seems reasonable to assume that the relatively pure, shelf-type limestone of the correlative Nansen Formation was laid down in shallower, clearer, and better aerated water.

The distribution of Hare Fiord exposures, more or less surrounded by the Nansen Formation, suggests that the clastic deposits of the Hare Fiord were winnowed in periodically from the southeast, across the shelf areas that were receiving Nansen deposits. However, the possibility of a contributing source area to the northwest cannot be ruled out (*see* p. 34). It seems reasonable to assume that the basin subsided more rapidly than the surrounding shelf areas in order to receive and entrap these clastic deposits. It is possible also that subsidence of the basin was so rapid that sedimentation did not keep pace with it and the sea floor stood lower in the basin than on the surrounding shelf areas.

Nansen Formation

Definition and Distribution

Nansen Formation is the name given here to a thick sequence of limestone with subordinate amounts of quartzose clastic sediments that constitute the most widespread unit of the late Paleozoic succession in the area of this report. The formation is named after Nansen Sound, which separates Axel Heiberg Island from northwestern Ellesmere Island, and together with Greely Fiord and connecting fiords comprises the longest fiord system in the world. Superb outcrops of the Nansen Formation that occur along Girty Creek near the head of Hare Fiord in northwestern Ellesmere Island are here chosen as the type section. These outcrops are shown in Plates II and VI, and illustrated graphically in section 68 on Figure 9.

The Nansen occupies two belts of exposures shown in Figure 3 as the northwestern carbonate belt, extending from northwestern Axel Heiberg Island into northwestern Ellesmere Island; and the southeastern carbonate belt, which extends northeasterly along western Ellesmere Island and unites with the northwestern belt east of the head of Hare Fiord in northwestern Ellesmere. Distribution of the Nansen is shown also on geologic maps *Eureka Sound South*, *Tanquary Fiord*, *Greely Fiord West*, *Otto Fiord*, *Cape Stallworthy*, and *Bukken Fiord*.

The Nansen is topographically prominent and offers many striking features in the landscape. It stands in steep fiord walls, forms craggy mountain peaks, nunataks and the crests of numerous ridges, all of which contribute to the grandeur and scenic beauty of these two northern islands.

Stratigraphic Relationships

Facies relationships of the Nansen are shown in Figures 8 and 9. That the formation is a facies equivalent of the Otto Fiord and Hare Fiord Formations, which occupy axial regions of the Sverdrup Basin, has already been noted in the description of those formations. Along the boundary of the southeastern carbonate belt and the marginal clastic and carbonate belt (*see* Fig. 3), the Nansen gives way in a southeasterly direction, either to a combination of two formations, the Canyon Fiord and overlying Belcher Channel, or to a combination of four formations which are, in ascending order, the Canyon Fiord, Antoinette, Mount Bayley, and Tanquary. The transition from the Nansen to the Canyon Fiord and Mount Bayley Formations involves changes from one rock type to another. On the other hand the Antoinette, Tanquary, and Belcher Channel Formations are lithologically similar to the Nansen, and are separated from it by arbitrary boundaries.

The upper contact of the Nansen is everywhere a disconformity, and in different regions different formations overlie the Nansen. The Nansen is generally overlain by one of four Permian formations: van Hauen, Esayoo, Degerböls, or Trold Fiord. Locally, east of Tanquary Fiord in northern Ellesmere Island, the Nansen is succeeded by the Lower Triassic Bjorne Formation (*see* Pl. XXVI). The lower contact relationships of the Nansen are variable also and involve four stratigraphic situations. (1) Throughout the greater part of its areal extent, the Nansen grades upward from the underlying Borup Fiord Formation without a sharp break. (2) Locally, in the vicinity of facies change with the Hare Fiord Formation, Nansen strata lie gradationally on Otto Fiord evaporites. (3) On Kleybolte Peninsula in northwestern Ellesmere Island, volcanic rocks of the Audhild Formation are intercalated between the Borup Fiord and Nansen Formations (*see* sec. 66, Fig. 9). (4) On Raanes Peninsula in western Ellesmere Island, Nansen beds lie with angular unconformity on the Middle Ordovician Cornwallis Group (*see* sec. 63, Fig. 8).

Thickness

Little concrete information is available on regional variations in the thickness of the Nansen, since only two uninterrupted sections were measured. One of these is the type section of the formation, which is 7,780 feet thick; the other section occurs near the northwestern extremity of Ellesmere Island and includes about 4,000 feet of strata (*see* sec. 66, Fig. 9). Nevertheless, on the basis of information provided in Figures 8 and 9, in which widely separated, complete and incomplete sections of the Nansen, and formations correlative with the Nansen, are arranged in consecutive lines across the Sverdrup Basin, it seems reasonably safe to conclude that: (1) the Nansen is thickest in the vicinity of facies with the Otto Fiord and Hare Fiord Formations, and that it thins in both a northwesterly or southwesterly direction; (2) the thicknessess of 4,000 and 7,780 feet probably represent orders of minimum and maximum for the Nansen.

Lithology

Measured sections of the Nansen are shown graphically in sections 57 and 58 on Figure 8, sections 65 to 68 on Figure 9, and section 78 on Figure 10. Where typically developed the Nansen is a remarkably uniform body of evenly bedded limestone that is sparingly fossiliferous. The most common limestone is a compact, aphanitic to fine-grained, mainly thick-bedded rock that contains no recognizable organic structures. Interstratified with these rocks are subordinate biogenic limestones that range from rare coquinas of fusulinaceans, brachiopod shells and bryozoans, to limestone with a granular texture containing many grains identifiable as fossil remains, particularly crinoid columnals, and the rare bed of oölitic and and pisolitic limestone. The limestones are commonly light grey to medium grey on fresh surfaces, and the prevailing weathering colours are light grey, yellowish grey, or greyish yellow.

In certain areas, bluish grey or light grey chert that occurs as nodules and beds constitutes an important lithologic type, particularly in the upper part of the formation on Axel Heiberg Island and on Kleybolte Peninsula of northwestern Ellesmere Island (*see* sec. 65, Fig. 9; and secs. 57 and 58, Fig. 8).

The transition from Nansen strata to the predominantly dark coloured clastic sediments of the correlative Hare Fiord Formation takes place along a fairly definite boundary, primarily by intergrading, but also by intertonguing of lithic units. Traced towards this facies boundary, the limestones of the Nansen become progressively darker, and more distinctly bedded owing to intercalated shale and siltstone that occur as beds and bedding plane partings. These transitional features are well displayed in an imposing line of cliffs on the south side of Otto Fiord (*see* Pl. X).

Outcrops of the Nansen in the southeastern carbonate belt (*see* Fig. 2) provide another interesting example of transitional rocks in that formation. In this belt, which can be followed from Blind Fiord to near the head of Tanquary Fiord, the Nansen is characterized by alternating units of limestone, siltstone and sandstone, and minor amounts of shale. Here as elsewhere in the Nansen, limestone is the dominant lithology, particularly in the upper few hundred feet of the formation where it is commonly thick bedded, coarse grained, biogenic, and in places reefoid (*see* Pl. XIII). Indeed, biogenic limestones represent the dominant carbonate, and granoblastic varieties become subordinate. Moreover, the limestones commonly contain various admixtures of silt, sand and clay, and are characterized by medium to dark grey fresh surface colours.

The sandstone and siltstone commonly occur in units as much as 50 feet or more thick. The weathering colours of these rocks, in harmony with the units of limestone, are generally light grey to greyish yellow and yellowish grey; they are variably calcareous and soft. Thus, although the overall light colours that typify the Nansen throughout most of its areal extent persist in these transitional rocks, the recessive clastics between harder units of limestone impart a distinctive banded appearance to the formation when viewed from a distance (*see* Pls. XIII, XXVI).

An unusual development of the southeastern transitional facies of the Nansen, mentioned earlier as lying with angular unconformity on Ordovician rocks on Raanes Peninsula, merits further note. More specifically the Nansen Formation in question is situated between the north-trending Blind Fiord thrust and Trold Fiord thrust (*Eureka Sound South*). Two partial, but nevertheless overlapping, sections of the formation in this area are illustrated graphically in sections 62 and 63 on Figure 8. In territory east of the Trold Fiord thrust, strata correlative with the Nansen are represented by the Canyon Fiord Formation (mainly red sandstone), and the overlying Belcher Channel Formation (mainly grey carbonate and clastic rocks). Although strata correlative with the Canyon Fiord and Belcher Channel can be differentiated on faunal grounds in the Nansen between these thrust faults there is no well marked lithologic break. However, the Canyon Fiord equivalents are characterized by greater amounts of light coloured limestone and clastic rocks than in typical developments of that formation, and units of red clastics which normally are absent in the Belcher Channel occur within Belcher Channel equivalents. Indeed, strata assigned to the Nansen between the thrust faults seem to represent a facies precisely intermediate between typical developments of that formation and typical developments of the Canyon Fiord and Belcher Channel Formations.

The northwesternmost exposures of the Nansen are found on the south side of Bunde Fiord on the west coast of Axel Heiberg Island, and an incomplete section studied there is of special interest because of a unit of quartzose sandstone, 360 feet thick, that occurs in an otherwise typical development of the formation for northwestern regions of the report area (*see* sec. 57, Fig. 8). The section includes 2,700 feet of beds, and its base is the Bunde Fiord thrust. The sandstone, 1,180 feet above the thrust, is light grey to medium light grey, fine grained, thin to medium bedded, and varies from very soft to hard. It represents the only significant occurrence of sandstone known in northwestern regions of the northwestern carbonate belt of the Nansen (*see* Fig. 3), and may indicate a northwest source area of quartzose clastic deposits in Nansen time.

The most common fossils in the Nansen are fusulinaceans, corals, brachiopods, and bryozoans. Fossils are sparse in typical developments of the Nansen where they are commonly silicified, but are relatively abundant in strata transitional between the southeastern carbonate belt and the marginal clastic and carbonate belt. There, fusulinaceans are important rock-formers and commonly compose more than half the volume of individual beds (e.g., sec. 61, Fig. 8).

Age

Sections of the Nansen that lie directly on the Borup Fiord Formation range from early Bashkirian to early Artinskian. Where the Nansen lies on complete developments of Otto Fiord evaporites the formation ranges from early Moscovian to early Artinskian. The latter age range is assigned also to the Nansen between Trold Fiord and Blind Fiord where the formation lies unconformably on Ordovician rocks.

The presence of strata representing each and every stage included in the span of time given above cannot be demonstrated solely on the basis of fossils collected in the Nansen. For instance there is no faunal evidence to indicate Bashkirian and Orenburgian rocks. The conclusion that all stages from the Bashkirian to early Artinskian are represented is based on: (1) studies of fusulinaceans and ammonoids collected in the Nansen; (2) faunal evidence obtained from correlative formations; and (3) apparent absence of physical breaks in the formation that might suggest missing stages.

Moscovian strata in the Nansen are indicated by such fusulinacean genera as *Profusulinella*, *Paraeofusulina*, and *Fusulina* found in Raanes Peninsula (*see* sec. 63, Fig. 8). In section 61 on Figure 8, measured also on Raanes Peninsula, several hundred feet of the formation are characterized by associated species of *Triticites* and *Fusulinella* that suggest a Zhigulevian age. Higher beds in the same section yield species of *Schwagerina* and *Fusulinella*, which are probably of Asselian or Sakmarian age. *Schwagerina hyperborea* (Salter), a form considered to indicate an early Artinskian age, was collected 20 feet stratigraphically below the top of the Nansen near McKinley Bay in northern Ellesmere Island (*see* Pl. XXVI).

Nassichuk (1969) has described the ammonoid *Parashumardites* sp., which he considers Zhigulevian in age, from rocks occurring in the region of facies change between the Hare Fiord and Nansen Formations on the north side of Hare Fiord in northwestern Ellesmere Island. Nassichuk originally regarded the host rock of this ammonoid as the Hare Fiord Formation, but he (pers. com.) now considers the rock more properly assigned to the Nansen.

Problem of the Nansen in Western Axel Heiberg Island

Westernmost exposures of the Nansen occur in the upthrown sides of several major faults in the environs of Bunde Fiord in western Axel Heiberg Island (*Bukken Fiord*). There is a possibility that Permian rocks may be absent in the Nansen of this region because fusulinaceans and other fossils that would indicate their presence have not been found. This interesting possibility is illustrated by an incomplete section of the Nansen that was studied on the south side of Bunde Fiord (*see* sec. 58, Fig. 8). The Nansen in this section is 2,400 feet thick. It is overlain disconformably by the late Artinskian van Hauen Formation, and its base is the Griesbach Creek thrust. The section has yielded fusulinaceans from two different stratigraphic levels. One collection was obtained 610 feet above the base of the section and consisted of species of *Fusulinella* that exhibit affinities with Moscovian forms. The second collection was made 150 feet below the top of the formation, and identified as *Triticites* sp. A. *Triticites* sp. A is a relatively primitive member of the genus, and suggests a Zhigulevian rather than Orenburgian age.

Triticites sp. A is known from one other locality in the report area. It occurs in the Antoinette Formation in western Ellesmere Island (*see* sec. 71, Fig. 9). There, 3,800 feet of strata that is demonstrably correlative with the upper part of the Nansen in other regions of Ellesmere Island, overlies *Triticites* sp. A. Included in this interval of strata is the upper, about one third, of the Antoinette Formation, and the Mount Bayley and Tanquary Formations, which collectively span the Zhigulevian or Orenburgian to early Artinskian Stages (*see* Table 1).

It is possible that the unusually small thickness of Nansen strata (150 feet) that overlies *Triticites* sp. A in section 58 south of Bunde Fiord is the result of depositional thinning in this region, and that these strata in fact accommodate the Zhigulevian or Orenburgian to early Artinskian Stages. Nevertheless, it seems more reasonable to assume that the absence of latest Carboniferous and Early Permian fossils reflects erosional thinning, particularly because of the disconformity that everywhere marks the top of the Nansen. If this is so, the Bunde Fiord area was probably the site of considerable uplift and erosion, postdating the Nansen and predating the van Hauen Formation. No clear choice of these two hypotheses can be made without further investigations of the Bunde Fiord region.

Volcanic Rocks of Uncertain Age in Northwestern Ellesmere Island

An unnamed formation composed of nearly flat lying volcanic flows and pyroclastic rocks of undetermined thickness is exposed over a large area of the peninsula formed by Audhild Bay and Emma Fiord in northwestern Ellesmere Island (*Cape Stallworthy*). The volcanic rocks lie concordantly on limestone strata of the Nansen Formation, which on this peninsula is only a few hundred feet thick. A collection of fusulinaceans that indicate a Late Carboniferous (Moscovian) age was obtained in the Nansen at locality 110, about 100 feet stratigraphically below the volcanic rocks. The unusually small thickness of the Nansen in this region and the absence of younger Carboniferous and Lower Permian faunas that are generally represented in the formation suggest that the lower part of the Nansen is all that remains here. No formation is known to overlie the volcanic rocks, and their age therefore is uncertain. These unnamed volcanic rocks may at one time have been intercalated in the Nansen Formation. Nevertheless, the possibility that they are the Lower Permian Esayoo Formation, or represent a still younger episode of extrusion, cannot be excluded on the basis of available evidence.

Canyon Fiord Formation

Definition, Distribution, and Stratigraphic Relationships

The Canyon Fiord Formation is a unit of redbeds that outcrops along the southern and southeastern margins of the Sverdrup Basin where it lies with angular unconformity on rocks of the Franklinian Geosyncline. The formation forms a narrow belt of exposures that trends west to east across northern Melville Island (Tozer and Thorsteinsson, 1964, p. 93; Nassichuk, 1965), and is exposed over a limited area on Grinnell Peninsula, Devon Island (Nassichuk, op. cit.). Exposures of the Canyon Fiord in the report area are confined to western Ellesmere Island where they are divisible into two belts characterized by different ranges in age.

1. The formation is most widely distributed in the marginal clastic and carbonate belt (*see* Fig. 3) that forms a narrow strip of territory trending northeasterly from Bjorne Peninsula to and beyond Tanquary Fiord. In this belt, the Canyon Fiord comprises, for the most part, strata of Late Carboniferous (Moscovian) age only that are overlain gradationally by either the Belcher Channel Formation (mainly carbonate and Late Carboniferous to Early Permian) or a succession of three formations (which are collectively correlative with the Belcher Channel Formation) called, in order upwards, the Antoinette, Mount Bayley, and Tanquary (*see* Pls. XIX, XX, XXI, and XXVII). An exception to the above generalization is found near the

headwaters of the Tschernyschew River on Hamilton Peninsula where the Canyon Fiord includes rocks as old as Bashkirian (*see* Pl. XVI).

2. The type section of the formation is a little over 2 miles southeast of Caledonian Bay, a small indentation on the north side of Cañon Fiord in western Ellesmere Island (*see* Pl. XIV). This section is part of a relatively narrow belt of Canyon Fiord outcrops—the marginal clastic belt of Figure 3—that extends north and south of Cañon Fiord. The Canyon Fiord in this belt is unique in that it ranges in age from Late Carboniferous (Bashkirian) to Early Permian (Sakmarian and possibly up to Early Permian), and includes beds that represent the facies equivalents of the Belcher Channel Formation. The areal distribution of the Canyon Fiord is shown also on geological maps, *Baumann Fiord, Eureka Sound South, Greely Fiord East, Greely Fiord West*, and *Tanquary Fiord.*

History of Study

The Canyon Fiord Formation was named by J. C. Troelson (1950, p. 65), geologist to the "Danish Thule and Ellesmere Land Expedition, 1939–41", under the leadership of James van Hauen. On this expedition, his first of two journeys to Cañon Fiord [1,2], Troelsen

[1] Cañon Fiord was discovered and named by members of Otto Sverdrup's "Second Norwegian Expedition in the *Fram*, 1898–1902" (Sverdrup, 1904). For several years following Sverdrup's work, many published maps applied the alternative spelling of "Canyon Fiord" to Sverdrup's "Cañon Fiord," which accounts for Troelsen's spelling of the name of the formation. Although the officially adopted spelling is now "Cañon Fiord," it seems most practical to retain Troelsen's original spelling of the formation's name (*see* Article 12, Code of Stratigraphic Nomenclature).

[2] Troelsen (1950, p. 67) proposed the name Greely Fiord Group for nine stratigraphic divisions, aggregating about 700 metres thick, that outcrop along the north shore of Greely Fiord, on either side of the junction with Tanquary Fiord. Troelsen's stratigraphic divisions are described briefly as follows: Division 1; reddish weathering fossiliferous limestone, about 60 metres thick, and apparently lying with angular unconformity on intensely folded rocks of the Cape Rawson Formation. Division 2; yellow, crossbedded, unfossiliferous sandstone and conglomerate, about 30 metres thick. Division 3; grey, massive, commonly arenaceous limestone with nodules of brown chert, at least 100 metres. Division 4; east of the mouth of Tanquary Fiord this division consists of slightly metamorphosed and folded shale and limestone; whereas west of the fiord it consists of "white and grey, fine-grained marble, certain layers of which are strongly brecciated, while others are locally folded because of differential movement between enclosing, more competent bed. . . ." This division is at least 162 metres thick. Division 5; brown limestone, commonly argillaceous or arenaceous, and characterized by nodules of chert; at least 65 metres thick. From this sequence Troelsen identified the following: *Dictyoclostus transversalis* (Tschernyschew), *Marginifera involuta* Tschernyschew, *Marginifera* sp., *Camarophoria* sp., of the group of *C. mutabilis* Tschernyschew, and *Fenestella* sp. Division 6; greenish white, unfossiliferous limestone; about 60 metres thick. Division 7; yellow sandstone, about 40 metres thick. Division 8; red calcareous sandstone, replete with productid brachiopods, and 5 to 10 metres thick. Division 9; calcareous, glauconitic sandstone, replete with brachiopod and bryozoan biostromes. This division is described as resting gradationally on division 8, and as overlain disconformably by Mesozoic sandstone. It is about 100 metres thick.

Photographs of the Greely Fiord area displayed as Figures 11, 15, and 16 in Troelsen's report portray vividly the adverse conditions of heavy snow cover under which he worked. Moreover, it is understandable that Troelsen's observations, made in subzero temperatures and without an adequate topographic map, were necessarily brief and probably partly in error. Consequently, identification of Troelsen's nine stratigraphic divisions of the Greely Fiord Group with the formation delineated and mapped by the present studies in this territory is uncertain (*Greely Fiord East*). The most probable relationships are:

Divisions 1 and 2 = Canyon Fiord Formation
Division 3 = Antoinette Formation
Division 4 = Mount Bayley Formation
Divisions 5 and 6 = Tanquary Formation
Division 7 = Sabine Bay Formation
Divisions 8 and 9 = Trold Fiord Formation.

Troelsen found no evidence of disconformities within the Greely Fiord Group, for which available evidence indicated an Early Permian age. The present investigations, however, have shown that the Greely Fiord Group embraces three separate sedimentary successions, all of which are bounded below and above by unconformities: (1) Canyon Fiord Formation, Antoinette Formation, Mount Bayley Formation, and Tanquary Formation; (2) Sabine Bay Formation; (3) Trold Fiord Formation. Moreover, the total time range of rocks included in the Greely Fiord Group is Late Carboniferous to Late Permian. Because of these circumstances the writer recommends that the name Greely Fiord Group be abandoned.

(op. cit.) did not observe the base to his Canyon Fiord Formation, and he considered the type section to represent only the uppermost part of the formation. Troelsen described the type section as comprising"... gray impure, highly fossiliferous limestone overlain by gray sandstone." He correlated the Canyon Fiord Formation with the Moscovian Stages (Upper Carboniferous), principally on the basis of fusulinaceans collected from the type section. This was the first authentic record of Carboniferous rocks in the Canadian Arctic Archipelago. Moreover, the Canyon Fiord Formation represented the oldest known Carboniferous rocks in this region until Kerr and Trettin's (1962) discovery of Viséan beds (Emma Fiord Formation of this report) on the north coast of Axel Heiberg Island.

Troelsen (op. cit., p. 66) gave a more detailed description of the "gray sandstone" which he judged to represent a distinct formation surmounting the Canyon Fiord Formation, as follows:" ... yellowish-gray, cross-bedded sandstone with conglomerate layers of varying thickness. The fragments in the conglomerate are ordinarily very small, but a few attain diameters of about 10 centimeters. They consist of quartzite, reddish sandstone, chert and gray limestone... The cross-bedded sandstone with the conglomerate layers cannot be said to belong to the same lithologic unit as the Canyon Fiord Formation, but as the sandstone is so imperfectly known that it will hardly be possible for the surveyor to recognize it in other localities, it does not merit a name of its own. About the geological age of the sandstone nothing is known except that it must be younger than the Canyon Fiord formation."

In 1952, Troelsen (1952) returned to Cañon Fiord where he made the important discovery that Carboniferous rocks in the general vicinity of the type section of the Canyon Fiord Formation lay with angular unconformity on Silurian strata.[1] This was the first unequivocal evidence that an orogeny of about mid-Paleozoic age had affected the Canadian Arctic Archipelago. Although Troelsen did not discuss the Canyon Fiord Formation *per se*, he implicitly included the type section of that formation in rocks described as Carboniferous conglomerate, sandstone and limestone in the geologic sketch map in his report (Troelsen, op. cit., Fig. 8, p. 206). In the area on this map shown to be underlain by Carboniferous rocks, Troelsen included also: (1) the "gray sandstone" which originally was considered by him to overlie the Canyon Fiord Formation and (2) the Carboniferous strata directly overlying the unconformity with Silurian rocks. These Carboniferous strata were observed by him for the first time in 1952 and were considered to be older, in part at least, than strata in his type section of the Canyon Fiord Formation.

Although the principal results of Troelsen's second journey to Cañon Fiord were published in 1952, a somewhat fuller account is given in a manuscript report dated 1954, a copy of which is housed in the library of the Geological Survey of Canada. In this report, Troelsen gives a more accurate characterization of the Canyon Fiord Formation than is found in his two previous accounts. He described the formations as "composed mainly of conglomerate, quartzose sandstone and impure limestone. The colours vary from gray and yellow to violet and upon weathering the rocks in some cases assume brilliant red colours." Troelsen also reported the discovery in these rocks of the fusulinacean genus *Triticites* which extended the age of the Canyon Fiord into latest Carboniferous or Early Permian.

Subsequent studies of the Canyon Fiord Formation on Ellesmere Island include those of McLaren (1963, p. 332) in the environs of Eids Fiord, Thorsteinsson (1963b, p. 399) south of Caledonian Bay, and Tozer (1963b, p. 376) around the head of Trold Fiord. These studies provided some additional information on the areal extent and lithologic characters of the formation.

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[1] The Canyon Fiord at this locality overlies rocks as young as Early Devonian, according to H. P. Trettin (pers. com.).

Type Locality of Canyon Fiord Formation

The writer has examined in considerable detail rocks in and around the type section of the Canyon Fiord Formation. It seems appropriate, therefore, to record some general observations, particularly those that relate to the definition of the formation and Troelsen's work in this region.

The entire unit of redbeds that lies with angular unconformity on lower Paleozoic rocks southeast of Caledonian Bay in Cañon Fiord constitutes a single formation in which Troelsen's type section is but a part (*see* Pl. XIV). Three measured sections in this region are illustrated graphically as composite section 75 on Figure 9. The basal part of this section (75a) is of Bashkirian and possibly also Moscovian age; the middle part which represents the entire type section (75b) is Moscovian; and the upper part (75c) is about Zhigulevian to Sakmarian. The Canyon Fiord Formation, as herein emended, includes the type section, and sections 75a and 75c as reference sections. (The thickness of Canyon Fiord beds in this area may be as much as 4,300 feet but accurate determination is impossible because of extensive folding and faulting.) A third reference section is discussed below.

The upper contact of the Canyon Fiord is not preserved in the vicinity of the type section southeast of Caledonian Bay, and the formation in this region therefore is incomplete. However, a full thickness of the formation is preserved south of Cañon Fiord in the southerly extension of the belt of exposure that includes the type section. A section measured in that region comprises the upper 1,900 feet of the Canyon Fiord, overlain disconformably by the Upper Permian Trold Fiord Formation, and is illustrated graphically in section 76 on Figure 9 (*see also* Pl. XV). The relationship of section 76 to section 75c, discussed earlier, is indicated by the common occurrence in these sections of the fusulinacean *Eoparafusulina* sp. A. Although section 76 is largely if not entirely Sakmarian in age, much of the section is younger than section 75 across the fiord. Moreover, as section 76 is correlative with upper beds of the Belcher Channel Formation (*see* p. 44) in other parts of Ellesmere Island, it is possible that the upper, unfossiliferous part of this section also includes rocks of early Artinskian age. Section 76 represents an important reference section which together with reference sections 75a and 75c supplements type section 75b. The maximum aggregate thickness of the Canyon Fiord Formation in the general vicinity of the type section is estimated to be 5,500 feet on the basis of the correlated sections illustrated in Figure 9.

The "gray sandstone" that Troelsen (1950, p. 66) considered to represent a distinct formation overlying the type section of the Canyon Fiord constitutes a part of the Canyon Fiord. Moreover, the sandstone is separated from the type section by a fault, and is older not younger than strata in the type section.

The estimated thickness of 5,500 feet for the Canyon Fiord Formation in environs of the type section in Cañon Fiord represents the greatest known thickness of the formation on Ellesmere Island. In places the Canyon Fiord thins to a feather edge. The highly variable thickness of the formation is the result of three circumstances, partly explained in the foregoing discussions, but summarized as follows: (1) The Canyon Fiord disappears in a northwesterly direction through gradation and intertonguing with the Belcher Channel and Antoinette Formations (*see* Fig. 9), or with the lower part of the Nansen Formation (*see* Figs. 7 and 8). (2) The formation thins southeastward as a result of truncation of the upper beds by post-Canyon Fiord erosion. Plate XVIII gives a good illustration of this kind of thinning in the territory northeast of Vesle Fiord. Another example is found east of Tanquary Fiord where the Belcher Channel Formation oversteps Canyon Fiord strata (*see* Fig. 10). (3) The Canyon Fiord thins also in the direction of the southeastern margin of the Sverdrup Basin by virtue of overstep of lower strata of the formation on to pre-Carboniferous basement rocks, as indicated by the Bashkirian age of basal beds in certain sections, and the Moscovian age in others.

Lithology

Measured sections of the formation on Ellesmere Island are shown graphically on Figures 7, 8, 9, and 10.

The Canyon Fiord differs in lithology from bed to bed and from area to area like most predominantly clastic formations. Hence a detailed description of its lithology at one place does not serve as a competent identification at another. In general, however, the formation is largely composed of quartzose sandstone with varying amounts of limestone, and subordinate amounts of mudstone, siltstone, and shale.

The sandstone ranges from very fine to very coarse grained, and from very thin to very thick bedded and massive. It is, however, characteristically fine to medium grained, and medium to thick bedded. Ripple-marks and crossbedding are rare but occur in most sections. A few beds are sparsely glauconitic, and ferruginous sandstone beds are fairly common. Many sandstone beds contain lenses or sparsely distributed granules and pebbles made up of rounded to subrounded brown or dark grey chert. A large variety of fresh surface colours occur of which the most common are light grey, greenish grey, and greyish green. Other colours include various hues of red, blue, yellow, and brown. Much of the sandstone is soft, porous and friable, although dense resistant layers are present also in most outcrops. A few grains of chert and feldspar can generally be found in most sandstone beds.

In general, the proportion of limestone intercalated in the sandstone is greatest in regions to the northwest and less to virtually absent towards the southeast. The limestone is characteristically sublithographic or bioclastic, and both rock types are commonly quartzose or argillaceous. As in the sandstone, the sublithographic limestone is notable for a large variety of fresh surface colours including hues of red, blue, yellow, brown, grey, and purple. Mottled effects in these rocks are common also. The limestone beds commonly contain chert in the form of irregular replacement masses, fossil replacements, and lenses parallel to the bedding.

The base of the formation commonly contains a conglomerate that ranges from a few inches to more than 250 feet in thickness. The conglomerate is generally resistant and stands out as prominent ledges and ridges in the landscape (*see* Pl. XIV). It is most commonly composed of cobble-sized phenoclasts embedded in a groundmass of calcareous quartzose sandstone and iron oxide. However, the size of the phenoclasts varies from place to place and may range from granules to boulders, whereas their shapes vary from angular and subangular to well-rounded forms. Chert phenoclasts are present in varying proportions in all studied sections. The composition of the phenoclasts in the basal conglomerate of any given section, however, generally reflects the lithology of the bedrock formation underlying the Canyon Fiord at that locality. Thus, for example, basal conglomerates that overlie the Ordovician Cornwallis Group commonly contain a large percentage of limestone phenoclasts (including fossils of that group) that are lithologically similar to Cornwallis rocks. McLaren (1963, p. 332) has identified a fauna, obviously derived from the Middle Devonian Blue Fiord Formation, that he collected from basal conglomeratic beds of the Canyon Fiord Formation south of Eids Fiord in southwestern Ellesmere Island. At this locality the Canyon Fiord overlies the Blue Fiord Formation. It seems probable, therefore, that the basal conglomerate of the Canyon Fiord represents, in part at least, debris resulting from the breaking up of lower Paleozoic basement rocks.

Conglomerate layers that are seldom more than 10 feet thick are sparsely represented throughout most sections of the formation. They are generally similar lithologically to the basal conglomerate described above, with the exception that the phenoclasts are seldom greater than cobble-size, and are generally composed of either varicoloured chert or limestone.

Rocks of the Canyon Fiord Formation lend colourful features to the landscape and enhance the scenic beauty of Ellesmere Island. Although a good deal of the various lithologic types in most sections of the Canyon Fiord exhibit red weathering, other weathering colours such as shades of grey, brown, green and yellow may be equally prominent, especially upon close inspection. Nevertheless a characteristic feature of the Canyon Fiord, particularly when viewed from a distance, is the dusky red and moderate red weathering colours that dominate most outcrops and the soil that develops on the formation. Much of this red colour appears to originate from iron oxide stain that is derived from the breaking up of the intercalated, subordinate mudstone, siltstone and shale beds—the only particularly outstanding characteristic of these lithologic types. It is largely on the basis of these weathering colours that the Canyon Fiord is differentiated from the Belcher Channel Formation or the Antoinette Formation, either of which may overlie the Canyon Fiord, and both of which are characterized generally by shades of drab grey and yellow weathering colours.

The Canyon Fiord Formation, composed of alternating hard and soft beds, is not especially topographically prominent. The formation generally weathers to smoothly contoured ridges and hills, and presents a characteristically banded appearance on aerial photographs (*see* Pls. XIV, XIX, and XXVII). This contrasts markedly with the underlying lower Paleozoic terrains, but not with the Belcher Channel or Antoinette Formations.

The regular bedded aspect of the Canyon Fiord throughout its areal extent, the scarcity of crossbedding and ripple-marks, and the local presence of carbonate rocks indicate that the formation was deposited in relatively quiet, marine water of moderate depth and stable tectonic conditions. Moreover, the increasing prominence of clastic sediments to the southeast indicates that much of the detritus came from that direction, probably from uplands developed on exposed parts of the Franklinian Miogeosyncline. In this region the Okse Bay Formation (McLaren, 1963) and Vendom Fiord Formation (Kerr, 1967), which are largely composed of red quartzose sandstone of Devonian age, provide a probable source of much of the Canyon Fiord.

An unusual section of the Canyon Fiord merits special note. Basal beds of the formation that overlie the Cornwallis Group (Ordovician) at locality 137, west of Trold Fiord (*see* Pl. V; and *Eureka Sound South*) include: (1) basal limestone and chert-pebble conglomerate, 20 feet thick; (2) covered interval apparently concealing redbeds 15 feet thick; and (3) anhydrite, 200 feet thick. No fossils were obtained from these units. The anhydrite is overlain by several hundred feet of beds that are typical of the Canyon Fiord. Fusulinaceans of Moscovian age were collected in strata immediately overlying the anhydrite. The anhydrite forms a belt of outcrops that extend about a mile along strike, but covered intervals occupy either end of this belt so that the stratigraphic relationships of the anhydrite to alternating limestone and sandstone that normally occupy the position of the anhydrite could not be determined. The anhydrite, if assigned correctly to the Canyon Fiord, represents a unique occurrence of evaporitic rocks in this formation; but it is possible that the anhydrite represents a thin outlier of the Otto Fiord Formation.

Age

The Canyon Fiord Formation exhibits its longest span of geological time in the environs of Cañon Fiord, where the formation ranges from early Bashkirian to about Sakmarian.

Evidence for this conclusion is derived entirely from Foraminiferida, particularly Fusulinacea. Mamet has identified four faunas consisting largely of Endothyracea, from lower strata in the Canyon Fiord. Collectively these faunas indicate a range in age of early Bashkirian to Moscovian. Mamet's report is given in Appendix. Fusulinaceans that indicate correlation with the Moscovian Stage constitute some of the most abundant and widespread fossils in the formation, and include such characteristic genera as *Profusulinella*, *Paraeofusulina*, and *Fusulina*. The association in section 75 on Figure 9 of *Fusulinella* sp., and *Quasifusulina* cf. *Q. eleganta* Shlykova, with *Triticites* sp., suggests a Zhigulevian age. Species of *Eoparafusulina* appear to characterize a persistently developed faunal zone in the Canyon Fiord, and correlative strata of the Belcher Channel and Tanquary Formations. This genus, according to Ross (1967), ranges from early to middle Wolfcampian and is widely distributed in western North America. Reference of *Eoparafusulina* to the Sakmarian is provisional, and is based on the presumed relationship of the American Wolfcampian Stage to the Russian Permian. The possibility that species of *Eoparafusulina* in the Canadian Arctic Archipelago are of Asselian age can not be ruled out. However, members of the genus are restricted to middle and upper parts of Permian sections in the Archipelago. For this reason they are judged to correlate with the Sakmarian, rather than Asselian Stage.

Belcher Channel Formation

Definition

The formation was originally defined by Harker and Thorsteinsson (1960; *see also* Thorsteinsson, 1963) for Permian rocks lying with angular unconformity on the Cornwallis Formation (Ordovician) and overlain disconformably by the Assistance Formation on the north coast of Grinnell Peninsula, Devon Island. The type section is along the lower reaches of Lyall River where Harker and Thorsteinsson (op. cit.) recognized three main units in the Belcher Channel Formation. These units are described briefly in ascending stratigraphic order as follows: Unit 1, pebble-conglomerate, 20 to 200 feet thick; Unit 2, green and red quartzose sandstone, about 140 feet thick; and Unit 3, mainly limestone, 490 feet thick. The possibility that Units 1 and 2 might represent the Canyon Fiord Formation was recognized by Harker and Thorsteinsson. This was confirmed later by Nassichuk (1965, p. 9), who also demonstrated that the surface of separation between the two formations is a disconformity.

As described by Harker and Thorsteinsson (op. cit.), the Belcher Channel (their Unit 3) consisted of " . . . limestone, which is mainly light grey, fine to coarse grained and thin to medium bedded. . . . The upper 330 feet is a highly fossiliferous, coarse-grained, bioclastic limestone which is variably quartzose with grey, green and dusky red shale, occurring as bedding plane partings. Many of the upper beds are veritable biostromes of colonial corals situated in the position of growth. Specks of limonite are common in beds throughout the entire unit and are especially characteristic of the bioclastic beds. These specks occur as pore fillings and as an intimate part of the matrix. The lower 160 feet of the unit consists of yellowish grey to light grey, fine-grained limestone and quartzose limestone, with minor beds of light grey, fine-grained quartzose sandstone. Bioclastic limestone is a minor constituent in these lower beds."

Distribution

The Belcher Channel is widely distributed along the southern and southeastern margins of the Sverdrup Basin. It occurs on Sabine Peninsula, Melville Island, where it is 75 feet thick and lies disconformably on the Canyon Fiord Formation (Tozer and Thorsteinsson, 1963,

p. 101). A thin selvage of the formation that overlies the Griper Bay Formation (Devonian) with angular unconformity has been identified on Helena Island, a small island lying off the north coast of Bathurst Island (Kerr and Christie, 1965, p. 924). Reference has been made already to the occurrence of the type section of Belcher Channel rocks on Devon Island. The Belcher Channel outcrops extensively in western Ellesmere Island where it occupies a narrow, southwest- to northeast-trending belt extending from Bjorne Peninsula to Tanquary Fiord (i.e., within the marginal clastic and carbonate belt of Figure 3). Distribution of the formation is shown also on geological maps, *Baumann Fiord*, *Eureka Sound South*, *Cañon Fiord*, *Greely Fiord West*, *Greely Fiord East*, and *Tanquary Fiord*.

Thickness

Measured sections of the formation on Ellesmere Island are shown graphically in sections 50, 51, 52, 54, and 55 on Figure 7, sections 73 and 74 on Figure 9, and section 83 on Figure 10. The section on Figure 10, measured east of Tanquary Fiord, is 480 feet thick and represents the smallest known thickness of Belcher Channel strata in the report area. The greatest recorded thickness of the formation is 1,910 feet, which represents the cumulative thickness of two complementary sections on Hamilton Peninsula, separated by about 20 miles.

Lithology

The description of the Belcher Channel Formation in the type section on Devon Island serves moderately well for the entire extent of the formation on Ellesmere Island. Characteristically, the formation on Ellesmere Island consists of units of resistant limestone alternating with units of less resistant quartzose sandstone and siltstone, which present a banded appearance from the air and on aerial photographs (*see* Pls. XIX, XX, and XXVII). Limestone is the dominant lithology, particularly in the upper few tens or hundreds of feet of the formation, where it is generally coarse grained, in places biostromal, in part porous, and commonly thick bedded to massive. Limestone in the lower part of the formation is generally variably quartzose, fine to coarse grained, and occurs in beds that are ordinarily 6 to 8 inches thick. The limestone of the Belcher Channel is generally fossiliferous and most sections yield abundant solitary and colonial corals, and brachiopods. Locally, intercalated beds and lenticular layers of chert form minor, but conspicuous constituents of the limestone. The sandstone and siltstone occur in units as much as 400 feet thick. They are generally calcareous, rarely crossbedded, variably hard and soft, and commonly porous. Dominant fresh surface and weathering colours of both carbonate and clastic strata are various shades of grey (mainly light to medium grey) and yellow.

The sandstone is generally fine grained. East of Tanquary Fiord however, where the base of the Belcher Channel is locally an unconformity, the basal 75 feet or more of the formation is made up of green and red weathering, coarse-grained sandstone, in part conglomeratic, and chert-pebble conglomerate (*see* sec. 83, Fig. 10).

Age

The Belcher Channel on Ellesmere Island ranges in age from Late Carboniferous to Early Permian. Evidence for this conclusion is based entirely on the contained fusulinaceans. Lower beds in most sections have yielded various species of *Triticites* that suggest a Zhigulevian or Orenburgian age, but cannot be determined more accurately. Strata of Sakmarian age are recognized by the presence of *Eoparafusulina* sp. A. *Schwagerina hyperborea* (Salter) which occurs in the upper few tens of feet of the formation, is apparently an advanced member of that genus, and suggests an Artinskian age. However, the principal reason for regarding upper beds of the formation as Artinskian in age is the occurrence of *Parafusulina* sp., 150 feet stratigraphically below *S. hyperborea*, on Hamilton Peninsula (*see* sec. 73, Fig. 9). This *Parafusulina* is an advanced member of the genus, comparing with Leonardian rather than late Wolfcampian forms, and is, therefore, presumably of about early Artinskian age.

Stratigraphic Relationships

The upper contact of the Belcher Channel on Ellesmere Island as elsewhere in the archipelago is a disconformity, and the formation is variously overlain by the Sabine Bay Formation, Assistance Formation, or the Lower Triassic Bjorne Formation. It is probable, however, that this contact is nearly synchronous as judged by the common occurrence of *Schwagerina hyperborea* (Salter) in upper beds of the formation.

The Belcher Channel exhibits two kinds of basal contact relations on Ellesmere Island: (1) Throughout much of its areal extent, the formation lies gradationally on the Canyon Fiord Formation. The transition from one formation to the other is marked by a change in colour and composition, in which dominantly red weathering sandstone and lesser amounts of limestone in the Canyon Fiord, give way to dominantly grey and yellow weathering limestone and lesser amounts of sandstone and siltstone in the Belcher Channel. The contact of these formations is moderately well defined and generally only a few feet of beds are not readily assigned to either formation. (2) East of Tanquary Fiord, the Belcher Channel oversteps the Canyon Fiord and lies with angular unconformity on rocks of Ordovician and Silurian ages (*see* sec. 83, Fig. 10; and *Tanquary Fiord*).

It is noteworthy that there is no paleontological evidence to indicate rocks older than Permian in the Belcher Channel on Melville, Helena, and Bathurst Islands, where the base of the formation is also an unconformity. Thus, although exposures of the Belcher Channel on Ellesmere Island may be regarded, for all practical purposes, as comprising wholly contemporaneous beds, this is not so for the entire extent of the formation in the archipelago.

The stratigraphic relationship of Belcher Channel rocks to laterally equivalent formations is complex. In the environs of Blind Fiord (*Eureka Sound South*; and Fig. 8), and Tanquary Fiord (*Tanquary Fiord*), combinations of the Belcher Channel and underlying Canyon Fiord Formation give way in a northwesterly direction to the Nansen Formation. In these regions the change from Belcher Channel to Nansen, both of which consist mainly of carbonate and lesser amounts of clastic rocks, is arbitrarily drawn stratigraphically above the facies change between redbeds of the Canyon Fiord and light coloured carbonate and clastic rocks in the lower part of the Nansen. Two other kinds of lateral relationships of Belcher Channel rocks are evidenced on Hamilton Peninsula where the formation comprises a northeasterly trending belt of exposures (*Cañon Fiord*; and Fig. 2). (1) To the northwest the Belcher Channel gives way to a combination of three formations, in order upwards, Antoinette (mainly carbonate), Mount Bayley (anhydrite), and Tanquary (clastics and carbonate). The Antoinette and Tanquary Formations are lithologically similar to the Belcher Channel, and exist as discrete rock units only by virtue of the Mount Bayley anhydrite which is a facies equivalent of a middle part of the Belcher Channel. Hence, in this region also an arbitrary separation is made between Belcher Channel rocks, and Antoinette and Tanquary rocks. (2) To the southeast, the Belcher Channel passes gradationally into redbeds that form the upper part of the type section of the Canyon Fiord. Support for this conclusion is based on paleontological evidence only (*see* Fig. 9), as rocks representing the transition from one formation to the other have been removed by erosion.

Antoinette Formation

Definition and Correlation

The name Antoinette is here proposed for a formation consisting mainly of dark grey, impure limestone with varying proportions of siltstone, sandstone, shale, and anhydrite. The formation is named after Antoinette Bay, which forms the eastern extremity of Greely Fiord. The type section is in the north wall of Greely Fiord, about 23 miles west of the head of the bay (*see* Pl. XXI). The formation is invariably overlain by evaporitic rocks of the Mount Bayley Formation. In some places the contact between these formations appears relatively abrupt; in others it is markedly gradational. Throughout much of its areal extent, the Antoinette overlies the Canyon Fiord Formation, and ranges in age from Zhigulevian or Orenburgian (Late Carboniferous) to Asselian (Early Permian). In this circumstance the formation represents the chronological and lateral equivalent of the lower part of the Belcher Channel Formation. However, a single, incomplete section of the Antoinette, described later, includes strata as old as Moscovian. Strata, laterally equivalent to the Antoinette are discussed under the heading of the Mount Bayley Formation (*see* p. 46).

Distribution

Outcrops of the Antoinette are confined to territory in western Ellesmere Island around Cañon Fiord and Greely Fiord. There the formation is distributed, more or less coextensively, with the Mount Bayley and Tanquary Formations which overlie Antoinette strata in that order. All three formations occupy a narrow strip of territory in the western part of the marginal clastic and carbonate belt shown in Figure 3. Two relatively small areas of Antoinette exposures near Mount Bridgman on the south side of Cañon Fiord represent the southeasternmost extent of the formation (*Cañon Fiord*). The most extensive exposures of the formation form a belt that extends northeasterly across Hamilton Peninsula (*Greely Fiord West*). Several smaller areas of outcrop, including the type section, that occur in the environs of the junction of Tanquary and Greely Fiord (*Greely Fiord East*), and a single small area between the head of Esayoo Bay and Greely Fiord (*Greely Fiord West*) represent the northeastern limit of the formation.

Lithology, Thickness, and Age

Three sections of the Antoinette described below will serve to illustrate the lithology, thickness, and age of the formation.

1. The type section, about 1,550 feet thick, represents the only full thickness of the formation that was measured, and is illustrated graphically in section 81 on Figure 10. It is composed mainly of dark grey limestone, medium to generally fine grained, thin to generally medium bedded, in part porous, and variably argillaceous and silty. This section of the Antoinette exhibits unusually large amounts of gypsum and gypsiferous limestone, which occur in thin beds throughout the formation. Calcareous siltstone is the dominant rock type in the upper 400 feet of the section. It is commonly thin bedded, medium light grey, and variably argillaceous and gypsiferous. The dominant weathering colours of rocks in the

sections are various shades of grey and yellow. Although the basal 330 feet of the type section is not exposed, beds representing this interval were studied about 7 miles south of the type section (*see* sec. 82, Fig. 10) on the south side of Greely Fiord. These consist mainly of limestone that is medium light grey to greenish grey, fine grained, and medium to thick bedded, alternating with lesser amounts of light grey, thin-bedded siltstone, and silty limestone.

Species of the fusulinacean *Triticites* represent the only datable fossils taken from the type section of the Antoinette, and these cannot be dated more accurately than Zhigulevian or Orenburgian. Because the youngest beds in the Canyon Fiord Formation are of Moscovian age on the basis of such fusulinaceans as *Profusulinella* sp., *Eofusulina* sp., and *Fusulina* sp. (*see* sec. 82, Fig. 10), it seems safe to conclude that, like the Belcher Channel, no part of the type section of the Antoinette is older than Zhigulevian or Orenburgian.

2. An incomplete section of the Antoinette, 2,650 feet thick, measured in the southern part at Hamilton Peninsula is shown graphically in section 71 on Figure 9. There, as elsewhere, the formation is conformably overlain by the Mount Bayley Formation. Though the base of the section is marked by the East Cape thrust, the section represents, so far as is known, the greatest thickness of Antoinette strata. The dominant lithology is limestone that is generally dark grey, fine grained, thin to thick bedded, and variably argillaceous. The section also includes minor interbeds of biogenic limestone, cherty limestone, fine-grained, calcareous sandstone, and dark grey calcareous shale that, in places, contains bitumen. The section yields abundant fusulinaceans, which indicate three and possibly four stages. The fusulinacean genera and their indicated stages, arranged in order upwards are as follows: (a) *Wedekindellina*, *Pseudostaffella*, and *Fusulina*—Moscovian; (b) *Triticites*—Zhigulevian and/or Orenburgian; and (c) *Schwagerina*—?Asselian. Strata of Moscovian age are included in the Canyon Fiord Formation only a short distance to the northeast and southeast (*see* Fig. 3 and Fig. 9). Thus, although the base of the Antoinette appears to fall at the same stratigraphic horizon over most of the area, the inclusion in this section of Moscovian strata indicates that the formation becomes older in a northwesterly direction.

3. Another incomplete section of the formation was measured on the slopes of Mount Bridgman, south of Cañon Fiord (*see* sec. 56, Fig. 7; and Pl. XXV). This section is 710 feet thick, its base is also the East Cape thrust, and the lower about 200 feet is poorly exposed. The section is made up principally of dark coloured, thin- to thick-bedded calcareous siltstone and limestone that is variably argillaceous and silty, and minor units of dark grey, calcareous shale. These strata are particularly interesting for having yielded, among others, the fusulinacean *Paraschwagerina* sp., which indicates clearly an Early Permian (probably Asselian) age.

Mount Bayley Formation

Definition and Thickness

The Mount Bayley Formation is mainly anhydrite and its alteration product gypsum. The type section of the formation is along the north wall of Greely Fiord, about 3 miles east of the junction of Tanquary and Greely Fiords, and near Mount Bayley after which the formation is here named (*see* Pl. XXI). The Mount Bayley ranges in thickness from zero to more than 800 feet. It overlies the Antoinette Formation and underlies the Tanquary Formation (clastic and carbonate rocks).

Distribution and Facies Relationships of Antoinette, Mount Bayley, and Tanquary Formations

The Antoinette, Mount Bayley, and Tanquary Formations are included in the marginal clastic and carbonate belt of Figure 3, and are distributed coextensively over a rather limited area of western Ellesmere Island, extending from the south side of Cañon Fiord to territory around the junction of Tanquary and Greely Fiords (*Eureka Sound North*, *Cañon Fiord*, *Greely Fiord West*, *Greely Fiord East*). The Antoinette and Tanquary Formations exist by virtue of the evaporitic rocks of the Mount Bayley that effects a tripartite division in dominantly carbonate beds included elsewhere on Ellesmere Island in the Belcher Channel Formation.

To the northwest, the Mount Bayley grades laterally into limestone of the Nansen Formation (*see* Fig. 3). This facies relationship is evident in the mountainous, thrust faulted terrain on the west side of Tanquary Fiord and southwest of McKinley Bay, where units of anhydrite and anhydritic limestone, too thin and sporadic in distribution to constitute a mappable unit, have been observed in about the middle of the Nansen Formation. Similarly, remnants of the Mount Bayley can be recognized by thin units of anhydrite and anhydritic limestone that occur in about the middle of the Belcher Channel Formation, a few miles north of the type section of the Mount Bayley. In both places, the Mount Bayley seems to disappear through intertonguing and intergrading. Although strata correlative with the Mount Bayley in the Belcher Channel Formation cannot be demonstrated with certainty on Hamilton Peninsula, a soft interval consisting mainly of calcareous siltstone and sandstone which is persistently developed within the Belcher Channel in this region appears to constitute strata most likely correlative with evaporitic rocks of the Mount Bayley. This correlation is based mainly on the suggested ages of fusulinaceans below and above this interval (*see* secs. 73 and 74, Fig. 9). Thus, with the facies change of the Mount Bayley to limestone in a northwesterly direction, the Antoinette and Tanquary Formations merge laterally with the Nansen Formation. Similarly, with the disappearance of the Mount Bayley in northeasterly and southeasterly directions, the Antoinette and Tanquary Formations merge laterally with the Belcher Channel Formation.

Lithology

The general character of the Mount Bayley, aside from variations in thickness, does not change greatly in different parts of the region. The formation is composed mainly of anhydrite and as such resembles more closely in lithology the Otto Fiord Formation than any other within the report area. The principal difference between the two formations is that interbeds in the anhydrite of the Mount Bayley are mainly quartzose siltstone and quartzose sandstone, whereas interbeds in the Otto Fiord are chiefly limestone. Four sections described below serve to show the lithologic characters of the Mount Bayley in widely separated localities.

1. The type section of the formation in Greely Fiord is illustrated graphically in section 80 on Figure 10. It is 500 feet thick, and consists mainly of anhydrite that is thin to thick bedded with subordinate interbeds of medium grey, calcareous quartzose siltstone and silty limestone.

2. A section of the Mount Bayley measured north of the Tschernyschew River, near the geographic centre of Hamilton Peninsula, is 820 feet thick, and represents the thickest known section of the formation (*see* loc. 164, *Greely Fiord West*).

Unit No.	Lithologic Character	Thickness (feet)
	Overlying strata, Tanquary Formation	
5	Anhydrite, thin- to mainly thick-bedded	525
4	Anhydrite, sandstone and siltstone, interbedded; anhydrite, thin- to thick-bedded; fine-grained, sandstone and siltstone, mainly medium light grey and variably anhydritic	95
3	Limestone, shale and sandstone, interbedded; limestone, variably silty, medium dark grey and thin-bedded; shale, variably silty, medium dark grey; sandstone, medium light grey, thin-bedded, fine-grained, soft	65
2	Anhydrite, medium-bedded	15
1	Sandstone, subordinate anhydrite, interbedded; sandstone, light to medium grey, fine-grained, thin- to medium-bedded, soft, anhydritic in upper beds; anhydrite, thin- to medium-bedded	120
	Total thickness of Mount Bayley Formation	820
	Underlying strata, Antoinette Formation	

3. Another section of the Mount Bayley Formation measured on Hamilton Peninsula is illustrated graphically in section 71 on Figure 9, and shown on Plate XXIV. It is 250 feet thick and composed almost entirely of thin- to medium-bedded anhydrite.

4. A section of the formation near the foot of Mount Bridgman, south of Canon Fiord is 190 feet thick. It is illustrated graphically in section 56 on Figure 7, and shown on Plate XXV. This section consists mainly of medium-bedded anhydrite with minor intercalated beds of quartzose siltstone that is variably argillaceous and gypsiferous.

Age

Evidence of age of the Mount Bayley is not entirely satisfactory. The formation is unquestionably Early Permian, and it is judged to be approximately Asselian on the basis of the occurrence of the fusulinacean, *Paraschwagerina* sp., collected in the upper beds of the Antoinette Formation, and *Schwagerina krotowi* (Schellwien) found in the lower part of the Tanquary Formation (*see* sec. 56, Fig. 7).

Tanquary Formation

Definition and Distribution

The name Tanquary Formation is here proposed for a unit of carbonate and clastic strata that overlies evaporitic rocks of the Mount Bayley Formation. The formation is named after Tanquary Fiord in northwestern Ellesmere Island, and is typically developed along the north side of Greely Fiord, some 3 miles east of the junction of Tanquary and Greely Fiords (*see* Pl. XXI).

Outcrops of the Tanquary Formation form a rather narrow, northeasterly trending belt in western Ellesmere Island, extending from Vesle Fiord to the environs of Tanquary and Greely Fiords. The most extensive exposures of the Tanquary are on Elmerson and Hamilton Peninsulas. Distribution of the formation is shown in Figure 3 and on geological maps, *Eureka Sound North*, *Cañon Fiord*, *Greely Fiord West*, and *Greely Fiord East*.

Contact Relationships

Both the lower and upper contact of the Tanquary are sharp, yet conformable at any given locality. While there is no evidence that the contact of the Tanquary with the underlying Mount Bayley Formation marks a break in sedimentation, the top of the Tanquary is unquestionably an erosional surface, and in different regions different formations, such as the Sabine Bay, Assistance, and Trold Fiord Formations, and the Triassic Bjorne Formation overlie Tanquary rocks. It is therefore somewhat surprising that, although the upper surface of the Tanquary may in places represent the coincidence of as many as four disconformities, the formation probably has not been extensively eroded as judged from the common occurrence of *Schwagerina hyperborea* (Salter) in its uppermost beds. Moreover, the varying thicknesses (700 to 2,740 feet) of measured sections of the Tanquary may be regarded, for all practical purposes, to involve more or less contemporaneous beds. Laterally equivalent strata of the Tanquary have been dealt with under the heading of the Mount Bayley Formation.

Lithology, Thickness, and Age

The Tanquary Formation is composed principally of sandstone and limestone, and lesser amounts of siltstone. The sandstone is ordinarily calcareous, fine grained, variably hard and soft, and well bedded; crossbedding is rare. The proportion of clastic sediments varies considerably, generally increasing to the southwest and decreasing to the northeast and northwest. The limestone is commonly quartzose, aphanitic to coarse grained, and bioclastic. Dominant weathering and fresh surface colours of both carbonate and clastic rocks are various shades of grey and yellow. The formation is commonly distinguished on aerial photographs by its prominent ledges (*see* Pls. XXI, XXIV, XXV).

Four complete sections of the Tanquary Formation described below will serve to illustrate the regional variations in lithology.

1. The type section of the Tanquary is illustrated graphically in section 80 on Figure 10, and shown on Plate XXI. It is 700 feet thick, almost entirely exposed, and consists of nearly equal parts of limestone, and siltstone and sandstone. The limestone is represented by seven prominent units, varying from 15 to 90 feet thick, that alternate with units of less resistant calcareous siltstone and sandstone. The limestone is predominantly medium light grey to greyish pink, fine to coarse grained and biogenic, and medium to thick bedded and massive. Limestone that is variably silty and sandy occurs in the upper part of the section. Fossils abound in the limestone; certain beds are made up almost entirely of fusulinaceans, whereas others are composed mainly of large, solitary corals. The sandstone and siltstone are generally medium light grey, thin to medium bedded, generally soft and variably porous. The sandstone is generally fine grained.

2. A section of the Tanquary measured north of Tschernyschew River in the northern part of Hamilton Peninsula (*see* loc. 164, *Greely Fiord West*) is described below.

Unit No.	Lithologic Character	Thickness (feet)
	Overlying strata, Sabine Bay Formation	
10	Limestone, variably quartzose, white, coarse-grained, massive, rubbly-weathering, and weathering white and yellow	40

Unit No.	Lithologic Character	Thickness (feet)
9	Limestone, slightly quartzose, greyish red-purple to dark reddish brown, coarse-grained, medium- to generally thick-bedded; contains medium dark grey calcareous siltstone partings; *Schwagerina hyperborea* (Salter) occurs abundantly 40 feet below top	60
8	Limestone, quartzose, medium light grey, fine- to medium-grained, medium- to thick-bedded; grading into underlying and overlying units	70
7	Siltstone, sandstone and lesser amounts of limestone, interbedded; all rocks are medium grey to medium light grey, and medium- to thick-bedded; sandstone, calcareous, fine-grained; limestone, variably quartzose, and coarse- to generally fine-grained	100
6	Siltstone and sandstone, alternating; both rock types calcareous, medium grey to medium light grey, medium- to thick-bedded, variably hard and soft, sandstone, fine-grained; *Zoophycos* occurs throughout	180
5	Limestone, variably quartzose and bioclastic; medium light grey to greyish pink, generally fine-grained, but including medium- and coarse-grained beds; upper part thin-bedded, lower part medium- to thick-bedded; minor amounts of siltstone, calcareous sandstone, and lenticular chert interbedded throughout	100
4	Limestone, pale pink, coarse-grained, massive	20
3	Siltstone, dark grey, thin- to medium-bedded; minor interbeds of argillaceous limestone	125
2	Limestone, pale pink, coarse-grained, thick-bedded, weathers greyish orange and light brown	35
1	Limestone, medium light grey, ordinarily fine-grained, irregular medium beds, minor chert nodules and silicified corals; minor amounts of medium light grey calcareous sandstone, siltstone and shale partings	455
	Covered interval	100
	Total thickness of Tanquary Formation	1,285
	Underlying strata, Mount Bayley Formation	

3. A section, 2,170 feet thick, measured in southern Hamilton Peninsula is illustrated graphically in section 71 on Figure 9, and shown on Plate XXIV. There the dominant lithology is calcareous sandstone. The section is divisible lithologically into three units of local extent: a lower unit, about 750 feet thick, consisting mainly of limestone, variably quartzose and biogenic, medium light grey to dark grey, thin to medium bedded, with minor interbeds of sandstone; a middle unit, about 1,050 feet thick, made up of calcareous sandstone, mainly light grey, fine grained, variably hard and soft, in part porous, and weathering to light gold and reddish yellow; *Zoophycos* occurs throughout; an upper member about 370 feet thick, comprising limestone, light grey, fine grained to aphanitic and thin to thick bedded. The occurrence of *Schwagerina krotowi* (Schellwien) in basal beds of this section is of interest in indicating an Asselian age.

4. The greatest thickness of Tanquary strata measured in the report area is 2,740 feet and occurs on the east slope of Mount Bridgman on the south side of Cañon Fiord. This section is represented graphically in section 56 on Figure 7, and shown on Plate XXV. The section is characterized by several covered intervals, but exposures indicate that the prevailing lithology is variably hard and soft, porous calcareous sandstone with lesser amounts of

siltstone and resistant limestone ledges. The section is particularly noteworthy for providing the best evidence regarding the range in age of the Tanquary. A fauna of fusulinaceans from the lower beds of the section, identified as *Pseudoschwagerina* sp. and *Eoparafusulina* sp. A indicate correlation with the late Wolfcampian (=Sakmarian) of the United States, whereas *Schwagerina* cf. *S. hyperborea* (Salter) collected near the top of the formation suggests an early Artinskian age.

Lower Permian (Artinskian) Nonmarine Sequence

Sabine Bay Formation

Definition and Distribution

Sabine Bay Formation is the name given by Tozer and Thorsteinsson (1964, p. 101) to a succession of light coloured, nonmarine, quartzose sandstone of Early Permian age that disconformably overlies the Belcher Channel Formation on Sabine Peninsula, Melville Island. These authors described the sandstone as generally pale orange, medium grained, thin to thick bedded, commonly crossbedded, and as containing layers of coal as much as 2 inches thick. Thin beds of chert-pebble conglomerate form minor constituents. The principal weathering colour is pale reddish brown. The Sabine Bay on Sabine Peninsula was subsequently studied by Nassichuk (1965, p. 10; 1970), who determined the range in thickness of the formation to be 20 to 400 feet. Moreover, he was the first to demonstrate that the Assistance Formation was present on Melville Island and that it lay disconformably on the Sabine Bay.

A body of quartzose sandstone and subordinate conglomerate that outcrops in the environs of Cañon Fiord and Greely Fiord in western Ellesmere Island, is provisionally referred to the Sabine Bay Formation (*Cañon Fiord* and *Greely Fiord West*). As in the type section, the lower and upper boundaries of the Sabine Bay on Ellesmere Island are disconformities that are well marked both on the ground and readily apparent on aerial photographs. The formation rests on either Tanquary Formation or equivalent strata of the Belcher Channel Formation. It is overlain throughout most of its areal extent by the Assistance Formation, but on the north side of Greely Fiord where Assistance strata are missing, the Sabine Bay is succeeded by the Trold Fiord Formation (*see* sec. 79, Fig. 10). The Sabine Bay has no known equivalents in axial regions of the Sverdrup Basin. Occurrences of this formation on Melville Island and Ellesmere Island are tentatively considered to be remnants of a once continuous body of sediments that were laid down along the southern and southeastern margin of the basin.

Lithology

The formation consists mainly of quartzose sandstone, and lesser amounts of quartz and chert-pebble conglomerate. The sandstone is mainly fine to medium textured, less commonly coarse textured; thin to medium bedded in places, but commonly thick bedded to massive; generally noncalcareous, and limonitic specks characterize many beds; crossbedding, though not common, is locally conspicuous. Unweathered surfaces are mainly white to light grey; less common colours include soft shades of red, brown, and yellow. The dominant weathering colours are light grey, pale yellowish orange, and pale reddish brown. As on Melville Island, Sabine Bay strata are generally porous and, for the most part, poorly consolidated. Nevertheless the topographic expression of the formation is dominated by the harder, massive units of sandstone which tend to form low ledges and ridges. This property and the relatively light weathering characteristics of the formation are useful in differentiating Sabine Bay Formation on aerial photographs (*see* Pls. XXI, XXIV, and XXV). Carbonaceous remains were noted throughout several feet of the formation in section 71 (*see* Fig. 9) on Hamilton Peninsula. At this locality also, a bed of porous sandstone contains bituminous residues.

Thickness

The thickness of this formation ranges from zero to a maximum of 635 feet. Five sections measured in *Greely Fiord West* are:

Locality 71	Hamilton Peninsula	635 feet
Locality 73	Hamilton Peninsula	390 feet
Locality 164	Hamilton Peninsula	260 feet
Locality 165	Hamilton Peninsula	255 feet
Locality 79	north side, Greely Fiord	91 feet

Age

No fossils were observed in the Sabine Bay Formation on Ellesmere Island, and its correlation with typical rocks of the formation on Melville Island is based on physical stratigraphy only. The age of the formation is fairly accurately dated as early Artinskian on the basis of its stratigraphic position above the Belcher Channel Formation and below the Assistance Formation. Nassichuk (1970, p. 79) has collected, from basal beds of the Sabine Bay on Melville Island, specimens of a single genus of ammonoids that he identified as *Sverdrupites* sp. and dated as Artinskian. These fossils indicate that the Sabine Bay is, at least in part, marine.

Esayoo Formation

The name Esayoo is here applied to dark coloured, basaltic volcanic flows and agglomerate that locally overlie the Nansen Formation in northwestern Ellesmere Island and northern Axel Heiberg Island. The formation is named after Esayoo Bay, an arm of Borup Fiord in northern Ellesmere Island (*Greely Fiord West*); the type section is about 2 miles northeast of the head of the bay. Outcrops are limited to five, widely separated, localities. The thicknesses of the Esayoo and the names of the overlying formations at these localities are:

Locality	Thickness (feet)	Overlying Formation
Type locality *Greely Fiord West*	250	Trold Fiord
Locality 78 Krieger Mountains; *Greely Fiord West*	975	Degerböls
Locality 68 Head of Hare Fiord; *Otto Fiord*	240	Trold Fiord
Locality 65 North coast, Axel Heiberg Island; *Cape Stallworthy*	120	van Hauen
Locality 166 northeastern Axel Heiberg Island; *Bukken Fiord*	150	Degerböls

The rocks herein referred to the Esayoo Formation were discovered by Per Schei (1904, p. 461) on the north coast of Axel Heiberg Island, and reported on by Bugge (1910).

The age of the Esayoo is Artinskian, and very probably early Artinskian, as judged from its stratigraphic position above the Nansen Formation and below the van Hauen Formation. But whether the Esayoo is older or younger than the Sabine Bay Formation cannot be determined on available evidence. For convenience, the formation is shown as older than the Sabine Bay in Table 1.

Lower Permian (Artinskian) Marine Sequence

Assistance Formation

Definition and Distribution

The Assistance Formation was named and defined by Harker and Thorsteinsson (1960, p. 9; *see also* Thorsteinsson, 1963a, p. 255). It consists of a succession of predominantly unconsolidated clastic sediments that overlies the Belcher Channel Formation near the northern extremity of Grinnell Peninsula, Devon Island. The type section is composed mainly of alternating units of fine-grained sand, and subordinate silt and clay. These rocks are mainly medium bedded, and variably calcareous and glauconitic. The predominant fresh surface colour is medium grey; weathering colours include yellowish orange and medium greyish green. Dusky red ironstone and calcareous sandstone concretions that are rich in fossils occur in the upper part of the formation.

The type section is about 200 feet thick. Although no definitely recognized formation is known to overlie the Assistance on Grinnell Peninsula, there is a possibility that the uppermost 12 feet of beds in the type section represents basal beds of the Trold Fiord Formation. These upper beds consist of sandstone, which weathers to a distinctive green, and resemble closely the Trold Fiord Formation that commonly overlies the Assistance in other parts of the Canadian Arctic Archipelago.

Nassichuk (1965; 1970) has shown that the Assistance outcrops on Melville Island where it is unusually thin, thickness ranging from 50 to 100 feet. Along the west side of Ellesmere Island it forms a narrow belt that extends from Bjorne Peninsula northeastward to Hamilton Peninsula (*Baumann Fiord*, *Canon Fiord*, and *Greely Fiord East*). The distribution of the Assistance and that of the correlative van Hauen Formation are shown in Figure 4. The Assistance and van Hauen are considered to represent near-shore and basinal deposits, respectively.

Throughout its areal extent the lower and upper boundaries of the Assistance are represented by disconformities, and in different areas different formations underlie and overlie Assistance beds. However, on Bjorne Peninsula the actual contact of the Assistance and overlying Degerböls Formation has not been observed.

Lithology and Thickness

On Ellesmere Island the Assistance is composed mainly of soft, quartzose sandstone and lesser amounts of siltstone. The formation thins to a feather edge at various places, the greatest thickness observed being 1,330 feet on Bjorne Peninsula. Three sections described below illustrate the lithologic variability of the formation.

1. A section measured on the east side of East Cape River on Hamilton Peninsula is illustrated graphically as section 73 in Figure 9, and shown in Plate XX. The Assistance, in this area, overlies the Sabine Bay Formation and underlies the Trold Fiord Formation. It is 410 feet thick and consists mainly of grey sandstone that is soft and friable, thin to medium bedded, and variably calcareous and glauconitic. The dominant weathering colour of this section is yellowish brown. A bed of chert-pebble conglomerate about 3 feet thick occurs at the base of the formation. Interbedded with the sandstone are harder units of calcareous sandstone which are topographically prominent.

The lithology of Assistance rocks described above bears a closer resemblance to the type section of the formation on Grinnell Peninsula than does that of any other section assigned to the Assistance Formation on Ellesmere Island. Moreover, as discussed later,

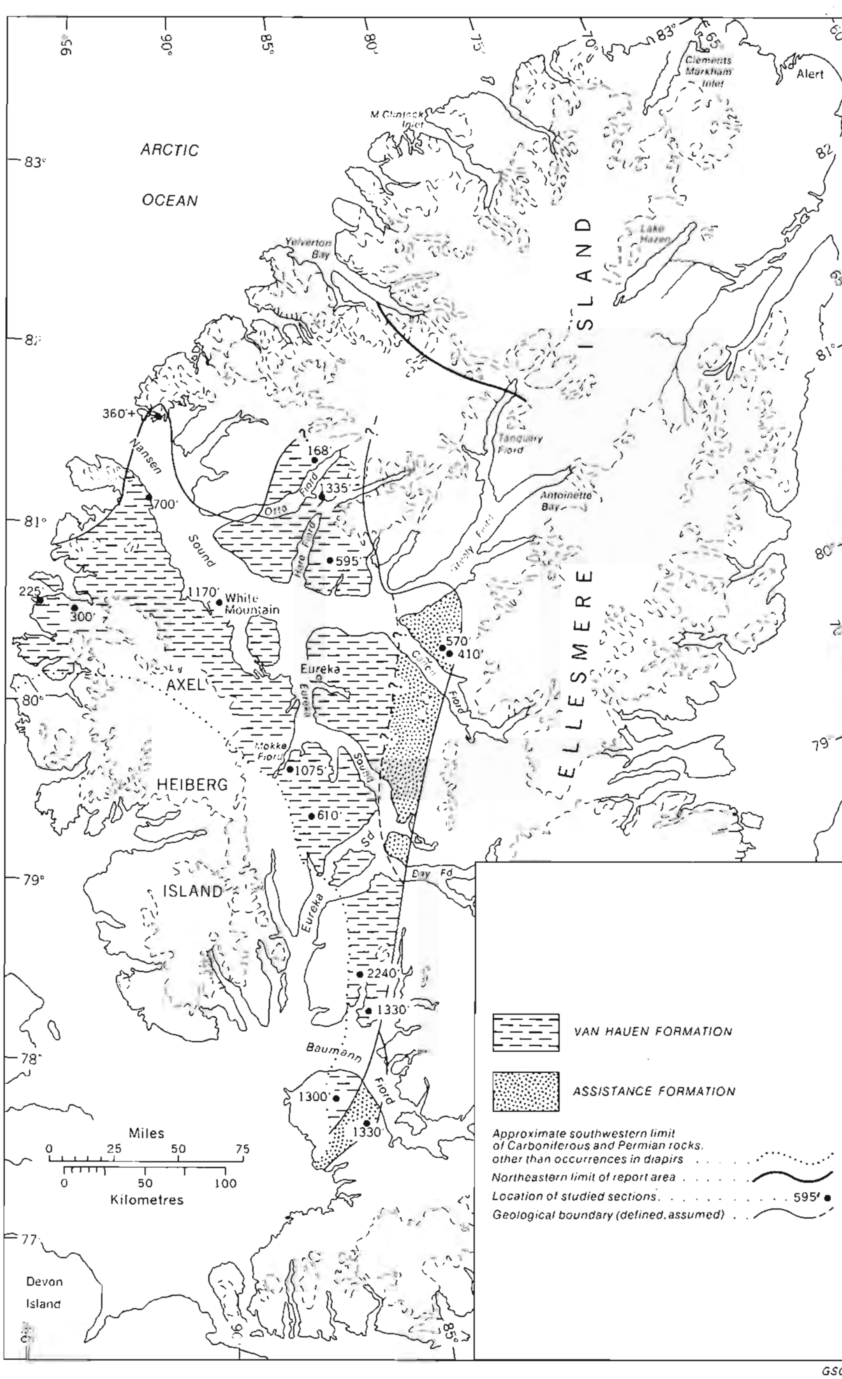

FIGURE 4. Distribution of Assistance Formation and correlative van Hauen Formation.

this is the only section of the Assistance on Ellesmere Island that has yielded a fauna that is correlative with the fauna in the type section.

2. Another section of the Assistance was measured on Hamilton Peninsula about 3 miles northwest of section 73 and across a major thrust fault. This section is illustrated graphically as section 71 on Figure 9 (*see also* Pl. XXIV). The section is 570 feet thick and is composed principally of quartzose sandstone that is generally fine grained, thin to medium bedded, and variably calcareous to noncalcareous. The predominant fresh surface colours are yellowish brown and greyish orange; the weathering colours are a distinctive dark yellowish orange and greyish yellow. Most of the sandstone is porous, irregularly bedded, and impregnated with limonite. Puzzling features in much of the sandstone are highly irregular, black filaments and tube-like structures, presumably composed of carbonaceous material, that cut indiscriminately across bedding planes.

Sparse fragments of brachiopods occur throughout the section. Generally the sandstones are poorly consolidated and weather to smooth, rounded slopes. Thin intercalated beds of harder, medium grey, calcareous sandstone and quartzose limestone, replete with fragmented brachiopods and bryozoans are minor constituents. The Assistance, in this section, underlies the Trold Fiord Formation and overlies the Sabine Bay Formation.

A noteworthy feature in virtually all outcrops of the Assistance, with the exception of those on Bjorne Peninsula, is the problematical fossil *Zoophycos*. These fossils occur sparingly in the Canyon Fiord and Sabine Bay Formations and are fairly common also in the Trold Fiord Formation, but they occur in prodigious numbers in the Assistance.

3. The Assistance Formation outcrops extensively in southeastern regions of Bjorne Peninsula, and grades northwestward into the van Hauen Formation. A moderately well exposed section of the Assistance measured on Bjorne Peninsula is illustrated graphically as section 52 on Figure 7 (*see also* Pl. XXVII). A broad, twofold lithologic division of the formation is differentiated in this section. The lower 400 feet or more consists largely of alternating hard and soft units of fine-grained sandstone and siltstone, which are light grey to medium grey, medium to generally thin bedded, and variably calcareous and argillaceous. Rocks of this interval are poorly exposed in this section, but are very well exposed some miles to the southwest at locality 114 on the north shore of Eids Fiord. The remaining 930 feet of the formation is composed mainly of resistant siltstone that is light grey to medium grey, thin to medium bedded, and variably argillaceous, calcareous and cherty; a small amount of bioclastic limestone is interbedded. On Bjorne Peninsula, the Assistance overlies the Belcher Channel Formation and underlies the Degerböls Formation.

Age and Correlation

Collectively, the faunas of the Assistance Formation from Grinnell Peninsula, Melville Island, and Ellesmere Island indicate an early to late Artinskian age. However, as is pointed out in the following discussion, the formation does not include strata of earliest Artinskian age.

In a systematic study of Permian ammonoids from the Canadian Arctic, Nassichuk, Furnish, and Glenister (1965) described and figured an ammonoid fauna that was collected 915 feet above the base of the Assistance in section 52 (*see* Fig. 7), on Bjorne Peninsula. The fauna included:

Locality 52; GSC Cat. No. 57719
Neoshumardites cf. *N. sakmarae* (Ruzhencev)
Paragastrioceras aff. *P. jossae* (de Verneuil)

Uraloceras burtiense (Voinova)
Uraloceras involutum (Voinova)
Metalegoceras crenatum n. sp.

Nassichuk *et al.* (op. cit., p. 9) stated that the fauna by itself would indicate either late Sakmarian age (i.e., Sterlitamakian substage) or early Artinskian age (i.e., Aktastinian substage), but because of the early Artinskian age indicated by the youngest fusulinaceans in the underlying Belcher Channel Formation these authors favoured an early Artinskian. Moreover, Nassichuk *et al.* regarded the fauna as appreciably older than the fauna described by Harker (*in* Harker and Thorsteinsson, 1960) from the type section of the Assistance.

Brachiopods associated with ammonoids discussed above have been submitted to J. B. Waterhouse whose list of identifications and remarks are as follows:

Locality 52; GSC Cat. No. 57719
orthotetacean
Echinoconchid, possibly *Bathymyonia* sp.
Kutorginella sp.
Linoproductus simensis (Tschernyschew)
Yakovlevia sp.
Septacamera mutabilis Tschernyschew
Camerisma sp. aff. *C. pentameroides* (Tschernyschew)
Orulgania sp. or *Pseudosyrinx* sp.
Spiriferella polaris (Wiman)
Martinia sp.

The fauna belongs to brachiopod fauna E in the northern Yukon, and probably to the *Jakutoproductus* zone, although the key genus is absent. This zone is considered to be Aktastinian in the Urals, and correlative with the Skinner Ranch Formation in the Glass Mountains on brachiopods and other faunal evidence. The fauna differs considerably from the type Assistance fauna.

The oldest fauna in the Assistance on Bjorne Peninsula is comprised of brachiopods collected about 100 feet stratigraphically above the base of the formation at locality 114 (*Baumann Fiord*) on the north side of Eids Fiord. The fauna is listed below:

Locality 114; GSC Cat. No. 57724
fragment of *Fimbriara* sp., or *Jakutoproductus* sp.
Anemonaria sp.
Linoproductus sp.
Stenoscisma sp.
Cleiothyridina sp.
Neospirifer sp. or *Septospirifer* sp.
Spiriferella sp.

Identifications are by J. B. Waterhouse who suggests that the fauna represents the *Jakutoproductus* zone and is, therefore, about the same age as the ammonoid and brachiopod faunas obtained at locality 52.

The fauna from locality 114 is of interest for three reasons: (1) Because the fauna occurs near the base of the Assistance it seems probable that no part of the Assistance on Bjorne Peninsula is older than early Artinskian (i.e., Aktastinian). (2) The suggested age of this fauna conflicts in no way with the writer's opinion that the fusulinaceans in the underlying Belcher Channel Formation range upward into the early Artinskian. (3) If the age limits of the Belcher Channel and Assistance Formations given above are correct, it follows that the length of time represented by the widespread disconformity at the contact between these two formations was not great.

An especially interesting feature of the type locality of the Assistance is the abundant and well-preserved fauna consisting mostly of brachiopods, but including a few ammonoids, nautiloids, pelecypods, scaphopods, and gastropods. This fauna, which occurs in the upper part of the formation, was described by Harker (*in* Harker and Thorsteinsson, 1960). Harker correlated the fauna with the Svalbardinian, a series erected by Stepanow (1957) as a marine equivalent of the Kungurian, and typified by the Spiriferenkalk of Spitsbergen. A correlation chart produced by Harker (op. cit., p. 14) shows the Assistance to be equivalent to the upper part of the Baigendzhinian Subseries of the Artinskian, and upper part of the Leonardian and lower Wordian. The age of the Assistance has been the subject of considerable discussion in recent years and, although Harker's opinion that the Assistance and Foldvik Creek Formation of East Greenland are of similar age has been generally rejected, his age assignment of the Assistance has been generally accepted. It should be noted that since the publication of Harker's (op. cit.) study, basal beds of the type Word Formation have been included in the Leonardian Series of the Lower Permian (Cooper and Grant, 1966).

Representatives of the fauna that occurs in the type section of the Assistance have been found on Ellesmere Island, in section 73, on Hamilton Peninsula. There, as in the type section, the fossils are concentrated in the upper part of the formation. Peter Harker collected the following fauna approximately 350 feet above the base of the formation. Determinations are by J. B. Waterhouse.

Locality 73; GSC Cat. No. 58968
Rhipidomella sp.
orthotetacean cf. *Arctitreta* sp.
Waagenoconcha sp. or *Aulosteges* sp.
Stenoscisma sp.
?*Cleiothyridina* sp.
Spiriferella sp.
Neospirifer sp. cf. *N. marcoui* (Waagen)
Phricodothyris sp.

In the same section of the Assistance, but 370 feet above the base of the formation, Harker collected the following fossils which are identified by J. B. Waterhouse:

Locality 73; GSC Cat. No. 58973
?*Waagenoconcha* sp.
Anemonaria sp.
Linoproductus sp.
Yakovlevia sp.
Horridonia sp.
Stenoscisma sp.
Spiriferella sp.
Neospirifer sp.
Phricodothyris sp.

The two faunas listed above are similar to the brachiopod fauna described by Harker (*in* Harker and Thorsteinsson, 1960) from the type section of the Assistance. Waterhouse dates these faunas as Ufimian [Ufimian is a Russian stage, inserted variously between the Artinskian and Kazanian, or between the Kungurian and Kazanian (Waterhouse 1969a, b)].

The ammonoids in the upper part of the Assistance, which seem to constitute one faunal assemblage, provide additional information on the upper age limit of the formation. Nassichuk *et al.* (1965) includes a study of two ammonoids, *Pseudogastrioceras fortieri* Harker, and *Spirolegoceras harkeri* Ruzhencev, that were obtained by Thorsteinsson from the type section of the Assistance. According to Nassichuk *et al.* (op. cit.), these ammonoids indicated correlation of the Assistance with the Road Canyon Formation of west Texas, equivalent formations in other parts of U.S.A., Soviet Union, and Australia, which these authors (following Cooper and Grant, 1966) assign to the uppermost Lower Permian. Moreover, Nassichuk *et al.* (op. cit.) regarded these formations as probably younger than the type Baigendzhinian. A further systematic study of a "late" Assistance ammonoid fauna has been given by Nassichuk (1970), on the basis of collections made largely by him from: (1) an interval 150 to 170 feet above the base of the type section; (2) exposures in the general vicinity of the type section of the Assistance on Grinnell Peninsula; and (3) the Assistance on Melville Island. The fauna includes the following:

Daubichites (= *Pseudogastrioceras*) *fortieri* (Harker)
Sverdrupites (= *Spirolegoceras*) *harkeri* (Ruzhencev)
Sverdrupites sp.
Popanoceras cf. *P. sobolewskyanum* (Verneuil)
Sverdrupites amundseni n. sp.
Snyartinskia belcheri n. sp.
Medlicottia aff. *M. orbignyana* (Verneuil)

Nassichuk's opinion on the correlation of this fauna differs from that previously expressed by Nassichuk *et al.* (op. cit.) only so far as it concerns correlation with the Russian standard of the Permian. According to Nassichuk, new forms in the fauna indicated affinities with ammonoid species from upper Artinskian strata (Baigendzhinian) of the Ural Mountains. Thus he regarded the ammonoids as both latest Early Permian and latest Artinskian (Baigendzhinian) age.

Although correlation of strata assigned to the Assistance Formation in the environs of Cañon Fiord with the type section of the formation on Grinnell Peninsula has been established beyond reasonable doubt, there is some uncertainty concerning the identity of the Assistance on Bjorne Peninsula. The bases of the problem posed here are as follows: (1) There is no paleontological evidence to indicate the presence of strata older than late Artinskian (Baigendzhinian) in the Assistance on Grinnell Peninsula, Melville Island, and in the environs of Cañon Fiord. Moreover, because the late Artinskian ammonoid fauna occurs throughout much of the thin development of the Assistance Formation on Melville Island (*see* Nassichuk, 1970), it appears improbable that these strata could include also the early Artinskian (Aktistanian) faunas represented on Bjorne Peninsula. (2) There is no paleontological evidence to indicate strata younger than early Artinskian in that assigned to the Assistance on Bjorne Peninsula. Nevertheless, in section 52 shown on Figure 7, about 450 feet of unfossiliferous strata overlies the youngest early Artinskian fossils, and it is possible that these upper beds are, at least in part, of late Artinskian age. (3) The van Hauen Formation has nowhere yielded diagnostic fossils. Strata assigned to the Assistance on Bjorne Peninsula are equated there with the van Hauen with reasonable certainty on the basis of lateral continuity. The Assistance on Grinnell Peninsula, Melville Island, and around Cañon Fiord has not been observed to grade basinward into the van Hauen. The opinion that these outcrops of the Assistance and the van Hauen are correlative is based partly on similar stratigraphic positions, and partly on the assumption that the Assistance in these areas can be correlated with strata classed as Assistance on Bjorne Peninsula.

The relationships just summarized suggest two alternative classifications of the various rock units: (1) The strata in question on Bjorne Peninsula are incorrectly assigned to the Assistance and comprise a new formation that is older than the Assistance Formation. Moreover, equivalents of the Assistance in deeper parts of the Sverdrup Basin, if present at all, are unknown. (2) The strata on Bjorne Peninsula are correctly assigned to the Assistance Formation and comprise a comparatively thick section deposited in deeper parts of the Sverdrup Basin where it ranges from early to late Artinskian. The formation thins rapidly in southerly and southeasterly directions, mainly by overstep of lower beds onto pre-Assistance rocks, with the result that sections on Melville Island, Grinnell Peninsula, and in the environs of Cañon Fiord preserve strata of late Artinskian age only. Exposures of the Assistance on Bjorne Peninsula are farther basinward than the three above-mentioned areas which accounts for the strata of early Artinskian and probably also Baigendzhinian ages.

No clear choice of the two alternatives set forth above can be made without further stratigraphic and paleontological work. Nevertheless, in the writer's opinion the second provides the simplest explanation of available facts, and represents the working hypothesis adopted in this report.

Van Hauen Formation

Definition, Distribution, and Thickness

The name van Hauen Formation is here given to a sequence of rocks represented principally by dark coloured shale, and well-bedded siltstone and chert that are bounded below and above by regional disconformities. Throughout much of its areal extent the van Hauen lies either on the Nansen Formation or on equivalent beds of the Hare Fiord Formation. It is generally overlain by either the Degerböls Formation or the assumed facies equivalent of the Degerböls, the Trold Fiord Formation. Locally, other formations come to underlie and overlie van Hauen strata. The formation is named after the van Hauen Pass, a low valley that forms a short overland route between Hare and Otto Fiords in northwestern Ellesmere Island. The type section is about a mile northeast of this pass (*see* Pl. IV).

Contact relations and thicknesses of 12 measured sections of the van Hauen Formation are summarized in Table 2. These sections are illustrated graphically in Figures 7, 8, and 9. The areal distribution of the van Hauen, and the location of measured sections of the formation are shown in Figure 4 (*Baumann Fiord*, *Eureka Sound South*, *Eureka Sound North*, *Greely Fiord West*, *Otto Fiord*, and *Bukken Fiord*).

Van Hauen strata were described for the first time by E. T. Tozer in his field studies on Bjorne Peninsula and around the head of Blind Fiord in southwestern Ellesmere Island (Tozer, 1963a, b). Tozer applied the informal term 'dark beds' to these rocks.

The thickness of the van Hauen is highly variable, and ranges from a trace to 2,260 feet. It generally attains its greatest thickness in the eastern part of its area of distribution. There also, van Hauen strata are commonly divisible into distinctive lower and upper members. In general the formation thins in a northwesterly direction, and progressively thinner sections show a proportionately smaller thickness of the upper member. In several localities, including those indicated by measured sections in the extreme western and northern regions of the area of study, the upper member is absent (*see* Fig. 8). That the van Hauen originally exhibited regional differences in total thickness of sediments can be demonstrated by markedly different thicknesses of the lower member in sections measured on Bjorne Peninsula and west of Blind Fiord in southwestern Ellesmere Island (these two sections are described later). Nevertheless, no clear understanding of such variations is now possible because at least one, and in some

TABLE 2 — *Locations of measured sections of van Hauen Formation showing underlying and overlying rock units, and thicknesses of the formation.*

Description of Localities	Underlying Formation	Overlying Formation	Thickness in Feet
Bjorne Peninsula, Ellesmere Island; locality 53; *MAP 1312A BAUMANN FIORD*	*BELCHER CHANNEL*	*BJORNE*	1300
Between Trold Fiord and Blind Fiord, Ellesmere Island; locality 62; *MAP 1300A EUREKA SOUND SOUTH*	*NANSEN*	*TROLD FIORD*	1330
West side of Blind Fiord, Ellesmere Island; locality 61; *MAP 1300A EUREKA SOUND SOUTH*	*NANSEN*	*TROLD FIORD*	2240
North of Whitsunday Bay, Axel Heiberg Island; locality 60; *MAP 1302A EUREKA SOUND NORTH*	*HARE FIORD*	*BLIND FIORD*	610
South of Mokka Fiord, Axel Heiberg Island; locality 59; *MAP 1302A EUREKA SOUND NORTH*	*HARE FIORD*	*BLIND FIORD*	1075
White Mountain, Axel Heiberg Island; locality 168; *MAP 1310A BUKKEN FIORD*	*HARE FIORD*	*BLIND FIORD*	1170
South of Bunde Fiord, Axel Heiberg Island; locality 57; *MAP 1310A BUKKEN FIORD*	*NANSEN*	*DEGERBÖLS*	225
South of head of Bunde Fiord, Axel Heiberg Island; locality 58; *MAP 1310A BUKKEN FIORD*	*NANSEN*	*DEGERBÖLS*	300
North coast of Axel Heiberg Island; locality 65; *MAP 1305A CAPE STALLWORTHY*	*ESAYOO*	*BLIND FIORD*	700
About 13 miles north of Blaa Mountain, Ellesmere Island; locality 70B; *MAP 1311A GREELY FIORD WEST*	*HARE FIORD*	*BLIND FIORD*	595
Type section of formation, northeast of van Hauen Pass, Ellesmere Island; locality 69; *MAP 1309A OTTO FIORD*	*HARE FIORD*	*DEGERBÖLS*	1335
North side of Otto Fiord, Ellesmere Island; locality 67; *MAP 1309A OTTO FIORD*	*NANSEN*	*DEGERBÖLS*	168

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places two periods of erosion have affected the van Hauen. Where van Hauen strata are overlain by the Trold Fiord Formation or correlative rocks of the Degerböls Formation one period of erosion is indicated by the disconformity that separates these formations. Where van Hauen rocks are succeeded by the Lower Triassic Bjorne Formation or correlative rocks of the Blind Fiord Formation it is reasonable to assume that sub-Triassic erosion has removed the Trold Fiord (or Degerböls) Formation and then subjected the van Hauen to a second period of erosion.

Lithology

In thicker, and therefore presumably more complete, sections of the van Hauen, two members are differentiated and are here informally designated, in ascending order, as members A and B. The contact between these members is fairly sharp and generally only a few feet of beds are not readily assigned to either member. Member A is recessive and commonly occupies topographic lows, in marked contrast to the resistant and ridge-forming member B (*see* Pls. IV and XI).

Member A, where typically developed, consists largely of interbedded shale and siltstone with lesser amounts of chert and sandstone, and rare bioclastic limestone. In some sections shale predominates, whereas in others siltstone is the most abundant rock type. The shale is dark grey to black, and commonly fissile and sooty. Small rounded ironstone concretions characterize some outcrops. In fresh exposures the shale commonly lacks bedding and may be described best as mudstone. The siltstone is dark grey to black, variably shaly, commonly siliceous, and very resistant; beds range from thin to thick. The member is mainly noncalcareous, poor in fossils, and not markedly bituminous. The sparse fossils consist mainly of fragmentary brachiopods and bryozoans.

Member B is a remarkably uniform succession of chert and subordinate siltstone that in places appear to intergrade; it is commonly a difficult matter to distinguish these lithic types in the field. Both the chert and siltstone are generally dark grey to black, exceedingly resistant, sharp and brittle. They are thin to thick bedded, but commonly medium bedded. Medium bluish grey chert is common in some places. Shale and shaly siltstone may occur as bedding plane partings. Thin sections have revealed that some of the chert is composed of spicules, presumably those of sponges. The siltstone is variably siliceous. Although the principal weathering colours are dark grey to black, some exposures weather to various shades of red, brown, and yellow.

The foregoing lithologic characterization typifies the van Hauen as represented throughout the greater part of its areal extent. However, strata assigned to this formation in western and northern regions of Axel Heiberg Island, and north of Otto Fiord in northwestern Ellesmere Island appear to represent somewhat atypical developments of the formation, especially in having proportionally greater carbonate content. The van Hauen Formation in western and northern regions is therefore thought to comprise facies variations different from those exposed in eastern and southeastern regions.

Probably the most characteristic features of the van Hauen as a whole are its prevailing, nearly black, fresh surface and weathering colours, and the sharp, brittle talus derived from these unusual rocks that produces a crunching sound underfoot.

The type section of the van Hauen (described below) is shown on Plate IV, and is represented as section 69 on Figure 9.

Unit No.	Lithologic Character	Thickness (feet)
	Overlying strata, Degerböls Formation	
	Member B	
4	Chert and subordinate siltstone, interbedded; both lithic types are dark grey to black, thin- to medium-bedded, very hard and brittle, regularly bedded; many bedding plains exhibit pock-marked surfaces; many chert beds are characterized by medium bluish grey colour; subordinate interleaves of dark grey shaly siltstone	595
	Member A	
3	Siltstone, quartzose, siliceous, noncalcareous, medium grey, thick-bedded, very hard	60
2	Sandstone, quartzose, noncalcareous, medium grey, fine- to medium-textured, thick-bedded, hard	50
1	Shale and siltstone, interbedded, noncalcareous; shale, dark grey to black, fissile, soft, constitutes about $\frac{2}{3}$ of the thickness of unit; siltstone, quartzose, dark grey to black	630
	Total thickness of van Hauen Formation	1,335
	Underlying strata, Hare Fiord Formation	

The van Hauen, and also the upper part of the Hare Fiord Formation, have not yielded diagnostic fossils. The two formations are separated on lithological differences.

The contact of the type section of the van Hauen and the underlying Hare Fiord Formation is not especially well marked where it is known to occur within rocks that are dark coloured and lithologically similar in certain other respects. Nevertheless, the contact does separate soft, predominantly noncalcareous strata from underlying, partly calcareous rocks, even though the placement of a few feet of beds at the contact remains in doubt. That this contact is more or less correct is indicated by the lithologic similarities of the type section of the van Hauen to strata assigned to this formation in nearby localities where the underlying rocks are those of the Nansen or Belcher Channel Formation, the lithology of which contrasts sharply with that of the van Hauen.

The most southerly exposures of the van Hauen occur in north-central regions of Bjorne Peninsula, southwestern Ellesmere Island, where excellent exposures occur on the west flank of the Schei Point anticline. The van Hauen on Bjorne Peninsula is especially interesting for three reasons: (1) van Hauen strata grade into light coloured sandstone and siltstone of the Assistance Formation a few miles to the south and southeast of the Schei Point anticline. This provides the principal basis for correlating these two formations and dating van Hauen strata as Artinskian. (2) Exposures of the van Hauen on Bjorne Peninsula are some 250 miles south of the type section of the formation, which occurs near the northern limit of these rocks within the area of study. Nevertheless, the thicknesses and lithologies of van Hauen strata in these two regions are more closely comparable to one another than to developments of this formation in other localities. The significance of this is uncertain. (3) All other late Paleozoic and Mesozoic formations on Bjorne Peninsula, with the exception of the van Hauen, are represented by near-shore deposits. The occurrence in this region of the van Hauen Formation which is interpreted as a basinal deposit, suggests that the shoreline of the Sverdrup Basin was probably situated farther to the southeast of Bjorne Peninsula during van Hauen time than at any other time in the sedimentary history of the basin.

A section of the van Hauen measured on the west side of the Schei Point anticline (illustrated as sec. 53, Figure 7) is described below.

Unit No.	Lithologic Character	Thickness (feet)
	Overlying strata, Bjorne Formation, Lower Triassic	
	Member B	
3	Chert and subordinate siltstone, interbedded; chert, dark grey to black, and bluish grey, thin- to mainly medium-bedded, and variably silty; siltstone, dark grey to black, thin- to mainly medium-bedded; both of the above lithic types are very hard and brittle but commonly separated by soft, bedding plane partings of dark grey shaly siltstone. A 3-foot bed of bioclastic limestone occurs 30 feet from top of unit	480
	Member A	
2	Shale, dark grey to black, partly silty, with ironstone bands and subrounded concretions; recessive	640
1	Siltstone and subordinate shale, interbedded; siltstone, medium dark grey, thin-bedded and very shaly; shale dark grey and variably silty; relatively resistant unit	180
	Total thickness of van Hauen Formation	1,300
	Underlying strata, Belcher Channel Formation	

Excellent exposures of the van Hauen occur on the west side of Blind Fiord in south-western Ellesmere Island. There the formation overlies the Nansen Formation, and is overlain for the most part by the Lower Triassic Blind Fiord Formation, or by a thin selvage of the Trold Fiord Formation. Both lower and upper contacts are remarkably sharp as seen on aerial photographs (*see* Pl. XI) and on the ground. Van Hauen exposures west of Blind Fiord occur more or less along a north-south line that includes the type section of the formation to the north, and outcrops of the formation on Bjorne Peninsula to the south. The Blind Fiord exposures represent the greatest known thickness of the formation, and are of further interest because of their lithologic characters which are similar to those of rocks of this formation in the type section and on Bjorne Peninsula.

The van Hauen was studied 4.5 miles southwest of the head of Blind Fiord (illustrated as sec. 61, Fig. 8). The section is described below.

Unit No.	Lithologic Character	Thickness (feet)
	Overlying strata, Trold Fiord Formation, Upper Permian	
	Member B	
3	Chert, dark grey to black, and medium bluish grey, thin- to mainly medium-bedded, very hard and brittle, ridge-forming; thin units of dark grey, bioclastic limestone are interbedded in upper part of member	800
	Member A	
2	Shale and subordinate siltstone, interbedded, noncalcareous; shale, variably silty, dark grey to black, fissile; siltstone, quartzose, variably shaly, dark grey to black, mainly thin-bedded, relatively recessive unit	720
1	Siltstone and subordinate shale, interbedded, lithologic character as above; relatively resistant unit	740
	Total thickness of van Hauen Formation	2,260
	Underlying strata, Nansen Formation	

A sequence of strata classified as Member A of the van Hauen is intercalated between the Hare Fiord Formation and Lower Triassic Blind Fiord Formation in two sections of Carboniferous and Permian rocks studied in eastern Axel Heiberg Island. One section south of the head of Mokka Fiord includes a thickness of 1,075 feet of van Hauen strata (sec. 59, Fig. 8); the other section north of Whitsunday Bay includes 710 feet (sec. 60, Fig. 8). The contact between Hare Fiord and van Hauen strata at these localities has been placed, by much the same criteria employed for this purpose in the type section of the van Hauen Formation, between a lower sequence composed of siltstone that is mainly thick bedded, resistant and variably calcareous, and an upper sequence made up of alternating units of soft, noncalcareous, shale and thin-bedded siltstone. The absence in these sections of the distinctive chert beds of Member B increases the uncertainty of identifying Member A, especially as soft units of shale and siltstone may occur within sequences of the Hare Fiord Formation (e.g., sec. 69, Fig. 9). Consequently, the assignment of strata to the van Hauen Formation in these sections must be regarded as questionable.

The Lower Triassic Blind Fiord Formation, which overlies van Hauen strata at these localities, consists of siltstone and shale. Thus the Permian–Triassic boundary lies within rocks of rather similar lithologies. Although the van Hauen–Blind Fiord contact is not readily apparent on aerial photographs it is easily recognized on the ground by subtle lithologic differences, such as the less resistant nature and lighter weathering colours of the Blind Fiord Formation.

Western Axel Heiberg Island. Two sections of strata assigned to the van Hauen that occur south of Bunde Fiord in western regions of Axel Heiberg Island are illustrated graphically as sections 57 and 58 in Figure 8. The most westerly about a mile southwest of Arthaber Creek, consists of a uniform sequence of dark grey, thin-bedded calcareous siltstone that is very brittle and 225 feet thick. The other, about 4 miles south of the mouth of Camp Five Creek, comprises an alternating succession of argillaceous limestone and limestone that is very dark grey, finely textured, thin bedded, and 300 feet thick. The two sections are about 16 miles apart and occur in separate thrust sheets. Both are intercalated between the underlying Nansen Formation and overlying Degerböls Formation. The relationship of these sections to typical developments of the van Hauen in areas to the east is not entirely certain, but they are provisionally regarded as a calcareous facies of Member A.

Svartevaeg Cliffs, northern Axel Heiberg Island. About 700 feet of strata tentatively referred to the van Hauen outcrops near the southeastern limit of the spectacular sea cliffs known as Svartevaeg Cliffs, along the north coast of Axel Heiberg Island (sec. 65, Fig. 9). In this region the van Hauen Formation overlies the volcanic Esayoo Formation, underlies the Lower Triassic Blind Fiord Formation, and is made up of three principal assemblages. (1) The basal 80 feet or so consists largely of dark grey shale. (2) The succeeding, approximately 560 feet of strata is poorly exposed, but comprises an alternating succession of quartzose siltstone and sandstone that is mainly medium light grey, thin to medium bedded, and variably calcareous and glauconitic; limestone that is medium grey, fine grained, thin to medium bedded and variably silty; and thin beds of dark grey chert. (3) The upper unit, about 60 feet thick, consists mainly of light to dark grey, thin-bedded chert, with subordinate interbeds of calcareous quartzose siltstone.

Attempts to relate the above described strata to typical rocks of the van Hauen Formation are beset with difficulties, especially because of the lack of faunal evidence and the isolated nature of the exposures at Svartevaeg Cliffs. Some 40 miles separates the van Hauen at Svartevaeg Cliffs from the nearest other known exposures of the formation. Nevertheless, it is suggested that the upper 60 feet of chert and subordinate siltstone is correlative with Member B, whereas the remaining lower 640 feet of strata comprises a facies variant of Member A.

North of Otto Fiord, northwestern Ellesmere Island. Some 10 miles west of the head of Otto Fiord a thin succession of van Hauen strata is intercalated between the Nansen Formation and the Degerböls Formation (sec. 67, Fig. 9). In this region van Hauen strata are divisible into three lithologic units: (1) The lower 65 feet of beds consists of bioclastic limestone that is medium dark grey, thin to medium bedded and variably silty, and associated thin interleaves of dark grey siltstone. Fossils occur throughout and include fragmentary brachiopods, bryozoans, and crinoid debris. (2) The middle unit is 60 feet thick and is made up of dark grey, thin-bedded shaly quartzose siltstone and intercalated beds of dark grey, thin-bedded silty limestone. (3) The upper part of the formation consists of dark grey, thin-bedded chert and siltstone beds, that total 30 feet thick. The relationship of the above-described rocks to typical developments of the formation is uncertain, but it is suggested that the lower two units are correlative with Member A, whereas the upper member is correlative with Member B.

Age and Correlation

The van Hauen has yielded a few small collections of poorly preserved brachiopods and bryozoans. These have not been studied critically. The formation is nevertheless dated as about early to late Artinskian on the basis of its presumed correlation with the Assistance Formation.

There is a good possibility that the van Hauen Formation is correlative with the Fantasque Formation on the Canadian mainland because of similar lithologic characteristics and stratigraphic positions. The Fantasque Formation was described originally by Harker (1963, p. 23) for Permian rocks consisting largely of chert in southwestern District of Mackenzie. This formation is also now known to be distributed widely in the Yukon Territory and northern British Columbia (Bamber, Taylor, Procter, 1968). Moreover, the name Fantasque has been applied to rocks as far south as the Crowsnest Pass in southern Alberta and British Columbia (Norris, 1965, p. 13). Description of the Fantasque Formation in northeastern British Columbia by Bamber, Taylor, and Procter (1967, p. 71) illustrates the remarkable lithologic similarity between this formation and the van Hauen Formation: "The thickness of the formation decreases from 150 feet in the north to approximately 40 feet in the south, near Halfway River. In southern La Biche Range, and in the eastern and central foothills between Toad and Halfway Rivers, the Fantasque Formation is composed of irregularly bedded, medium to dark grey chert, which is pyritic in part and contains abundant sponge spicules. North of Tuchodi River the chert beds in the lower 10–15 feet of the unit are separated by laminae and thin beds of dark grey shale, as in the lower 22 feet of the type section. At the western edge of the foothills, near South Tetsa River, there are laminae and beds of shale throughout the formation, and the chert is interbedded with siliceous mudstone and siltstone." The Fantasque Formation, where preserved, represents the youngest Permian deposits. It is bounded above by a regional disconformity and underlies Lower Triassic rocks; it overlies strata that cannot be more precisely dated than Permian. In some places at least, the lower contact is a disconformity. The Fantasque Formation contains few fossils, but it has yielded *Helicoprion* sp., and poorly preserved brachiopods. In the vicinity of Blind Fiord the van Hauen Formation has also yielded *Helicoprion* sp. (Nassichuk and Spinosa, 1970).

Upper Permian (Guadalupian) Marine Sequence

Trold Fiord Formation

Definition and Distribution

The name Trold Fiord is here proposed for a formation that consists chiefly of sandstone, and subordinate biogenic limestone, pebble-conglomerate, and chert. The type locality is on a small, unnamed tributary of East Cape River that issues into the northeast side of Cañon Fiord on the west coast of Ellesmere Island (*see* Pl. XXIV). There, the formation overlies the Assistance Formation and is overlain by the Lower Triassic Bjorne Formation. The Trold Fiord Formation is named after a prominent fiord on the west coast of Ellesmere

Island, some 100 miles south of the type locality. Excellent exposures of the formation occur also in the environs of Trold Fiord (*see* Pl. XII).

The Trold Fiord is confined to near-shore regions of the Sverdrup Basin, and besides Ellesmere Island it outcrops on two other islands in the Canadian Arctic Archipelago: it forms a narrow east-west trending belt of outcrop across northern Melville Island[1], and across southern Cameron Island[2]. On Ellesmere Island, Trold Fiord strata occur in a narrow belt that extends from the environs of Trold and Blind Fiords in the south to territory between Tanquary Fiord and the head of Hare Fiord in the north (*see* Fig. 5; also *Baumann Fiord, Eureka Sound South, Eureka Sound North, Greely Fiord West, Greely Fiord East, Otto Fiord* and *Tanquary Fiord*).

Stratigraphic Relationships and Thickness

The Trold Fiord Formation and its assumed correlative, the Degerböls Formation, comprise the youngest Permian deposits in the Sverdrup Basin. Both formations are delimited below and above by regional disconformities and they are invariably overlain by either the Lower Triassic Bjorne Formation or its facies equivalent, the Blind Fiord Formation.

The Trold Fiord Formation ranges in thickness from a trace to over 900 feet, and thicknesses may be extremely variable over short distances (*see* Table 3). This is partly the result of post-Permian erosion of upper beds and partly to overstep of lower beds towards the southeastern margin of the Sverdrup Basin. That the Trold Fiord is a transgressive deposit is suggested by the fact that it overlies progressively older Permian and Carboniferous formations when traced from northwest to southeast (*see* Table 3). Both lower and upper contacts of the formation are well marked on the ground and readily apparent on aerial photographs.

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[1] Tozer (1963c), on the basis of field studies in 1955, was the first to establish the presence of Carboniferous and Permian rocks on Sabine Peninsula, Melville Island. His sequence of formations comprising rocks of these ages may be summarized briefly in ascending stratigraphic order, as follows: Canyon Fiord Formation, unnamed formation of quartzose limestone, unnamed formation of sandstone, and Assistance Formation. Of special interest here are the strata that Tozer referred to the Assistance Formation. They were described as being 1,600 feet thick and consisting essentially of calcareous quartz sandstone.

In 1958, Tozer and Thorsteinsson (1964, p. 93–111, 229) restudied the Carboniferous and Permian rocks of Sabine Peninsula. They also recognized four formations in rocks of these ages and these formations corresponded to those recognized earlier by Tozer (*op. cit.*), but with some important changes in terminology. The formations recognized by Tozer and Thorsteinsson are summarized briefly from oldest to youngest, as follows: Canyon Fiord Formation; Belcher Channel Formation; Sabine Bay Formation—a new name for Tozer's (*op. cit.*) unnamed formation of sandstone—, and an unnamed formation. According to these authors the Assistance Formation was absent on Melville Island and most if not all of the 1,600 feet of strata referred earlier to that formation by Tozer (*op. cit.*) was in fact, a new formation; the Trold Fiord as defined in the present report.

In 1964, Nassichuk (1965) conducted detailed stratigraphic and faunal studies of the Carboniferous and Permian rocks of Sabine Peninsula. His stratigraphic conclusions regarding rocks included in the Canyon Fiord, Belcher Channel, and Sabine Bay Formations are in essential agreement with those of Tozer and Thorsteinsson (*op. cit.*). On the other hand, Nassichuk's research produced a new and interesting interpretation of the strata assigned previously to the Assistance Formation by Tozer (*op. cit.*) and later regarded as a new formation by Tozer and Thorsteinsson (*op. cit.*). In these strata Nassichuk recognized three distinctive formations, all of which are apparently bounded below and above by disconformities. The three formations are summarized in ascending stratigraphic order as follows: (1) Assistance Formation, overlying the Sabine Bay Formation, and consisting of unconsolidated grey sand and ironstone concretionary bands, and varying in thickness from less than 85 to 100 feet; (2) Unit A, made up chiefly of bioclastic limestone, and 465 feet thick; and (3) Unit B, consisting of green glauconitic sandstone, black chert and minor limestone, and attaining a maximum thickness of 800 feet. Unit B is the Trold Fiord Formation as defined in this report.

[2] Rocks classified as the Assistance Formation in southern regions of Cameron Island by Greiner (1963a, p. 636) were undoubtedly misidentified. They are here referred to the Trold Fiord Formation.

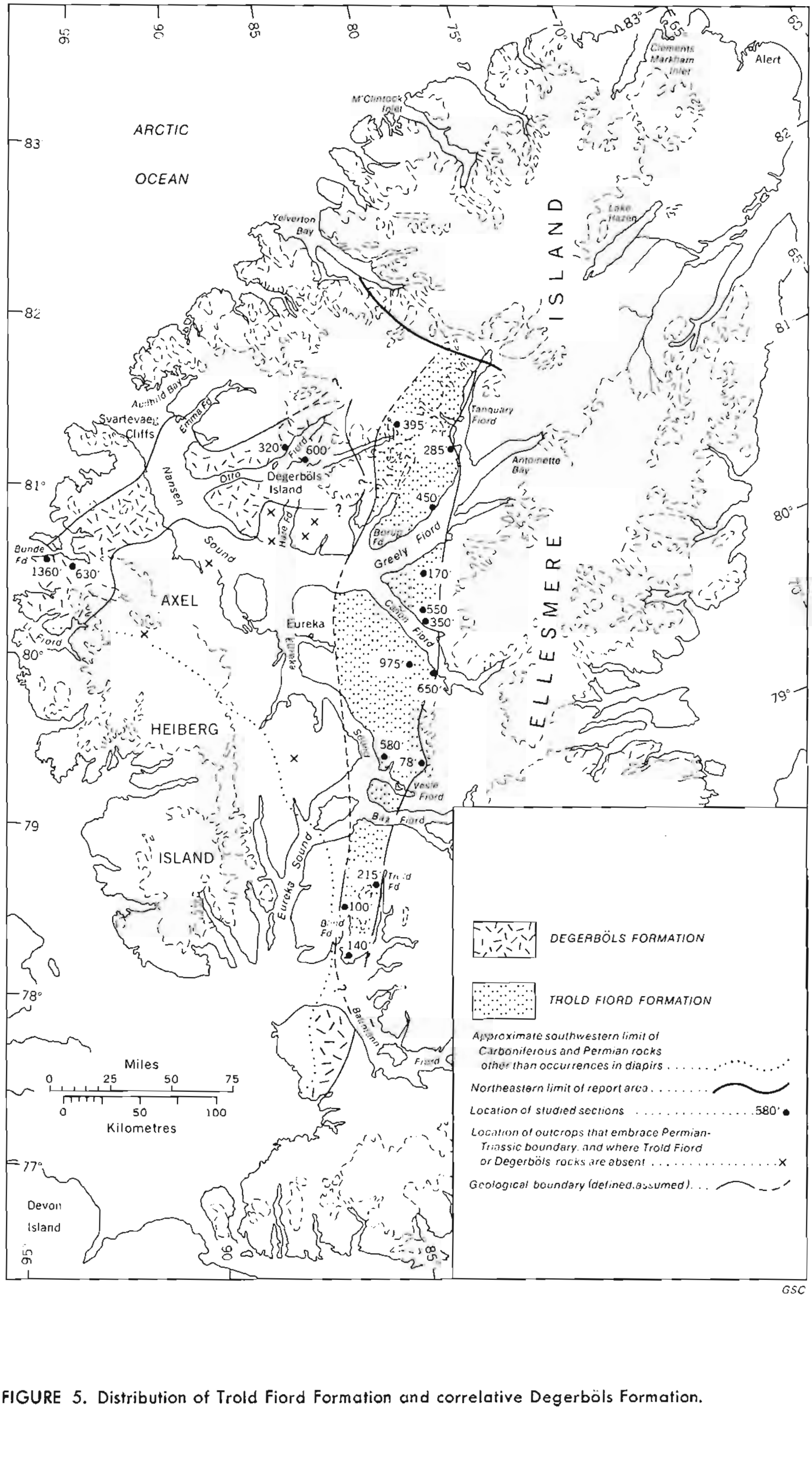

FIGURE 5. Distribution of Trold Fiord Formation and correlative Degerböls Formation.

TABLE 3 | *Locations of measured sections of Trold Fiord Formation showing underlying and overlying rock units, and thicknesses of the formation.*

Description of Localities	Underlying Formation	Overlying Formation	Thickness in Feet
Between Trold Fiord and Blind Fiord, Ellesmere Island; locality 62; *MAP 1300A EUREKA SOUND SOUTH*	*VAN HAUEN*	*BJORNE*	140
Near head of Trold Fiord, Ellesmere Island; locality 64; *MAP 1300A EUREKA SOUND SOUTH*	*CANYON FIORD*	*BJORNE*	215
West side of Blind Fiord, Ellesmere Island; locality 61; *MAP 1300A EUREKA SOUND SOUTH*	*VAN HAUEN*	*BLIND FIORD*	100
North of Vesle Fiord in Sawtooth Mountains, Ellesmere Island; locality 169; *MAP 1302A EUREKA SOUND NORTH*	*ASSISTANCE*	*BJORNE*	580
Northeast of head of Vesle Fiord, Ellesmere Island; locality 77; *MAP 1308A CAÑON FIORD*	*CANYON FIORD*	*BJORNE*	78
Between Wolf Valley and South Bay, Ellesmere Island; locality 76; *MAP 1308A CAÑON FIORD*	*CANYON FIORD*	*BJORNE*	650
About 12 miles south of Mount Bridgman in Sawtooth Mountains, Ellesmere Island; locality 170; *MAP 1308A CAÑON FIORD*	*ASSISTANCE*	*BJORNE*	975
Type locality of formation, north side Cañon Fiord, Ellesmere Island; locality 72; *MAP 1311A GREELY FIORD WEST*	*ASSISTANCE*	*BJORNE*	350
North side Cañon Fiord, Ellesmere Island; locality 71; *MAP 1311A GREELY FIORD WEST*	*ASSISTANCE*	*BJORNE*	550
North side of Greely Fiord, Ellesmere Island; locality 79; *MAP 1311A GREELY FIORD WEST*	*SABINE BAY*	*BJORNE*	450
West side of Tanquary Fiord, Ellesmere Island; locality 200; *MAP 1348A GREELY FIORD EAST*	*TANQUARY*	*BJORNE*	285
Northwest of head of Hare Fiord, Ellesmere Island; locality 68; *MAP 1309A OTTO FIORD*	*ESAYOO*	Fault contact	390+

GSC

Lithology

The formation consists mainly of quartzose sandstone that is grey, green or brown, fine to coarse textured, thin to thick bedded and massive, variably calcareous and glauconitic[1], and ranges from resistant to mainly friable and soft. The sandstone is predominantly fine grained and medium bedded. Interbedded at various intervals with the sandstone are subordinate units of fossil fragmental limestone and coquinoid limestone, pebble-conglomerate and, less commonly, beds of grey or blue chert. The limestone is grey, pink or brown, commonly irregularly and medium bedded, and variably quartzose and glauconitic. The conglomerate is made up of granules and pebbles in a groundmass of calcareous quartzose sandstone. The clasts are subrounded to subangular and consist mainly of red jaspers, limestone, sandstone, and quartz. The conglomerate and limestone units are generally resistant and form topographically prominent ridges and low cliffs.

Two outstanding characteristics of the Trold Fiord are its remarkable profusion of fossils and its almost startling green weathering by which this formation is readily identified. Although green as a fresh surface colour is secondary to various shades of grey, green glauconite as an ubiquitous weathering product tends to coat most Trold Fiord outcrops and colours the soft slopes that commonly develop on parts of this formation. Nevertheless, dusky red and moderate red weathering characterize certain beds in most exposures of the formation, particularly in the territory between Borup Fiord and the head of Hare Fiord in northwestern Ellesmere Island where these colours are dominant.

[1] The term glauconite is used here in the broad sense of including the clay minerals chlorite, montmorillonite, and kaolinite (Triplehorn, 1966).

The following is a detailed description of the Trold Fiord at the type locality northeast of Cañon Fiord (*see also* sec. 72, Fig. 9).

Unit No.	Lithologic Character	Thickness (feet)
	Overlying strata, Bjorne Formation, Lower Triassic, quartzose sandstone	
3	Sandstone, quartzose, glauconitic, mainly light grey and dark greenish grey, fine- to medium-grained, thin- to thick-bedded, generally medium-bedded, commonly irregularly bedded, alternating hard and very soft units, variably calcareous; sparse brachiopods and *Zoophycos* throughout	240
2	Sandstone, quartzose, glauconitic, coquinoidal calcareous, dark greenish grey, fine- to coarse-grained, thin- to mainly thick-bedded, highly fossiliferous; alternates with limestone, quartzose, glauconitic, medium light grey, mainly coarse-grained, thin- to medium-bedded; hard, resistant unit greenish and brownish weathering colours	62
1	Sandstone, quartzose, glauconitic, dark greenish grey, fine-grained, thin-bedded, soft. A three-foot bed of chert-pebble conglomerate occurs 13 inches above base of unit; consists of rounded to subrounded, multicoloured chert in a calcareous quartzose sandstone cement; sparse brachiopods throughout	48
	Total thickness of Trold Fiord Formation	350

Age and Correlation

Most exposures of the Trold Fiord in the report area are abundantly fossiliferous, but the fossils are commonly not so well preserved as on Melville Island, nor are they as easy to collect. The most characteristic fossils are brachiopods, bryozoans, and rare gastropods, pelecypods, and horn corals. Many of the brachiopods and bryozoans are uncommonly large.

Three collections of brachiopods were examined by J. B. Waterhouse who reports:

Locality 71; GSC Cat. No. 57687, obtained 60 feet above base of type section
Thamnosia (*Thuleproductus*) n. sp. A
Spiriferella sp.

Locality 72; GSC Cat. No. 57688, 100 feet above base of type section
?Kuvelousia sphiva Waterhouse
Neospririfer cf. *N. striatoparadoxus* (Toula)

Locality 73; GSC Cat. No. 58951, collected in lower part of the formation about 4 miles northeast of locality 71
giant *Waagenoconcha—W. purdoni* not Waagen of Wiman from Productuskalk of Spitsbergen and Bear Island
Horridonia granulifera
Thamnosia sp.
Yakovlevia
?Stenoscisma
Neospirifer aff. *N. striatoparodoxus* (Toula)

According to Waterhouse the faunas indicate a Kazanian (Wordian Substage) age.

Corals associated with the fauna from locality 73 have been identified as *Sochkineophyllum* sp. by E. W. Bamber who reports that the genus occurs mainly in the Lower Permian, but is known also from the Carboniferous. According to Bamber the species of *Sochkineophyllum* represented at locality 73 occurs also in the Degerböls Formation on Bjorne Peninsula (loc. 52), and in talus at the base of the Trold Fiord Formation on Melville Island (GSC Cat. No. C-484). Bamber regards these corals as similar to *Sochkineophyllum artiense* (Soshkina) from the Artinskian on Lytva River, central Urals, U.S.S.R.

A single specimen of an ammonoid collected by A. H. MacNair from the Trold Fiord on Cameron Island has been described as *Neogeoceras macnari* by Nassichuk, Furnish, and Glenister (1965). According to these authors species of *Neogeoceras* are confined to rocks of Guadalupian age.

Several collections of brachiopods made by W. W. Nassichuk from the Trold Formation on Melville Island have been identified by R. E. Grant who suggests that the brachiopods are of Guadalupian age. He also regards these faunas as probably correlative with the Wordian Substage, and with the brachiopods described by Dunbar (1955) from the Foldvik Creek Formation of central East Greenland (Grant, pers. com.).

It would seem very unlikely that the Trold Fiord is older than Guadalupian because of its stratigraphic position above the Assistance Formation, which is considered to include strata of latest Artinskian age. A Guadalupian age is accepted for the Trold Fiord Formation in this report.

Degerböls Formation

Definition, Distribution, and Stratigraphic Relationships

The Degerböls Formation is a relatively thin, resistant carbonate unit which commonly forms prominent dip slopes in the mountains of northwestern Ellesmere Island. It is here named after Degerböls Island, a small island near the head of Otto Fiord in northwestern Ellesmere Island. The type section is less than a mile east of van Hauen Pass, and about 12 miles east of Degerböls Island (*see* Pl. IV). It is illustrated graphically in section 69, Figure 9. The type section is completely exposed and exhibits both lower and upper contacts. As a point of interest, a nearly complete section of the formation outcrops on Degerböls Island.

The Degerböls is distributed in southwestern and northwestern Ellesmere Island, and northern Axel Heiberg Island (*Baumann Fiord*, *Greely Fiord West*, *Otto Fiord*, *Cape Stallworthy*, and *Bukken Fiord*). Distribution of the Degerböls and its presumed equivalent, the Trold Fiord Formation are shown in Figure 5. The Degerböls and Trold Fiord are regarded as basinal and near-shore facies, respectively.

Like the Trold Fiord Formation, the Degerböls constitutes the top of the Permian, and is separated from overlying Lower Triassic strata by a widespread erosion surface. Throughout most of its areal extent, the Degerböls lies disconformably on the van Hauen Formation. However, in some places, for example on Svartfjeld Peninsula (*Greely Fiord West* and *Bukken Fiord*), the van Hauen Formation has been removed by erosion and Degerböls strata rest directly on the Nansen Formation. On Bjorne Peninsula the Degerböls lies with structural conformity on the Assistance Formation, but the actual contact of the two formations has not been observed.

Lithology and Thickness

The type section of the Degerböls consists mainly of alternating units of coarse-grained limestone and lesser amounts of aphanitic to fine-grained limestone. These rocks are light to medium grey, and thick to generally medium bedded. The dominant weathering colours are various shades of grey and yellow. Grey and blue chert is rather common throughout the section, and occurs principally as irregular nodules and as individual beds, or more rarely as fossil replacements. The biogenic limestone is characteristically medium to coarse grained, medium grey, and commonly contains fragments of fossils that are recognizable as brachiopods, bryozoans, and crinoid columnals. Except for the absence of fusulinaceans, rocks of the Degerböls resemble closely those of typical developments of the Nansen Formation.

The thickness of the Degerböls is extremely variable, a character that reflects the removal of different amounts of strata by sub-Triassic erosion; at several places the entire formation has been removed. The type section is 600 feet thick. The thickest known section is south of Bunde Fiord in western Axel Heiberg Island, where 1,270 feet was measured (sec. 57, Fig. 8). In that area the Degerböls is somewhat atypical in that it consists of nearly equal parts of limestone and chert.

An unusual section of the Degerböls that outcrops in the Krieger Mountains of northern Ellesmere Island was studied by D. Morris and T. A. Frisch (*see* sec. 78, Fig. 10). There, the formation is 920 feet thick and consists mostly of thin-bedded, light grey to bluish grey chert, and minor amounts of cherty limestone.

Rocks assigned to the Degerböls on Bjorne Peninsula in southwestern Ellesmere Island include two relatively small areas of limestone exposures where partial sections were measured (secs. 49 and 52, Fig. 7; Pl. XXVII). The present-day erosion surface forms the top of the formation in both areas. On Bjorne Peninsula the Degerböls conforms more or less to the lithologic characters given above, although the lower part of the formation there contains small amounts of interbedded siltstone and shale which is not unusual. The best outcrops of the Degerböls are found at Great Bear Cape where 465 feet of strata is exposed.

Age and Correlation

It was from the limestone at Great Bear Cape that Per Schei (1904), geologist on the "Second Norwegian Expedition in the *Fram*, 1898–1902", under the command of Otto Sverdrup (1904), collected most of the Permian fossils described by Tschernyschew and Stepanow (1916). The fossils included a sponge, corals, bryozoans, brachiopods, and pelecypods, and the report by Tschernyschew and Stepanow made Great Bear Cape one of the best known geological localities in the Canadian Arctic Archipelago. Nevertheless, the age of the Great Bear Cape fauna is still a matter of disagreement among paleontologists. Troelsen (1950, p. 72) reviewed the problem of the age of the Great Bear Cape fauna and concluded that; "Although some of Tschernyschew's identifications may need revision, the present writer is inclined to agree with Tschernyschew and Stepanow (1916) that the Great Bear Cape sequence should be referred to the zone of *Pseudoschwagerina*." (*Pseudoschwagerina* is regarded as an index fossil of the Wolfcampian Series.) Dunbar (1955, p. 59), in his monographic study of the Permian brachiopods of central East Greenland, expressed the opinion that the Great Bear Cape fauna is of Early Permian age, and distinctly older than the brachiopod faunas of central East Greenland which he regarded as Late Permian (Zeckstein). Gobbet (1963, p. 191), in a comprehensive study of Carboniferous and Permian brachiopods of Svalbard, stated that the brachiopods in the Great Bear Cape fauna, as described by Tschernyschew and Stepanow (1916), compare with the Early Permian elements in the Svalbardian fauna but that Late Permian forms are absent. In 1960, Minato described *Ipciphyllum tschernyschewi* as a new species of coral based on materials from the Great Bear Cape fauna which had been originally referred to *Lithostrotion borealis* Stuckenberg by Tschernyschew and Stepanow (op. cit.). Partly on the basis of other occurrences of the genus *Ipciphyllum* and partly on the basis of a re-evaluation of the brachiopods from Great Bear Cape, Minato argued convincingly for correlating the Great Bear Cape fauna with the upper part of the *Parafusulina* zone of Thompson (1948). Thus, Minato dates the Great Bear Cape (=Degerböls) fauna as Guadalupian, or early Late Permian.

Minato's age assignment of the Degerböls is followed in the present report. It is the most readily acceptable age on the bases of: (1) the latest Early Permian age assignment of the Assistance Formation that immediately underlies the Degerböls; (2) the presumed correlation of the Degerböls and Trold Fiord Formations; and (3) the age determinations of a few small fossil collections obtained by the writer from the Degerböls.

Fossils are plentiful in the Degerböls at Great Bear Cape, but the outcrops generally form steep ledges that are not easily accessible. Fossils are most easily obtained in the talus apron at the foot of the cape, and it seems reasonable that Per Schei, who collected under conditions of snow cover at Great Bear Cape, obtained most of his excellent materials from this source. The following forms were obtained about 360 feet stratigraphically above the base of exposures at Great Bear Cape by the writer. They have been identified by R. E. Grant who comments:

Locality 49; GSC Cat. No. 67265
Kochiproductus? sp.
Linoproductus dorotheevi (Fredericks)
Neophricadothyris asiatica (Chao)
"*Productus*" *arcticus* Whitfield
Spiriferella keilhavi (Boch)
Waagenoconcha payeri (Toula)
Yakovlevia sp.

Spiriferella keilhavi is too loosely defined to be of value in detailed correlation; "*Productus*" *arcticus* provides a link with some Word and Guadalupe correlatives in Alaska and Western Canada; *Yakovlevia* sp. and *Kochiproductus* suggest correlation with the Central East Greenland fauna. The age would seem to be "Svalbardian", but whether early or late is uncertain. Comparison of this list with the list from the Assistance Formation (Harker and Thorsteinsson, 1960, p. 11) shows very little in common: only the questioned (by them) species of *Waagenoconcha*, and the specifically indeterminate and generically doubtful *Kochiproductus* from Bjorne Peninsula.

Brachiopods obtained from the type section of the Degerböls, about 475 feet above the base of the formation, are tabulated below:

Locality 69; GSC Cat. No. 47846
Waagenoconcha sp.
Anemonaria sp.
alate *Pterospirifer* n. sp.
Spiriferinaella sp.
Choristites sp.

Identifications are by J. B. Waterhouse who suggested an early Kazanian age (= early Guadalupian) for the collection.

PERMIAN–TRIASSIC BOUNDARY

Basal Mesozoic deposits in the Sverdrup Basin are represented by two correlative Lower Triassic rock units: the Bjorne Formation, a marginal facies consisting mainly of red quartzose sandstone that extends northeasterly in western Ellesmere Island from Bjorne Peninsula to and beyond the environs of Tanquary Fiord; and the Blind Fiord Formation, a basinal facies made up chiefly of dark coloured siltstone, shale, and fine-grained sandstone. The Blind Fiord is widely distributed throughout Axel Heiberg Island, and western and northwestern regions of Ellesmere Island. Tozer (1967, p. 13) correlates the *Otoceras concavum* Zone at the base of the Blind Fiord Formation with the *Otoceras woodwardi* Zone of the Himalayas. The latter zone is generally accepted as constituting the base of the Triassic. According to Tozer (pers. com.), basal beds of the Bjorne and Blind Fiord Formations may be regarded as synchronous for all practical purposes. Throughout much of their areal extent, the Bjorne and Blind Fiord Formations overlie rocks of Permian age. However, in western regions of Ellesmere Island, Permian rocks locally have been removed by erosion and Triassic rocks lie on Carboniferous rocks (*see* Pl. XVIII).

The Trold Fiord Formation (green glauconitic sandstone) and its facies equivalent, the Degerböls Formation (limestone), both of Guadalupian age, constitute the youngest Permian deposits in the Sverdrup Basin. As there is no paleontological evidence to indicate the Dzhulfian Stage (latest Permian) in this region, the break between Permian and Triassic rocks denotes a considerable hiatus in the sedimentary record. Furthermore, as the Bjorne and Blind Fiord Formations include the oldest known Triassic rocks it is apparent that the hiatus represents Permian time only.

Actual exposure of the Permian–Triassic contact has been observed at many widely separated localities on Axel Heiberg and Ellesmere Islands, and in all instances the contact is a sharp surface of separation between structurally conformable formations. Basal conglomeratic beds are rarely present in the Bjorne Formation, and have not been observed in the Blind Fiord Formation. In general the upper surface of Permian rocks beneath the sub-Triassic disconformity shows little or no evidence of erosion. However, the upper 20 feet or more of beds in the type section of the Degerböls Formation in northwestern Ellesmere Island consists of vuggy limestone infilled with iron oxide, indicating that the formation was probably leached prior to deposition of the Blind Fiord Formation.

The regional relationships of Permian and Triassic rocks leave no doubt that the two systems are separated by a regional disconformity, involving not only withdrawal of marine waters from the Sverdrup Basin, but also differential uplift and widespread erosion. Late Permian tectonic adjustments in the basin are indicated clearly in Figures 7 to 10 by the different formations that underlie Triassic rocks in different regions. The absence of both the Trold Fiord and Degerböls Formations over large areas of eastern and northeastern Axel Heiberg Island, and neighbouring regions of Ellesmere Island as shown in Figure 5, is probably due to broad, differential uplift along the axis of the Sverdrup Basin in latest Permian time.

DIAPIRS

History of Study

B. W. Waugh, in the course of indexing trimetrogon aerial photographs of the Canadian Arctic Archipelago taken by the RCAF in 1950, noticed several distinctly circular landforms on Melville and Ellef Ringnes Islands; these he brought to the attention of the Geological Survey where the photographs were studied by I. C. Brown (1951). Brown recognized that these landforms were probably structurally controlled, and, after proposing several hypotheses to explain their origin, he concluded that they probably represent igneous intrusions.

In 1952 and 1953, W. W. Heywood (1955, 1957), using the Isachsen weather station as his base of operation and travelling on foot, carried out the first geological studies on Ellef Ringnes Island. In 1953, he walked from Isachsen to the nearest circular structure, a distance of some 30 miles, where he made the startling discovery that the core rock in what he referred to as the Isachsen Dome (= Isachsen Diapir in this report) was intensely deformed anhydrite and its alteration product gypsum, with minor intercalated beds of limestone, and inclusions of limestone, diabase, basalt, and gabbro. Equally surprising was Heywood's discovery that the anhydrite was not cap rock but was of primary sedimentary origin, and that it constituted the mobile rock in the diapir.

Subsequent to Heywood's (op. cit.) studies, the diapirs of the Sverdrup Basin attracted a great deal of attention, not only because of their intrinsic interest but also because of the association of petroleum with diapirs in various parts of the world. Although much information has been added to our knowledge of these interesting structures since Heywood's pioneer work, the outstanding general features of the Isachsen Diapir, which he determined after his arduous walk from the weather station, have been found to characterize the scores of diapirs now known to occur in Sverdrup Basin.

In 1955, members of Operation Franklin established that large numbers of diapirs occur in the Sverdrup Basin, particularly on Axel Heiberg Island. Their report (Fortier *et al.*, 1963) contains descriptions of several diapirs (Roots, 1963a, b, c).

In 1956, Thorsteinsson and Tozer (1957) discovered a formation of bedded anhydrite and gypsum (the Otto Fiord Formation of the present report) in normal stratigraphic position in the vicinity of Hare Fiord in northwestern Ellesmere Island, and determined its age to be Pennsylvanian or Permian. In the same general region, these authors traced this formation laterally into a large diapir (Hare Fiord Diapir) and concluded that the formation probably represented the same rocks that gave rise to the anhydrite and gypsum diapirs in other parts of Sverdrup Basin.

In 1957, Fortier (p. 431) suggested that the development of diapirs in the Sverdrup Basin was related to the Tertiary orogeny that affected a major part of the Sverdrup Basin. This concept was accepted by Thorsteinsson and Tozer (1960).

E. H. Kranck (1961), on the basis of field work carried out in 1959 in western Axel Heiberg Island, noted that the Strand Fiord region was characterized by mainly broad, open synclines and tightly folded anticlines, and that the latter were commonly pierced by diapirs. He attributed this style of folding to compressional and isostatic forces acting at the same time on thick Mesozoic sediments (rendered competent by a unit of volcanic flows and numerous basic igneous sills) overlying incompetent late Paleozoic anhydrite and gypsum. Kranck visualized the evaporitic rocks as having moved upwards under the influence of compressional and isostatic forces to pierce anticlines and form elongated diapirs. Kranck recognized a second type of diapir in this region: large, circular domal structures, typified by the South Fiord Diapir, which he (p. 440) regarded as probably having formed ". . . more or less in step with sedimentation," and mainly as a result of ". . . load pressure," but he offered no evidence for this assertion.

During the field seasons of 1960, 1961, and 1962, the Dominion Observatory in conjunction with the Polar Continental Shelf Project conducted a program of reconnaissance gravity surveys over a large area of Queen Elizabeth Islands. On the basis of the work done during the first two years, Sobczak (1963) published a Bouguer anomaly map of Ellef Ringnes and Amund Ringnes Islands, and a report in which he interpreted negative gravity anomalies over Isachsen Diapir and Dumbbell Diapir (Ellef Ringnes) to indicate intrusive gypsum, while a pronounced gravity high over North Cornwall Diapir (Amund Ringnes) is regarded as indicating a basement arch and basic intrusions. Sobszak *et al.* (1963) summarized the three-year program with a report and four Bouguer anomaly maps covering much of the Sverdrup Islands group and Parry Islands group. In the report these authors stated, "The local negative anomalies on Ellef Ringnes Island coincide with gypsum intrusions that in turn may be underlain by masses of salt."

In the field season of 1960, Hoen (1964) carried out a detailed study of ten representative diapirs in western Axel Heiberg Island. He rejected the possibility that the anhydrite in core rocks represents residual cap rock that resulted from upward migrating meteoric water. He also discounted the possibility that the anhydrite cores originated as a bedded unit of evaporite that originally overlay bedded halite and rose passively upwards above rising columns of salt. Instead, Hoen concluded that the Axel Heiberg diapirs are structurally similar to halite diapirs, and originated in the same manner.

Hoen (op. cit.) stated that certain of the larger diapirs in western Axel Heiberg Island developed under static conditions prior to the Tertiary orogeny. He accepted the hypothesis that attributes diapirs to the isostatic rise of materials having greater plasticities and lesser specific gravities than those of superincumbent rocks. He regarded the specific gravity and strength of anhydrite as too great to permit diapirism, and therefore suggested that the anhydrite cores originated as bedded gypsum which, subsequent to burial to depths of about 2,000 metres, commenced to rise isostatically. Hoen believed that dehydration did not commence until the sedimentary cover reached thicknesses of about 5,000 metres, and that isostatic rise of the core ceased when mixed gypsum and anhydrite achieved a specific gravity comparable to, or somewhat greater than, the country rocks. The smaller anticlinal, and fault diapirs, Hoen regarded as having been induced by orogenic forces.

Schwerdtner and Clark (1967) devoted the field season of 1963 to detailed studies and mapping of two diapirs on Axel Heiberg Island; South Fiord Diapir (studied also by Hoen, 1964) and Mokka Fiord Diapir. These authors are at one with previous workers in regarding the role of anhydrite in these diapirs as active rather than passive. While accepting the possibility that halite may underlie the anhydrite at depth in normal stratigraphic position, Schwerdtner and Clark did not regard halite as essential to the development of diapirs. These authors differed from Hoen (op. cit.) in regarding anhydrite and not gypsum as the original source material, and they considered that differences in plasticity between source rocks and overburden can induce diapirism under suitable stress conditions, regardless of differences in specific gravity. Moreover, they pointed out that the viscosity of anhydrite is comparable to that of halite.

According to Schwerdtner and Clark (op. cit.), the South Fiord Diapir is composed of three subcores, whereas the Mokka Fiord Diapir represents a single core. They also stated that the two diapirs were emplaced prior to the Tertiary orogeny, but their reasons for this belief are not clear.

Diapirism in the Sverdrup Basin is the subject of a paper by Gould and de Mille (1964), based on extensive photogeologic studies and field investigations conducted in 1960 on Ellef Ringnes, Amund Ringnes, and Axel Heiberg Islands. These authors distinguished two major categories of diapirs: (1) Large domal structures that intrude weakly deformed sediment in western regions of the Sverdrup Basin, as for example on Ellef Ringnes and Melville Islands. These diapirs are regarded to be essentially halite diapirs consisting of, ". . . halite cores beneath the exposed gypsum and anhydrite;" (2) Generally smaller, elongate diapirs that are associated with faults or anticlinal axes, and which occur in the intensely deformed regions of the Sverdrup Basin on Axel Heiberg and Ellesmere Islands. According to Gould and de Mille (op. cit.), such diapirs probably did not involve halite but have resulted from the tectonic squeezing of anhydrite. [The paper by Gould and de Mille, as well as that of Hoen (1964), contains many excellent illustrations of diapirs in the Sverdrup Basin.]

The thinning of the Cretaceous Hassel Formation in the direction of the Isachsen Diapir is cited by Gould and de Mille (op. cit.) as evidence that some movement of this diapir took place as early as Cretaceous time. Furthermore, these authors state that, locally, Cretaceous sediments along the periphery of the Isachsen Diapir appear to lie unconformably on core rocks. Stott (1969), who carried out regional stratigraphic and structural studies on Ellef Ringnes Island in 1967, has produced considerable stratigraphic evidence to support the opinion that certain diapirs in this island were rising as early as Late Jurassic time. Moreover, he suggested that movement of the core rocks may have occurred continually since then. According to Stott (op. cit., p. 38) ". . . the Tertiary orogeny was at most a secondary influence rather than the primary cause of the development of diapirs on Ellef Ringnes Island."

Spector and Hornal (1970) interpreted negative gravity anomalies over Cape Colquhoun Diapir (Melville Island), Isachsen Diapir (Ellef Ringnes Island), and South Fiord Diapir (Axel Heiberg Island) in order to estimate heights of the evaporite stocks. Each stock was assumed to represent a right-vertical cylinder consisting of two homogeneous parts, high density anhydrite overlying low density gypsum and/or salt. Each stock was assumed to be surrounded by country rock of uniform density. On the basis of these assumptions, depth calculations indicated a maximum depth of 700 to 2,800 metres for Cape Colquhoun Diapir, 3,500 to 4,500 metres for Isachsen Diapir, and 800 to 2,000 metres for South Fiord Diapir. Spector and Hornal (op. cit.) stressed that these depth estimates are gravity minima because of the following possibilities: "(a) the existence of a transition zone in which a gradation occurs between the low density (gypsum/rock salt) and high density (anhydrite) zones; (b) the cross-sectional area of the dome decreases with depth, i.e., it has a tear-shaped cross-section; (c) the density contrast of the low density region is less in magnitude than 0.1 gm/cm^3 with respect to the surrounding medium."

Observations and Remarks on Diapirs

Anhydrite diapirs are common in Axel Heiberg Island and northwestern Ellesmere Island, particularly along the axis of the Sverdrup Basin (*see* Fig. 6). The size of the diapirs

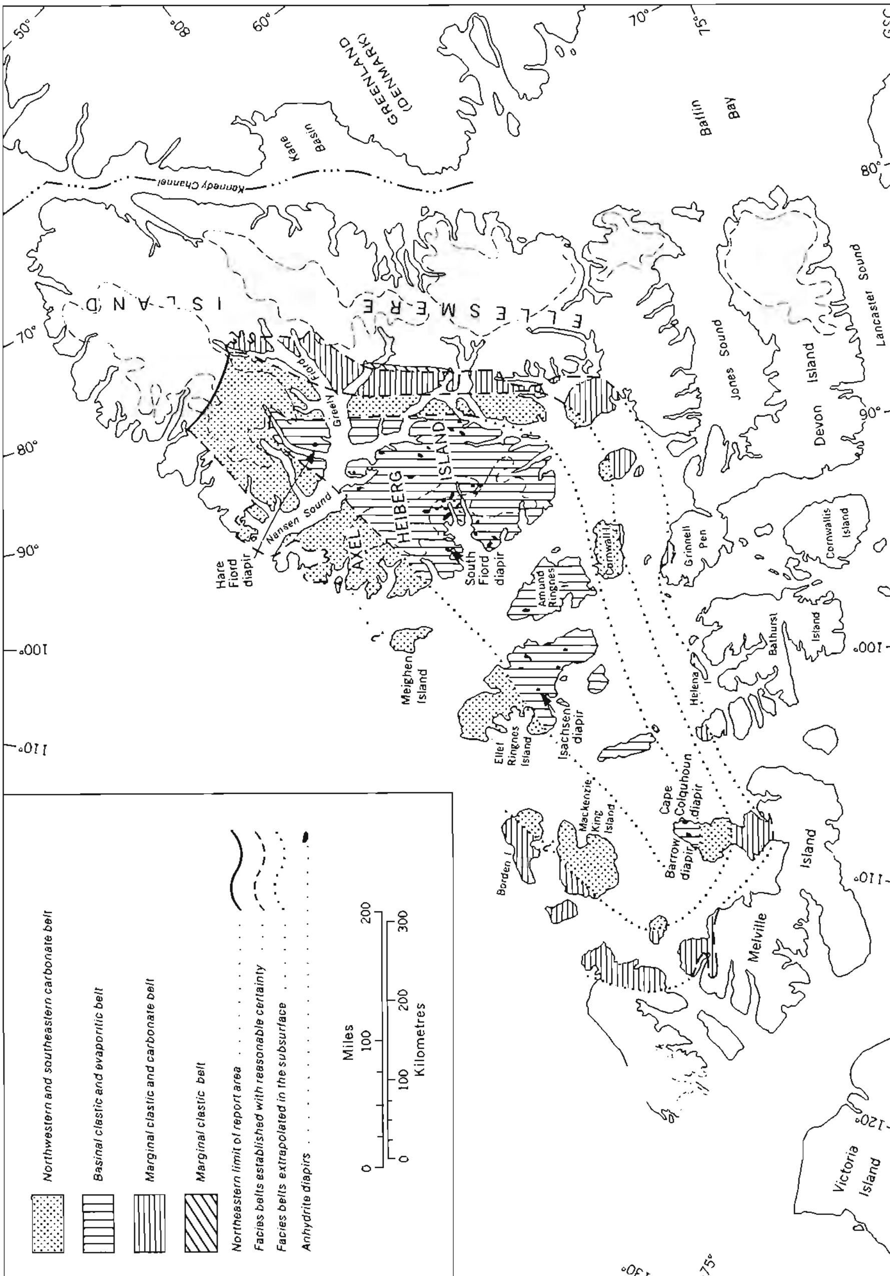

FIGURE 6. Distribution of lower Bashkirian to lower Artinskian facies belts throughout greater part of Sverdrup Basin.

ranges from a few square feet to prominent topographic features such as the South Fiord Diapir, which is about 5 miles in diameter and towers some 1,500 feet above the surrounding countryside. Although it is impossible to offer a meaningful estimate of the total number of diapirs of all sizes on the two islands, 98 diapirs are of sufficient size to be shown on the published geological maps. These diapirs are distributed among the following map-areas: *Haig-Thomas Island, Glacier Fiord, Middle Fiord, Strand Fiord, Eureka Sound North, Bukken Fiord, Greely Fiord West, Cape Stallworthy,* and *Otto Fiord.* The largest concentration of diapirs is in the environs of Strand Fiord in western Axel Heiberg Island. A total of 40 diapirs are shown on the *Strand Fiord* map-area alone, but some of these are probably connected at depth.

Scores of small diapirs are represented simply as low mounds or, in some places, topographic lows containing tumbled and disordered blocks of gypsum and lesser amounts of selenite. Large diapirs are commonly intricately dissected by streams, a feature which, combined with the extreme tectonic disturbance of core rocks, presents the appearance of a chaotic landscape. Gypsum is the most common rock observed in the cores, but fresh surface exposures are generally found to be anhydrite. Selenite is common also in most large diapirs, and occurs as inclusions, veins and individual beds. Inclusions of limestone, diabase, gabbro, and basalt are common also, particularly in extremely contorted and sheared parts of the core. Partial sections of the anhydritic formation that gave rise to these diapirs, 300 feet or more thick, can be found in many of the larger diapirs, particularly in peripheral regions where the strike of the anhydrite generally conforms to the edge of the core.

Three principal kinds of diapirs are differentiated in the report area on the basis of regional setting: (1) Diapiric dome. This diapir is generally large and rounded in plan. It occurs in regions of gently inclined to flat-lying sediments, and is common in western regions of the Sverdrup Basin such as Ellef Ringnes and Melville Islands. The South Fiord Diapir, Cape Levvel Diapir, and Sand Bay Diapir in western Axel Heiberg Island (*Middle Fiord*) are probably the only representatives of this type of diapir in the report area. (2) Diapiric anticline. This diapir is found in the axial region of anticlines. It is generally elongate and its principal axis coincides more or less with the axis of the anticline. It is well exemplified by the Kanguk Diapir in western Axel Heiberg Island (*Middle Fiord*). (3) Fault diapir. This diapir is associated with both gravity and thrust faults. The anticlinal diapir and fault diapir are comparable in size and shape; both are generally smaller than the diapiric dome, and occur in the more intensely deformed terrains of Axel Heiberg Island and northwestern Ellesmere Island. It is not always possible to distinguish diapiric anticlines and fault diapirs. Several examples of fault diapirs occur along the Stolz thrust in eastern Axel Heiberg Island (*Eureka Sound North*). A special type of fault diapir may be recognized in anhydrite dykes that intrude certain gravity faults. An excellent example of this kind of diapir occurs along the east side of Hare Fiord in northwestern Ellesmere, some 15 miles northeast of the junction of Hare Fiord and Greely Fiord (*Greely Fiord West*).

The reasons for regarding the Otto Fiord Formation as having provided the source materials for diapirs, not only on Axel Heiberg and Ellesmere Islands but for the entire Sverdrup Basin, are as follows: (1) Correlation of the Otto Fiord Formation and diapirs is suggested by the Bashkirian age of that formation based on its stratigraphic position within normal stratigraphic successions around Hare Fiord in northwestern Ellesmere Island, and the Bashkirian age of ammonoids found in core rocks of the South Fiord Diapir (western Axel Heiberg Island) and Barrow Diapir (Melville Island, *see* p. 27). (2) Partial sections of anhydrite, generally including minor interbeds of limestone that have been studied in several of the large diapirs in the Sverdrup Basin, bear closer lithological similarity to the Otto Fiord

Formation than to any of several other anhydritic formations in the Archipelago. (3) Diapirs of moderate size at two widely separated localities, namely Hare Fiord Diapir some 10 miles northeast of the mouth of Hare Fiord in northwestern Ellesmere Island (*Greely Fiord West*) and Whitsunday Bay Diapir in eastern Axel Heiberg Island (*Eureka Sound North*), are continuous with outcrops of the Otto Fiord Formation in normal stratigraphic position along major thrust faults. (4) Fossils older than Carboniferous have not been found in any diapir in the Sverdrup Basin. On the basis of available evidence the Otto Fiord Formation represents the only possible source of diapirs in the Sverdrup Basin.

Gould and de Mille (1964, p. 725) and Stott (1969, p. 38) have suggested that evaporites of lower Paleozoic age may be involved in diapirs of the Sverdrup Basin. Of particular interest in this connection are the Baumann Fiord and Bay Fiord Formations, both of Ordovician age. These formations are distributed widely in the Franklinian Miogeosyncline of southeastern and southern Ellesmere Island (Kerr, 1968). One or both formations are exposed in the Franklinian Miogeosyncline on Devon Island, Cornwallis Island, and Bathurst Island (Kerr, 1967a). However, neither the Baumann Fiord nor the Bay Fiord, nor any other evaporitic formation is known to occur in the Franklinian Eugeosyncline of northern Axel Heiberg and northern Ellesmere Islands (Trettin, 1969a, b). Moreover, as the Sverdrup Basin appears to lie mainly on rocks of the Franklinian Eugeosyncline (Thorsteinsson and Tozer, 1960) there would seem to be little possibility that evaporites of pre-Carboniferous age are present beneath the basin.

There is an interesting relationship in northwestern Ellesmere Island and neighbouring parts of Axel Heiberg Island between the occurrence and character of anhydrite diapirs, and the regional distribution of the Otto Fiord, Hare Fiord, and Nansen Formations. It is apparent in this region that diapirs of moderate and large size occur only where the Otto Fiord Formation is overlain by relatively incompetent siltstone and shale beds of the Hare Fiord Formation; where the Otto Fiord Formation is overlain by relatively competent carbonate rocks of the Nansen Formation, diapirs are few and generally very small. On the basis of this relationship it seems reasonable to suggest that the Otto Fiord and Hare Fiord Formations are distributed more or less coextensively in the subsurface throughout parts of the Sverdrup Basin characterized by diapirs of large and moderate size, but in which Carboniferous and Permian formations in normal stratigraphic sequence are hidden beneath younger sediments (*see* Fig. 6).

In connection with the above discussion the geologic settings of three other anhydrite formations are: Baumann Fiord (Kerr, 1967a), Lower Ordovician; Bay Fiord (Kerr, op. cit.), Middle Ordovician; and Mount Bayley, Lower Permian. The Baumann Fiord and Bay Fiord Formations crop out extensively in southeastern and southern Ellesmere Island, whereas the Mount Bayley Formation is distributed in the environs of Cañon Fiord and Greely Fiord in western Ellesmere Island. All three formations are more or less comparable to the Otto Fiord Formation in thickness and lithology and, like the Otto Fiord, the three formations occur in folded and thrust faulted terrains. All are overlain everywhere by relatively thick, competent carbonate formations, and none gives rise to diapirs.

Hoen (1964, p. 78) stated that the South Fiord Diapir, Expedition Diapir, and Strand Diapir in western Axel Heiberg Island have had a long history of growth, and that they were emplaced prior to the Tertiary orogeny. His assertion is based mainly on the character and contact relationships of basic dykes and sills in certain of these diapirs. Hoen (op. cit.) accepted the opinion that dykes and sills of Sverdrup Basin are of Late Cretaceous age, and he interpreted the presence of long, unbroken sills, and cross-cutting dykes in the anhydrite of South Fiord Diapir as having been intruded after diapirism. The writer believes that the sills are coextensive with at least equally long and unbroken, partial sections of anhydrite beds within the diapir, and it is therefore just as reasonable to regard the sills as having been emplaced before as after diapirism. With regard to Expedition Diapir and Strand Diapir, Hoen (op. cit.) cited the presence of diabase sills in peripheral regions of the core rocks as evidence that the sills were intruded after diapirism. The writer has examined the sills and concludes that nowhere are the contacts of the sills and diapiric cores sufficiently well exposed to determine whether they are in fault or intrusive contact with the cores.

There are geological circumstances other than those offered by Hoen (1964, p. 78) that suggest that emplacement of certain diapirs in western Axel Heiberg Island may have occurred over a long period of time which predates the mid-Cenozoic orogeny. The structural setting of such large diapirs as South Fiord and Cape Levvel, which pierce weakly deformed sediments, is similar to that of diapirs on Ellef Ringnes Island, which Gould and de Mille (1964), and Stott (1969) consider to have risen progressively with sedimentation. Moreover, in size and configuration, South Fiord Diapir and Cape Levvel Diapir resemble more closely diapirs on Ellef Ringnes Island than those in other parts of Axel Heiberg Island and Ellesmere Island.

With the possible exception of certain large diapirs in western Axel Heiberg Island discussed above, there can be little doubt that most diapirs on Axel Heiberg and Ellesmere Islands were induced by the mid-Cenozoic orogeny. Not only are most diapirs clearly related to anticlines and faults effected by this orogeny, but some are known to intrude the Tertiary Eureka Sound Formation (*Eureka Sound North*). Evidence suggests that this may be true of all diapirs on these two islands: (1) There is no known evidence that formations thin in the direction of any diapir. (2) All exposed contacts of diapirs and country rock that were examined are represented by faults or zones of intense shearing; none is represented by an unconformity. (3) Inclusions of basic rocks, ostensibly representing fragments of dykes and sills, are common in many diapirs. They are particularly common in large diapirs such as South Fiord Diapir, Sand Bay Diapir, and Cape Levvel Diapir. The inclusions represent evidence that considerable movement of diapirs occurred after the intrusion of the dykes and sills. Consideration of the time of emplacement of the dykes and sills is therefore pertinent to the time of emplacement of the diapirs. Basic dykes and sills are common in rocks of the Sverdrup Basin, and are known to intrude virtually all formations older than, and including, volcanic rocks of the Upper Cretaceous Strand Fiord Formation which crops out in western Axel Heiberg Island. Dykes and sills are not known to intrude the Upper Cretaceous Kanguk Formation or the Tertiary Eureka Sound Formation. Although extrusive rocks occur in the Lower Cretaceous Isachsen and Christopher Formations on Axel Heiberg Island (*Bukken Fiord*), and are represented by the Carboniferous Audhild Formation in Ellesmere Island, and by the Permian Esayoo Formation in Axel Heiberg and Ellesmere Islands, no dykes are demonstrably correlative with any of these volcanics. Therefore, the time of emplacement of dykes and sills in the Sverdrup Basin is generally regarded as Late Cretaceous, an event that was probably correlative with the extrusion of the Strand Fiord Formation. (4) Despite the prevalence of dykes, none is known to cut the boundary of any diapir and its country rock on Axel Heiberg and Ellesmere Islands, or for that matter any diapir in the Sverdrup Basin.

Hoen (1964, p. 76) has argued convincingly against the possibility that halite played a significant role in the development of the diapirs which he studied in western Axel Heiberg Island. He (op. cit.) found no evidence of rock salt in any of the diapirs, and suggests that if salt were responsible for these structures it should have reached the surface where it would be preserved today because of the unusually low annual precipitation—about 15 cm in Axel Heiberg Island. (Hoen's arguments against the presence of halite apply equally to all diapirs in the Sverdrup Basin.) The writer has not observed halite or any indication that halite was present in any diapir or outcrop of the Otto Fiord Formation on Axel Heiberg or Ellesmere Island. Compelling evidence that halite is not essential to the development of diapirs is provided by the Hare Fiord Diapir and Whitsunday Bay Diapir (discussed earlier), which are continuous with outcrops of the Otto Fiord Formation in normal stratigraphic position.

The Hare Fiord and Whitsunday Bay Diapirs are of considerable significance to the central problem of diapirism. There are today two divergent hypotheses that purport to explain the cause of diapirism, given the necessary pressure environment: (1) bouyancy of light source material beneath an overburden of higher density; or (2) differences in plasticity between source material and overburden, regardless of differences in density. The geological setting of the Hare Fiord and Whitsunday Bay Diapirs favours the latter hypothesis.

Negative gravity anomalies over certain diapirs in western regions of the Sverdrup Basin obtained by reconnaissance surveys during the early part of the last decade (Sobczak, 1963; Sobczak *et al.*, 1964) provide reasonable indication that halite is involved in these diapirs. These anomalies are the bases for Gould and de Mille's (1964, p. 745) suggestion that these diapirs are principally halite diapirs consisting of cores of halite beneath exposed masses of anhydrite, and the analogous suggestion by Spector and Hornal (1970) that the diapirs consist of exposed anhydrite and subsurface halite and/or gypsum.[1] As the structure of the anhydrite in these western diapirs indicates clearly that the anhydrite behaved as active source material, it is reasonable to suppose that halite, if present, originally constituted a considerable thickness of beds underlying a considerable thickness of anhydrite, and that both units of rock were intruded concomitantly to form bipartite diapirs. There is one disconcerting element in this bipartite concept; that is the barely credible coincidence that the present-day erosion surface transects in all instances the anhydrite part and not the halite part of these western diapirs.

[1] In the light of MacDonald's (1953) study of anhydrite–gypsum equilibrium relations, it seems most improbable that gypsum can exist at depths greater than about 2,000 feet. Moreover, a leading authority on marine evaporites, Frederick H. Stewart (1963, p. 40Y), states that, "Gypsum is practically absent in nature except in near-surface deposits." Depths to the source beds of the evaporites involved in the three diapirs discussed by Spector and Hornal (op. cit.) may be estimated as in the order of 15,000 to 22,000 feet. These figures are based on the cumulative thicknesses of formations (mainly Mesozoic) exposed around these diapirs, and formations (mainly Carboniferous and Permian) exposed only in northern Axel Heiberg and Ellesmere Islands, but which may be reasonably assumed to occur in the subsurface in the environs of these diapirs. Consequently, if negative gravity anomalies in western regions of the Sverdrup Basin do indicate a subsurface deposit of an evaporitic mineral of relatively low specific gravity, the mineral is probably halite and certainly not gypsum.

Furthermore, MacDonald's (op. cit.) study renders improbable Hoen's (1964, p. 79) suggestion that certain large diapirs in western Axel Heiberg Island originated as bedded gypsum which commenced to rise isostatically upon burial to depths of about 2,000 m (about 6,000 feet).

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APPENDIX

Identification of Foraminifera from the Borup Fiord and Canyon Fiord Formations

by B. L. Mamet

Biota, Borup Fiord Formation

About 4,000 specimens of Foraminifera from recrystallized biomicrite were obtained from unit 3 in the type section of the Borup Fiord; GSC Cat. No. C-266.

Ammovertella sp.
Archaediscus of the group *A. chernoussovensis* Mamet, *in* Mamet, Choubert, and Hottinger
Archaediscus of the group *A. krestovnikovi* Rauzer-Chernoussova
Archaediscus of the group *A. moelleri* Rauzer-Chernoussova
Archaediscus pauxillus Schlykova
Asteroarchaediscus sp.
Asteroarchaediscus baschkiricus (Krestovnikov and Teodorovitch)
Biseriella parva (Chernyscheva)
Bradyina sp.
Calcisphaera laevis Williamson
Calcivertella sp.
Climacammina of the group *C. patula* Brady
Climacammina of the group *C. prisca* Lipina
"*Cornuspira*" sp.
Cribrospira sp.
Deckerella? sp.
Diplosphaerina sp.
Earlandia elegans (Rauzer-Chernoussova)
Earlandia clavatula (Howchin)
Earlandia vulgaris (Rauzer-Chernoussova and Reitlinger)
Endothyra of the group *E. bowmani* Phillips *in* Brown *emend* Brady
Endothyranopsis sp.
Endothyranopsis sphaerica (Rauzer-Chernoussova and Reitlinger)
Eostaffella sp.
Eostaffella of the group *E. radiata* (Brady) (= *Eostaffela mosquensis* of the Russian authors)
Eostaffella of the group *E. ikensis* Vissarionova
Eostaffella sp. (umbilicated forms)
Eostaffellina sp.
Eotuberitina sp.
"*Globivalvulina*" sp.
Globoendothyra sp.
Globoendothyra globulus d'Eichwald
Monotaxinoides sp.
Neoarchaediscus sp.
Neoarchaediscus gregorii (Dain)
Neoarchaediscus incertus (Grozdilova and Lebedeva)
Neoarchaediscus parvus (Rauzer-Chernoussova)
Neoarchaediscus postrugosus (Reitlinger)
Neoarchaediscus subbaschkiricus (Reitlinger)
Palaeonubecularia sp.
Palaeotextularia of the group *P. longiseptata* Lipina
Palaeotextularia of the group *P. consobrina* Lipina
Planospirodiscus sp.
Planospirodiscus minimus (Grozdilova and Lebedeva OBJ)
Pseudoendothyra of the group *P. kremenskensis* Rozovskaia
Pseudoendothyra cf. *P. concinna* Schlykova
Pseudoendothyra sp.
Pseudoglomospira sp.
Radiosphaerina sp.
Tetrataxis sp.
Yanichewkina sp.
Zellerina discoidea (Girty)

About a dozen undetermined species

Age: The forms *Asteroarchaediscus baschkiricus* and *Biseriella parva* indicate zone 18 of microfaunal assemblage zones, which is correlative with the upper part of the *Eumorphoceras* zone. The fauna is of early Namurian age (Armstrong and Mamet, 1970).

Distribution of families and principal genera observed in sample (see Fig. A-1).

I Archaediscidae (*Neoarchaediscus*)
II Eostaffellidae (*Eostaffella*)
III Endothyridae (*Endothyra*)
IV Attached forms (*Apterrinellidae*)
V Palaeotextulariidae (*Climacammina*)
VI Earlandiidae (*Earlandia*)
VII Cornuspiridae ("*Cornuspira*")
VIII Pseudoendothyridae (*Pseudoendothyra*)
IX Primitive Eolasiodiscidae (*Monotaxinoides*)
X Tetrataxidae (*Tetrataxis*)
XI Primitive Bradyinidae (*Yanichewkina*)
XII Biseriamminidae (*Biseriella*)

Biota 1, Canyon Fiord Formation: About 2,500 specimens of foraminifers that occur in weakly recrystallized biomicrite were obtained 4 feet above the base of formation shown in section 74 on Figure 10 (*see* Pl. XVI; GSC Cat. No. C-264).

Ammovertella sp.
Asteroarchaediscus sp.
Asteroarchaediscus baschkiricus (Krestovnikov and Teodorovitch)
Biseriella parva (Chernyscheva)
Bradyina sp.
Bradyina cribrostomata Rauzer-Chernoussova and Reitlinger
Calcisphaera laevis Williamson
Climacammina of the group *C patula* Brady

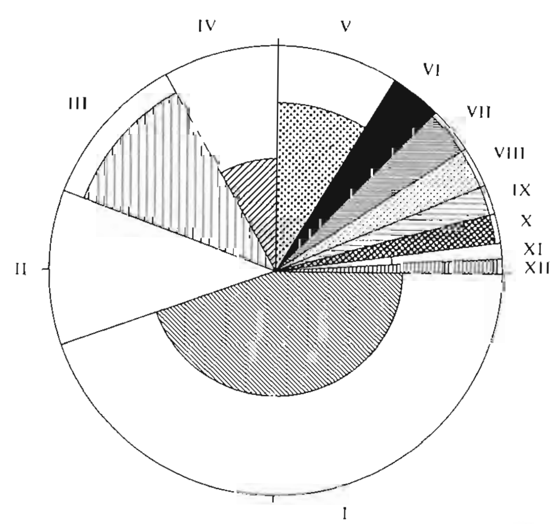

FIGURE A-1. Distribution of families and principal genera of the Borup Fiord and Canyon Fiord Formations. Circumferential distribution gives the percentage of each family. Radial distribution within each section gives the percentage of most prominent genus.

Climacammina of the group *C. prisca* Lipina
"*Cornuspira*" sp.
Earlandia clavatula (Howchin)
Earlandia vulgaris (Rauzer-Chernoussova and Reitlinger)
Endothyra sp.
Eolasiodiscus sp.
Eostaffella oblonga Ganelina
Eostaffella pseudostruvei (Rauzer-Chernoussova and Beljaev)
Eostaffella cf. *E*? *rossica* (Rosovskaia)
Globivalvulina sp.
Globivalvulina of the group *G. bulloides* (Brady)
"*Globivalvulina*" *moderata* Reitlinger
Lipinella sp.
Millerella (*Seminovella*) sp.
Millerella (*Millerella*) sp.
Monotaxinoides sp.
Neoarchaediscus sp.
Palaeonubecularia sp.
Palaeotextularia of the group *P. consobrina* Lipina
Palaeotextularia of the group *P. longiseptata* Lipina
Pseudoendothyra sp.
Pseudoglomospira sp.
Tetrataxis sp.
Tuberitina sp.
About a dozen undetermined species

Age: The forms *Globivalvulina* sensu stricto and *Lipinella* sp. indicate zone 20, which equates with the *Reticuloceras* ammonoid zone. The fauna is of early Bashkirian age (Armstrong and Mamet, 1970).

Distribution of the families and principal genera observed in the sample (see Fig. A-2).

I Archaediscidae (*Asteroarchaediscus*)
II Eostaffellidae (*Eostaffella*)
III Endothyridae (*Endothyra*)
IV Attached forms (*Apterrinellidae*)
V Palaeotextulariidae (*Climacammina*)
VI Earlandiidae (*Earlandia*)
VII Cornuspiridae ("*Cornuspira*")
VIII Pseudoendothyridae (*Pseudoendothyra*)
IX Primitive Eolasiodiscidae (*Eolasiodiscus*)
X Tetrataxidae (*Tetrataxis*)
XI Bradyinidae (*Bradyina*)
XII Biseriamminidae (*Globivalvulina*)

Biota 2, Canyon Fiord Formation: About 1,000 specimens of Foraminifera were obtained from recrystallized, quartz-bearing, intraclastic biosparite and recrystallized quartzose biomicrite. The collection was taken from beds 360 feet above base of Canyon Fiord Formation shown in section 74 on Figure 9 (GSC Cat. No. C-404).

Ammovertella sp.
Asteroarchaediscus sp.
Bradyina sp.
Calcisphaera sp.
Calcivertella sp.
Climacammina sp.

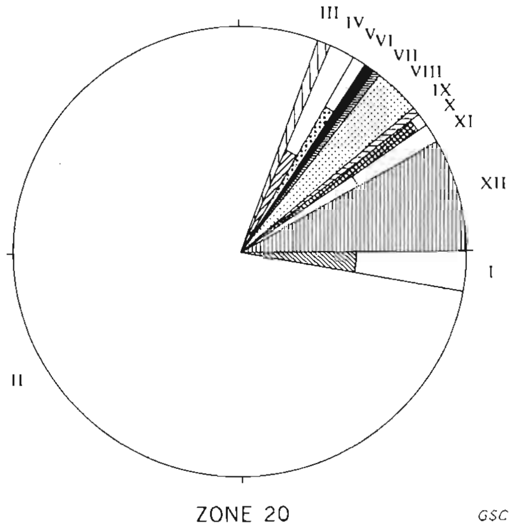

FIGURE A-2. Distribution of families and principal genera of the Borup Fiord and Canyon Fiord Formations. Circumferential distribution gives the percentage of each family. Radial distribution within each section gives the percentage of the most prominent genus.

"*Cornuspira*" sp.
Earlandia sp.
Endothyra sp.
Eolasiodiscus sp.
Eoschubertella sp.
Eostaffella sp.
Globivalvulina of the group *G. bulloides* (Brady)
trilayered *Globivalvulina* sp.
Globivalvulina granulosa Reitlinger
Komia sp.
cf. *Ozawainella* sp.
Palaeonubecularia sp.
Palaeotextularia sp.
Profusulinella sp.
Pseudoendothyra sp.
Pseudoglomospira? sp.
Pseudostaffella sp.
Tetrataxis sp.
Tetrataxis of the group *T. maxima* Schellwien
Tuberitina sp.

Age: The microfacies represents zone 23 of microfaunal assemblage zones, and is of early Moscovian age.

Distribution of families and principal genera, zone 23 (see Fig. A-3).

I Archaediscidae (*Asteroarchaediscus*)
II Eostaffellidae (*Eostaffella*)
III Endothyridae (*Endothyra*)
IV Sedentary attached forms (*Pseudoglomospira*?)
V Palaeotextulariidae (*Palaeotextularia*)

VI Earlandiidae (*Earlandia*)
VII Cornuspiridae ("*Cornuspira*")
VIII Pseudoendothyridae (*Pseudoendothyra*)
IX primitive Eolasiodiscidae (*Eolasiodiscus*)
X Tetrataxidae (*Tetrataxis*)
XI Bradyinidae (*Bradyina*)
XII Biseriamminidae (*Globivalvulina*)
XIII Fusulinidae (*Profusulinella*)
XIV Ozawainellidae (*Ozawainella*)

Biota 3, Canyon Fiord Formation: About 2,000 specimens were obtained from recrystallized biomicrite collected 630 feet above base of formation shown in section 74 on Figure 9 (GSC Cat. No. C-405).

Ammovertella sp.
Asteroarchaediscus sp.
Bradyina sp.
Bradyina eonautiliformis Reitlinger
"*Bradyina*", cf. *B. pauciseptata* Reitlinger
Beresella sp.
Calcisphaera sp.
Climacammina sp.
Climacammina cf. *C. ivanovae* Reitlinger
Climacammina of the group *C. moelleri* Reitlinger
Deckerella sp.
Diplosphaerina sp.
Earlandia sp.
Endothyra sp.
Endothyra mosquensis Reitlinger
Endothyranella sp.
Eolasiodiscus sp.
Eostaffella of the group *E. parva* (Rauzer-Chernoussova)

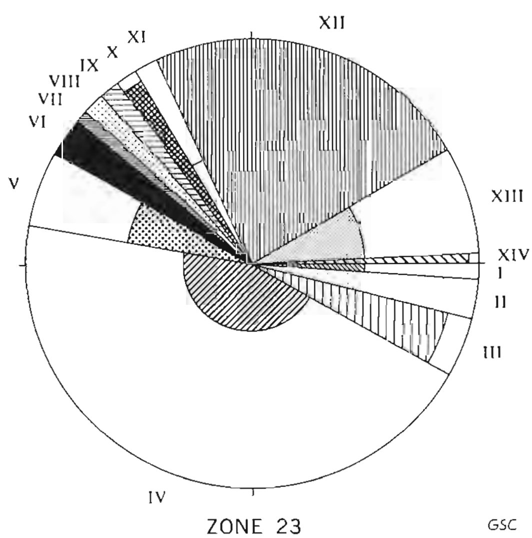

FIGURE A-3. Distribution of families and principal genera of the Borup Fiord and Canyon Fiord Formations. Circumferential distribution gives the percentage of each family. Radial distribution within each section gives the percentage of the most prominent genus.

Eostaffella postmosquensis Kireeva
Eugonophyllum sp.
Globivalvulina sp.
Globivalvulina of the group *G. bulloides* (Brady)
trilayered *Globivalvulina* sp.
Glomospirella sp.
Haplophragmina sp.
Haplophragmina kashirica Reitlinger
Hemigordius sp.
Komia sp.
Lipinella sp.
Neoarchaediscus cf. *N. postrugosus* (Reitlinger)
Ozawainella sp.
Palaeotextularia sp.
Profusulinella sp.
Psuedobradyina sp.
Pseudoglomospira sp.
Pseudostaffella sp.
Tetrataxis of the group *T. conica* Ehrenberg *emend* von Möller
Tetrataxis of the group *T. maxima* Schellwien
Trepeilopsis sp.
Tuberitina sp.
Ungdarella sp.

Age: The presence of "*Bradyina*" cf. *B. pauciseptata, Climacammina* of the group *C. moelleri*, trilayered *Globivalvulina*, and abundant *Haplophragmina kashirica* indicates a middle Moscovian age. Similar microfaunas are known in the Russian, Kashira and Podolsk horizons (Reitlinger, 1950). The microfauna is correlative with zones 24 to 26.

Distribution of families and principal genera observed in sample (see Fig. A-4).

I Archaediscidae (*Asteroarchaediscus*)
II Eostaffellidae (*Eostaffella*)
III Endothyridae (*Endothyra*)
IV Attached forms (*Apterrinellidae*)
V Palaeotextulariidae (*Climacammina*)
VI Earlandiidae (*Earlandia*)
VII Pseudoendothyridae (*Pseudoendothyra*)
VIII Eolasiodiscidae (*Eolasiodiscus*)
IX Tetrataxidae (*Tetrataxis*)
X Bradyinidae (*Bradyina*)
XI Biseriamminidae (*Globivalvulina*)
XII Fusulinidae (*Profusulinella*)
XIII Ozawainellidae (*Ozawainella*)
XIV Fischerinidae? (*Hemigordius*)

Biota 4, Canyon Fiord Formation: About 500 specimens are preserved in calcareous sandstone collected 640 feet above the base of the formation as shown in section 77 on Figure 9 (GSC No. C-406).

Ammovertella sp.
"*Cornuspira*" sp.
Earlandia sp.
Endothyra sp.
?*Eoschubertella* sp.
Eostaffella of the group *E. parva* (Rauzer-Chernoussova)
"*Globivalvulina*" of the group "*G.*" *moderata* Reitlinger

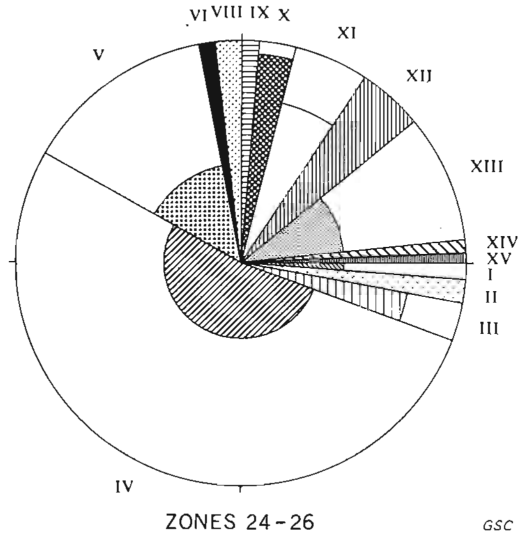

FIGURE A-4. Distribution of families and principal genera of the Borup Fiord and Canyon Fiord Formations. Circumferential distribution gives the percentage of each family. Radial distribution within each section gives the percentage of the most prominent genus.

Glomospirella sp.
Lipinella sp.
Monotaxinoides sp.
cf. *Stacheoides* sp.

Age: The precise age of the microfacies is uncertain. However, *Lipinella* sp. and the possible *Eoschubertella* suggest a late Bashkirian or early Moscovian age.

Remarks

The Carboniferous microfacies of the Borup Fiord and Canyon Fiord Formations in Ellesmere Island are represented by abundant foraminifers and algae that suggest shallow-water environments. Moreover, recrystallization of the matrices is only slight to moderate. Because of these circumstances the collections identified herein are particularly useful for micropaleontological zonation.

The populations resemble most closely those of Siberia and Alaska which are transitional between the more typically Eurasian and North American realms.

Zone 18

Microfacies. The zone is characterized by the outburst of the early Namurian *Asteroarchaediscus baschkiricus* and "*Biseriella*" *parva*. The abundance of *Asteroarchaediscus* and of *Neoarchaediscus* and the presence of *Eostaffellina* provide additional indication of an early Namurian age (Mamet and Gabrielse, 1969; Armstrong, Mamet, and Dutro, 1970; Armstrong and Mamet, 1970). *Eostaffellina*, although reported by Reitlinger (1963) from the uppermost Viséan, is in the author's opinion, characteristic of the Namurian.

Population analysis. The populations contain many late Viséan elements and is still "Lower Carboniferous" in many aspects, Archaediscidae, Eostaffellidae, Endothyridae, and Palaeotextulariidae are the major components of the free vagrant benthonic foraminifers.

Zone 20

Microfacies. The zone is characterized by the appearance of *Globivalvulina* of the group *G. bulloides*, and *Lipinella. Bradyina cribrostomata* is also characteristic of this zone. The first representatives of *Pseudostaffella antiqua* ("*Staffella*" *antiqua*) occur in this zone throughout much of Eurasia, but have not been observed in the Arctic or North American realms (Armstrong, Mamet, and Dutro, 1970; Armstrong and Mamet, 1970).

Population analysis. Zone 20 has a distinct Middle Carboniferous aspect. Indeed, the gradual decline of the Archaediscidae and Endothyridae and the development of Biseriamminidae and non-vagrant forms that characterize zone 20 are already evident in Namurian time.

Zones 21–22

This interval is poorly developed in Canadian Arctic microfacies, while it is well documented in the Central and Eastern Brooks Range, of the Arctic Slope of Alaska.

Correlations of the North American standard succession with the original European stages are difficult with regards to the Namurian–Westphalian boundary. Although it is generally accepted that the base of the Atoka Series (Zone 21) is correlative with the base of the Moscovian (Thomson *in* Loeblich and Tappan, 1964), recent work in the Dniepr–Donets region (Brazhnikova *et al.*, 1967), indicates that zones 21 and 22 should be included in the Bashkirian. Unfortunately no recent foraminiferal description of the original Bashkirian of Bashkiria is available and the contention of Brazhnikova *et al.* cannot be checked. However, if their view is correct, the basal Moscovian should be correlated with the Des Moines Series and the Atoka fauna should be considered as Bashkirian.

Zone 23

Microfacies. Zone 23 retains scarce Namurian endothyroids and witnesses the first appearance of *Globivalvulina granulosa* in association with abundant *Eoschubertella* and primitive *Ozawainella.* (The latter genus is used here in the sense of Rauzer-Chernoussova.)

Population analysis. Population analysis indicates the numerical importance of such non-vagrant forms as Palaeotextulariidae and Fusulinidae. The early Moscovian is regarded by Reitlinger (1950) as the time of extinction of the Archaediscidae. However, this family is known in rocks as young as Asselian, and the writer has encountered it in association with *Profusulinella* and *Triticites.* Members of the Archaediscidae occur in zone 23.

Zones 24–26

Microfacies. Bradyina, exhibiting reduction of the keriotheca, extremely thick-walled, *Climacammina* of the group *C. moelleri* and trilayered *Globivalvulina* are characteristic forms in the middle Moscovian. Moreover, the abundance of *Haplophragmina kashirica* and *Bradyina eonautiliformis* confirms this age, although it is not possible at this time to suggest precise correlation with the zonal scheme of the Russian Platform (Reitlinger, 1950).

Population analysis. The results of analysis are similar to those of zone 23; abundance of non-vagrant forms, Palaeotextulariidae, Biseriamminidae and Fusulinidae. Archaediscidae are present also, though numerically negligible.

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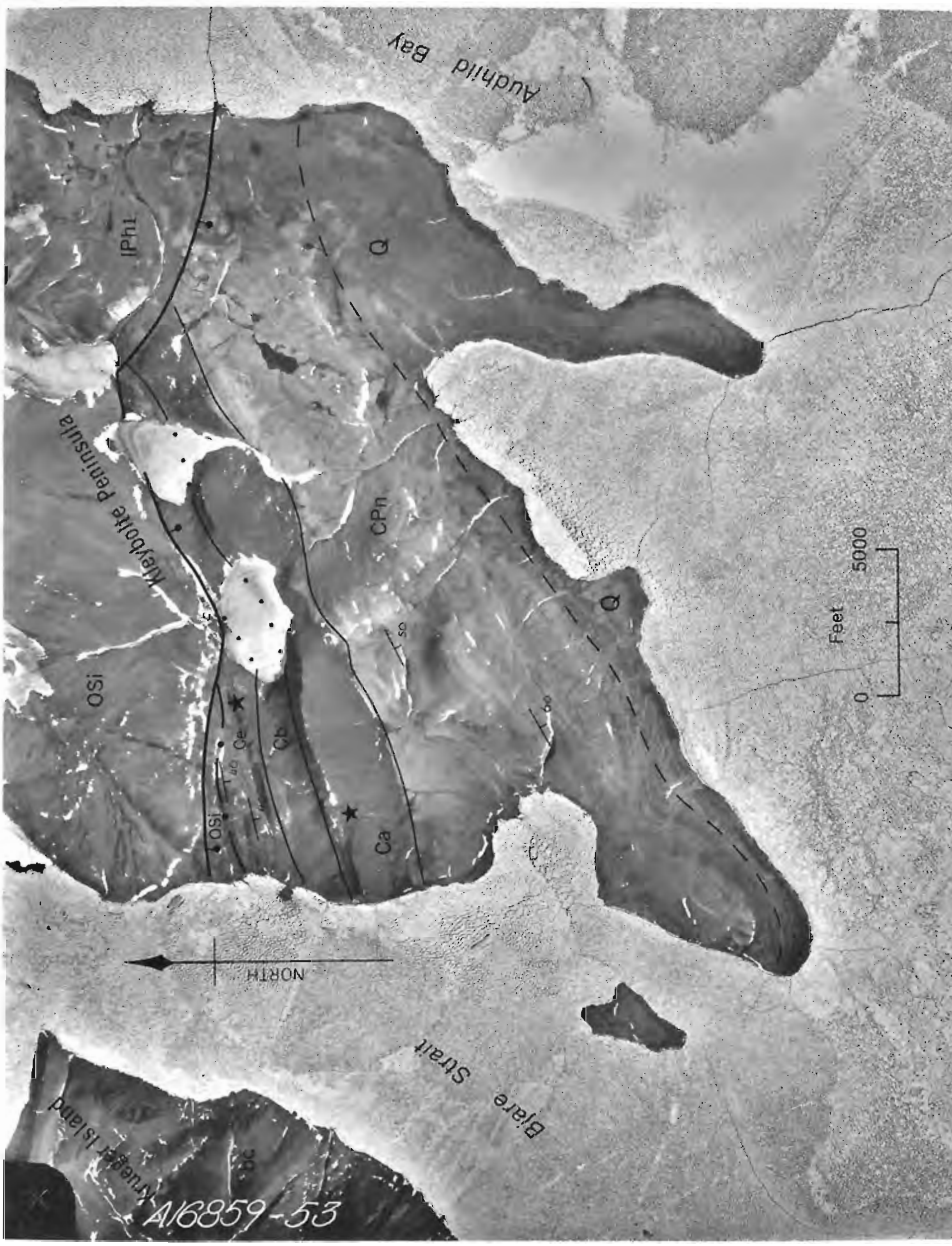

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PLATE I. Vertical aerial photograph of Kleybolte Peninsula that forms the northwestern extremity of Ellesmere Island. The type sections of Emma Fiord Formation and Audhild Formation are indicated by solid stars. Dotted and dashed line marks angular unconformity between basal beds of the Sverdrup Basin and rocks of the underlying Franklinian Geosyncline. Geology by R. Thorsteinsson and H. P. Trettin. bc, Bourne Complex, slaty siltstone, shale, tuffaceous (?) green phyllite, volcanic flows, and hornfels of uncertain age, but probably pre-Silurian. The complex is cut by numerous diabase intrusions of unknown age; lPhl, thermally metamorphosed shale, siltstone, sandstone and limestone with dioritic intrusions, probably Middle or Late Devonian age; Ce, Emma Fiord Formation; Cb, Borup Fiord Formation; Ca, Audhild Formation; and CPn, Nansen Formation.

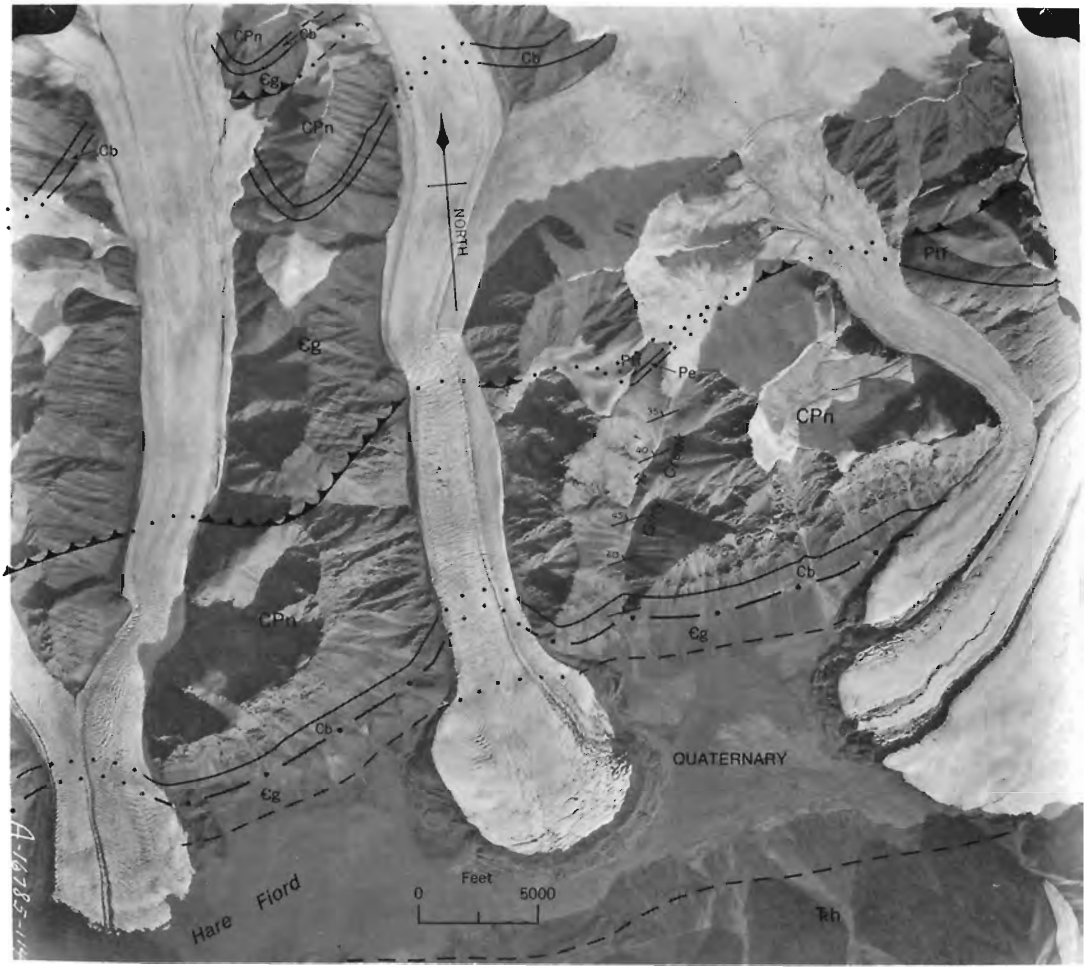

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PLATE II. Vertical aerial photograph of thrust faulted mountains north of head of Hare Fiord in northwestern Ellesmere Island showing type section of Nansen Formation. Crossed hammers are located at approximate centre of traverse along which stratigraphic column 68 in Figure 9 was measured. Dotted and dashed line marks angular unconformity between basal beds of Sverdrup Basin and rocks of underlying Franklinian Geosyncline. Geology by R. Thorsteinsson and H. P. Trettin. Cg, Grant Land Formation, Early Ordovician and/or Cambrian age; Cb, Borup Fiord Formation; CPn, Nansen Formation; Pe, Esayoo Formation; Ptf, Trold Fiord Formation; and Trh, Heiberg Formation, Upper Triassic.

PLATE III

Type sections of Otto Fiord Formation (Co) and Hare Fiord Formation (CPh) about three miles east of van Hauen Pass in northwestern Ellesmere Island. The view is west towards the pass. The Otto Fiord is composed mainly of anhydrite and gypsum and is characteristically light coloured. It also contains interbeds of limestone that stand out as dark layers. The Otto Fiord is thrust over the Middle and Upper Triassic, Blaa Mountain Formation (Trba). The Hare Fiord comprises dark coloured, impure limestone, siltstone and shale and is typically dark weathering.

PLATE IV

Aerial view of type sections of the formations, Otto Fiord (Co), Hare Fiord (CPh), van Hauen (Pv), and Degerböls (Pd), which are represented graphically as section 69, in Figure 9. The view is to the east from above van Hauen Pass. The formations dip steeply to north. The arrow points to a prominent ravine shown above dog sledge in photograph reproduced above as Plate III. Trbl, Blind Fiord Formation, Lower Triassic.

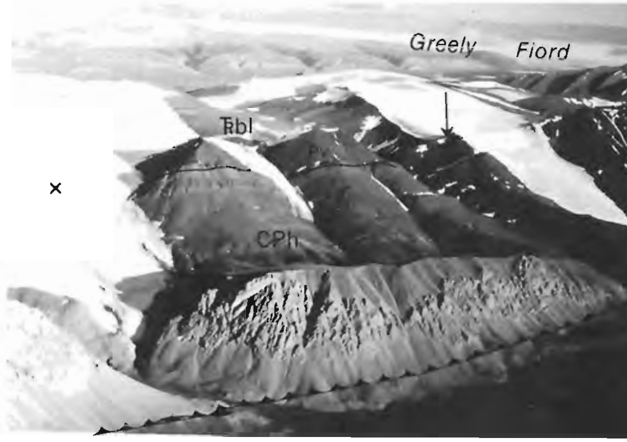
PLATE V

Basal strata of the Canyon Fiord Formation (Cc) lying with angular unconformity on the Cornwallis Group (Oc) on the west side of Trold Fiord, western Ellesmere Island (see loc. 137, *Eureka Sound South*). Cc-a, basal unit of conglomerate and redbeds, 45 feet thick; Cc-b, anhydrite and gypsum, 200 feet thick; and Cc-c, limestone containing Moscovian fusulinaceans. The latter unit clearly belongs to the Canyon Fiord, but units Cc-a and Cc-b, are only tentatively assigned to that formation. These two units may in fact, represent the Lower and Upper Carboniferous Otto Fiord Formation that outcrops extensively in eastern Axel Heiberg Island and northwestern Ellesmere Island.

PLATE VI. View looking west from valley bottom at head of Hare Fiord in northwestern Ellesmere Island. The type section of Nansen Formation (CPn), a uniform sequence of light weathering limestone, was measured on ravine seen in right foreground. Dotted and dashed line marks angular unconformity between Borup Fiord Formation (Cb), and Cg, Grant Land Formation, Early Ordovician and/or Cambrian age. This figure supplements photograph reproduced as Plate II.

PLATE VII. Characteristic exposures of anhydrite and gypsum of the Otto Fiord Formation (Co), overlain by dark grey to black shale, siltstone and impure limestone of Hare Fiord Formation (CPh). Arrow points to small bioherm in basal Hare Fiord beds from which R. L. Christie and W. W. Nassichuk collected an ammonoid fauna of early Moscovian age (see Nassichuk and Furnish, 1965). View is to west from delta of Stepanow Creek. About 24 miles separate this locality and the locality shown in Plate VI. The Otto Fiord Formation and Hare Fiord Formation are correlative with the Nansen Formation.

PLATE VIII



Aerial view southeastward over spectacular limestone masses in basal part of Hare Fiord Formation (CPh), that is thrust over Lower Triassic Blind Fiord Formation (Trbl), in Blue Mountains between Hare Fiord and Greely Fiord in northwestern Ellesmere Island. Crossed hammers are positioned on locality that yielded the Lower Permian ammonoid, *Paragastrioceras* n. sp., described by Nassichuk, Furnish and Glenister (1965, p. 18). Section 68B in Figure 9, was measured in ravine to right of crossed hammers. Arrow points to prominent cuesta developed in van Hauen Formation (Pv), the upper surface of which marks Permian and Triassic boundary.

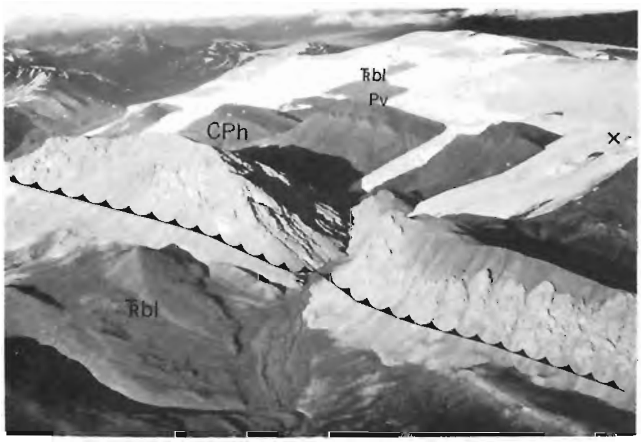


PLATE IX

Aerial view eastward and supplementing photograph reproduced in Plate VIII. The x on this plate and that of Plate VIII mark corresponding localities.

PLATE X

Aerial view eastward along fiord wall that rises to an elevation of 2,900 feet above sea level on south side of Otto Fiord in northwestern Ellesmere Island. Standing in this imposing line of cliffs are the formations; Nansen (CPn), van Hauen (Pv), and Degerböls (Pd) overlain on backslope by Lower Triassic Blind Fiord Formation (Trbl). Dark layers in Nansen limestone are interbeds of shale and siltstone that reflect proximity to region of facies change with the predominantly clastic, Hare Fiord Formation that occurs a few miles to south.

PLATE XI

Aerial view of Nansen Formation (CPn), van Hauen Formation (Pv) and Lower Triassic, Blind Fiord Formation (Trbl), on west side of Blind Fiord in western Ellesmere Island. View is to north and along the strike of the van Hauen. All three formations dip fairly steeply to the west. Note the contrasted topographic expressions of the lower shale and siltstone member and the upper chert member of the van Hauen.

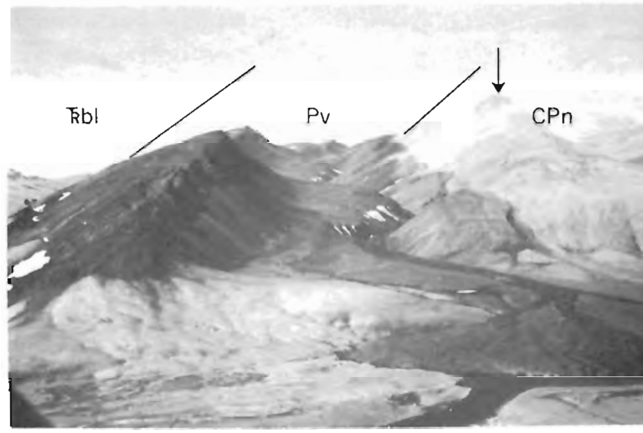


PLATE XII

Green beds of the Trold Fiord Formation (Ptf) lying on redbeds of the Canyon Fiord Formation (Cc), and overlain by redbeds of the Lower Triassic, Bjorne Formation (Trb). This locality is about a mile west of Trold Fiord in west-central regions of Ellesmere Island, and some 4 miles south of the head of the fiord. View is to south and across the ravine in which was measured stratigraphic column 64 in Figure 8. Note the angular relations of the Canyon Fiord–Trold Fiord contact.

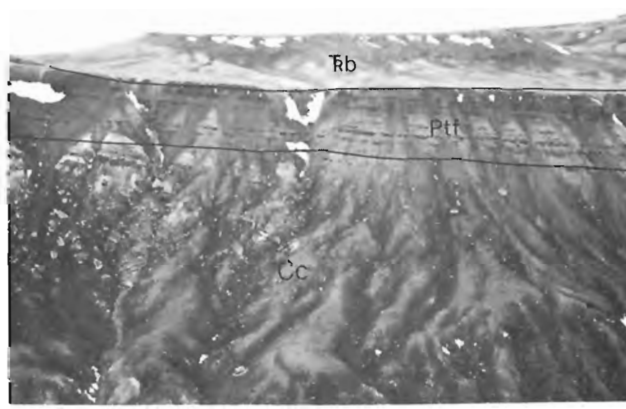


PLATE XIII

Aerial view of the same territory shown above in Plate XI. The arrows here and in Plate XI point to one and the same reefoid mass of Permian age. In this region the Nansen Formation (CPn) is characterized by alternating hard units of limestone and softer units of mainly calcareous siltstone which impart a pronounced banded appearance to the formation, especially when viewed from a distance.

A16606-60

PLATE XIV. Vertical aerial photograph showing type section of Canyon Fiord Formation on northeast side of Cañon Fiord in western Ellesmere Island. The three dotted lines indicate traverses along which composite section 75 on Figure 9 was measured. Dotted and dashed line marks angular unconformity between rocks of Sverdrup Basin and Franklinian Geosyncline. Arrow points to ravine designated by J. C. Troelsen (1950) as the type locality of Canyon Fiord Formation, and illustrated as Figure 9 in his report. Geology by J. Wm. Kerr, R. Thorsteinsson and H. P. Trettin. Oc, Cornwallis Group, Middle Ordovician; OSa, Allen Bay Formation, Upper Ordovician and Lower Silurian; SDcp, Cape Phillips Formation, Lower, Middle and Upper Silurian and Lower Devonian; Di, Imina Formation, Lower Devonian; De, Eids Formation, Lower Devonian; and CPc, Canyon Fiord Formation. In this part of Ellesmere Island the Canyon Fiord Formation includes both Carboniferous and Permian rocks.

PLATE XV

Exposures of Canyon Fiord Formation (CPc) overlain by Trold Fiord Formation (Ptf), on south side of Cañon Fiord, western region of Ellesmere Island. These exposures are depicted as column 76 of Figure 9. In this part of Ellesmere Island the Canyon Fiord includes strata of both Carboniferous and Permian ages.

PLATE XVI

Angular unconformity between Canyon Fiord Formation (Cc) and the Middle Ordovician Cornwallis Group (Oc), at locality described below under Plate XVII. Hammer rests on unconformity. Basal 4.5 feet of the Canyon Fiord is composed of interbedded, light coloured limestone, pebble-conglomerate and quartzose sandstone. Strata in upper half of photograph consist of mainly thick-bedded conglomerate that normally characterizes base of formation. Crossed hammers are located on limestone that has yielded Foraminifera (GSC Cat. No. C-264) dated as early Bashkirian.

PLATE XVII

Canyon Fiord Formation (Cc) unconformably overlying Cornwallis Group (Oc) at headwater of Tschernyschew River, Hamilton Peninsula in western Ellesmere Island. View to north. Icefield of Albert and Victoria Mountains barely visible to right of photograph. Arrow points to outcrops (just off photograph) shown above in Plate XVI, and which constitute basal beds of measured section shown as section 74 in Figure 9.

A16706-93

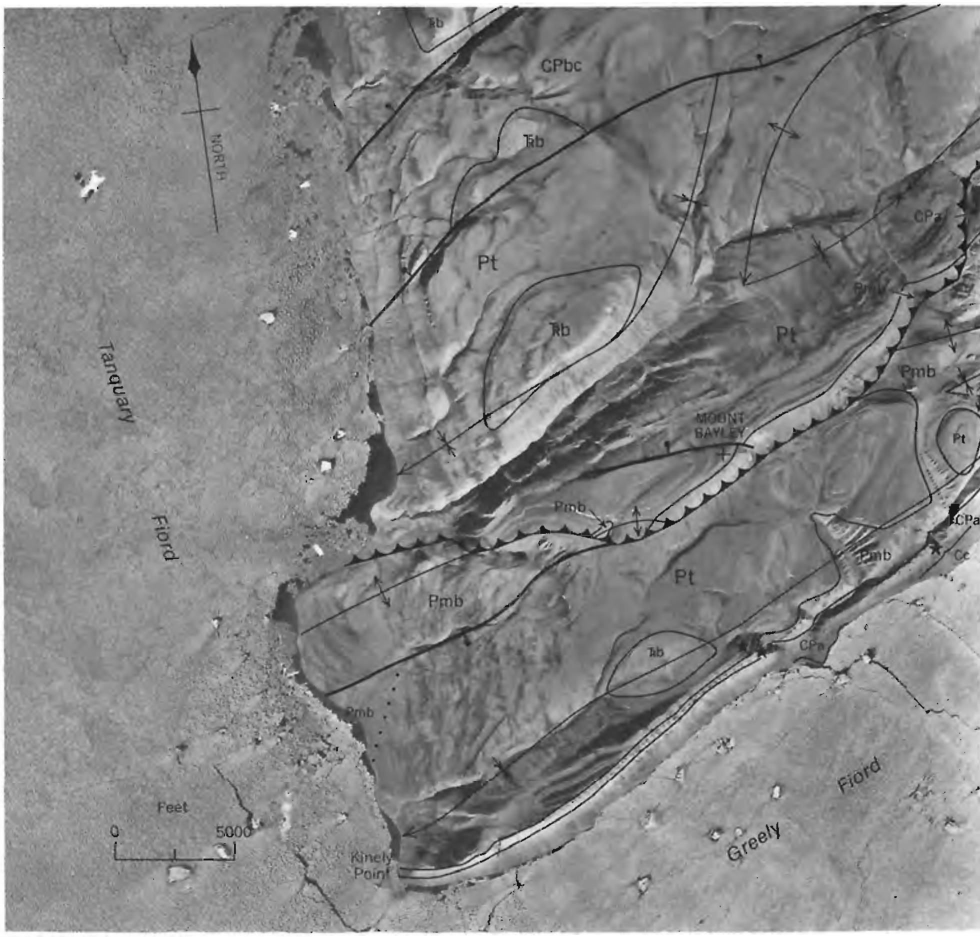
PLATE XVIII. Vertical aerial photograph of territory northeast of head of Vesle Fiord in western regions of Ellesmere Island. Dotted and dashed line marks angular unconformity between basal strata of Sverdrup Basin and rocks of the underlying Franklinian Geosyncline. The territory shown here is of particular interest in depicting the complex structural relationships that characterize formations in near-shore regions of the Sverdrup Basin. Note pinch out of Bjorne Formation and Canyon Fiord Formation owing mainly to transgressive nature of the Isachsen Formation. Geology by J. W. Kerr, R. Thorsteinsson and E. T. Tozer. Oe, Eleanor River Formation, Lower Ordovician; Oc, Cornwallis Group, Middle Ordovician; OSa, Allen Bay Formation, Lower Ordovician and Lower Silurian; SDcp, Cape Phillips Formation, Middle Silurian to Lower Devonian; De, Eids Formation, Lower Devonian; Dbl, Blue Fiord Formation, Lower and Middle Devonian; Dob, Okse Bay Formation, Upper Devonian; Cc, Canyon Fiord Formation; Trb, Bjorne Formation, Lower Triassic; Ki, Isachsen, Lower Cretaceous; Kc, Christopher Formation, Lower Cretaceous; Kh, Hassel Formation, Upper Cretaceous; Kk, Kanguk Formation, Upper Cretaceous; and Te, Eureka Sound Formation, Tertiary.

A16186-13

PLATE XIX. Vertical aerial photograph of environs of Eids Fiord, southwestern Ellesmere Island. Dotted and dashed line marks angular unconformity between basal strata of Sverdrup Basin and underlying Franklinian Geosyncline. Crossed hammers are located at approximate centre of traverse along which was measured section 50 in Figure 7. Bedded character of Canyon Fiord Formation results from alternating soft and harder units of quartzose sandstone; that of Belcher Channel Formation is the result of resistant units of limestone that alternate with softer units of quartzose sandstone. Geology south of Eids Fiord by J. W. Kerr. Geology north of Eids Fiord by R. Thorsteinsson. De, Eids Formation, Lower Devonian; Dbl, Blue Fiord Formation, Lower and Middle Devonian; Cc, Canyon Fiord Formation; CPbc, Belcher Channel Formation; Pa, Assistance Formation; and Ki, Isachsen Formation, Early Cretaceous.

A16606-57

PLATE XX. Vertical aerial photograph of Hamilton Peninsula in western Ellesmere Island. Dotted and dashed line marks angular unconformity between basal strata of Sverdrup Basin and rocks of underlying Franklinian Geosyncline. Note weathering characteristics and topographic expressions of various Carboniferous and Permian Formations. Note also overstep of Trold Fiord Formation from northwest to southeast. Crossed hammers mark approximate centre of traverse along which was measured section 73 in Figure 9. Pl, undivided lower Paleozoic rocks; Cc, Canyon Fiord Formation; CPbc, Belcher Channel Formation; CPan, Antoinette Formation; Ps, Sabine Bay Formation; Pa, Assistance Formation; Ptf, Trold Fiord Formation; and Trb, Bjorne Formation, Lower Triassic.



A16693-138

PLATE XXI. Vertical aerial photograph of unnamed peninsula formed by junction of Tanquary Fiord and Greely Fiord in northern Ellesmere Island. Solid stars mark locations of type sections of Antoinette Formation (illustrated graphically as section 81 in Figure 10), and Mount Bayley and Tanquary Formations (illustrated graphically as section 80 in Figure 10). The anhydrite of the Mount Bayley Formation, a few miles north of these type sections, grades laterally into limestone and minor siltstone and sandstone that are indistinguishable from the Antoinette and Tanquary Formations. This facies change thus produces a single stratigraphic unit that is mapped as the Belcher Channel Formation. As the facies change takes place largely in the subsurface the line of separation between equivalent rock units has been arbitrarily placed along a fault. Note characteristic light colour of anhydrite and gypsum of Mount Bayley Formation; also the distinctly bedded nature of Tanquary Formation that results from alternating units of resistant limestone and softer units of siltstone and sandstone. Cc, Canyon Fiord Formation; CPa, Antoinette Formation; Pmb, Mount Bayley Formation; Pt, Tanquary Formation; CPbc, Belcher Channel Formation; and Trb, Bjorne Formation, Lower Triassic.

PLATE XXII

Svartevaeg Cliffs near northern extremity of Axel Heiberg Island. View looking northwest from the ice of Nansen Sound and towards Arctic Ocean. The cliffs seen here rise to over 1,000 feet above sea level. They consist of nearly flat lying limestone and lesser amounts of chert that are assigned to the Nansen Formation (CPn). The prominent cleft in cliffs that is visible in centre background may be seen in centre background of a photograph of Svartevaeg Cliffs that is reproduced opposite page 196 in Dr. Frederick A. Cook's (1911) narrative, *My Attainment of the Pole.*

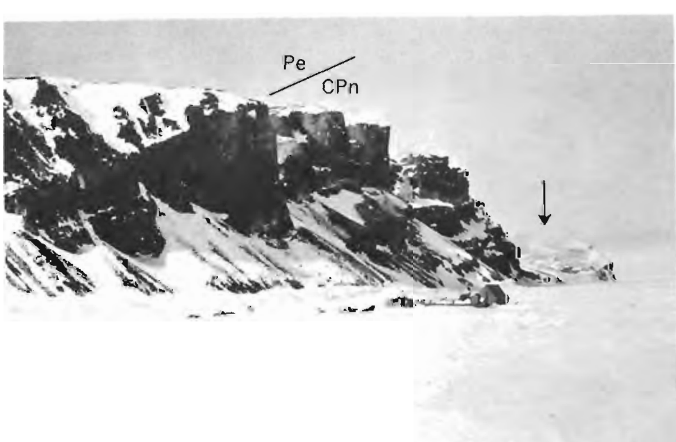
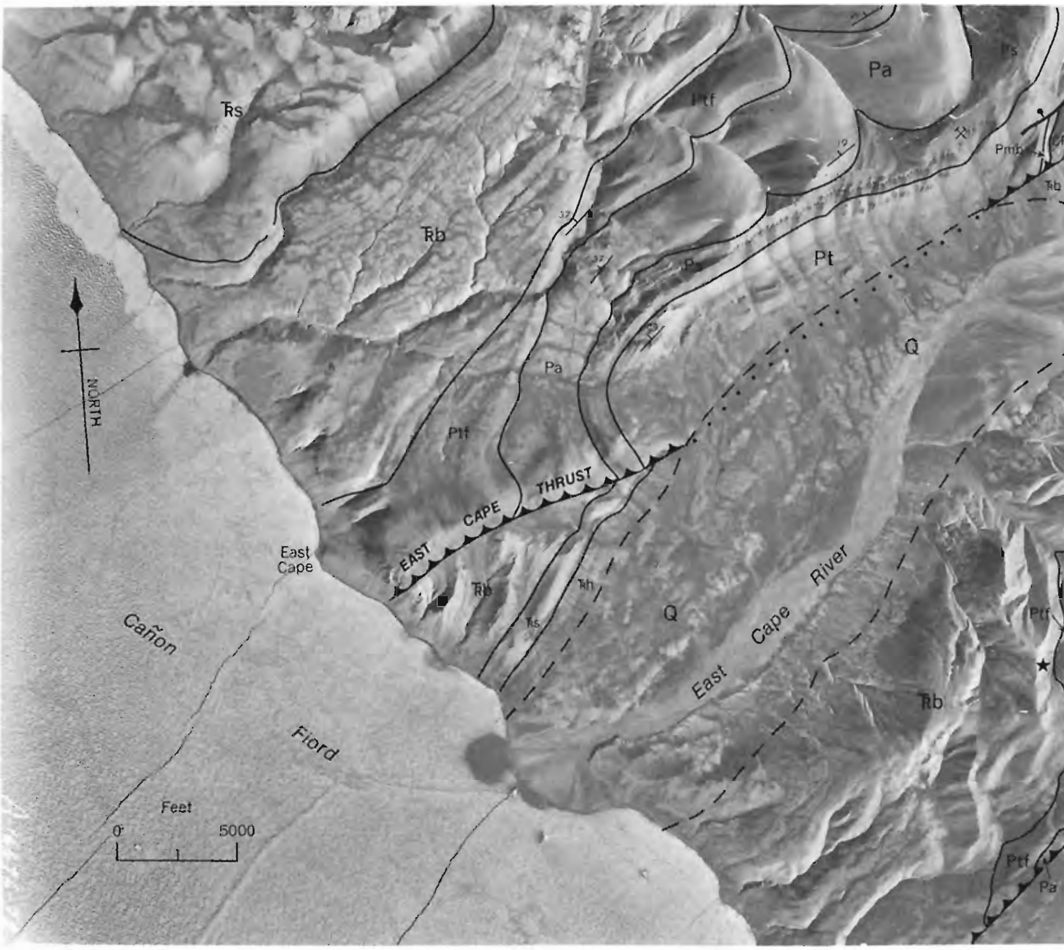


PLATE XXIII. Southeastern extremity of Svartevaeg Cliffs showing volcanic rocks of Esayoo Formation (Pe) overlying Nansen Formation (CPn). Arrow points to location of cliffs shown above in Plate XXII. The volcanic rocks shown here were discovered by Per Schei (1904, p. 461).

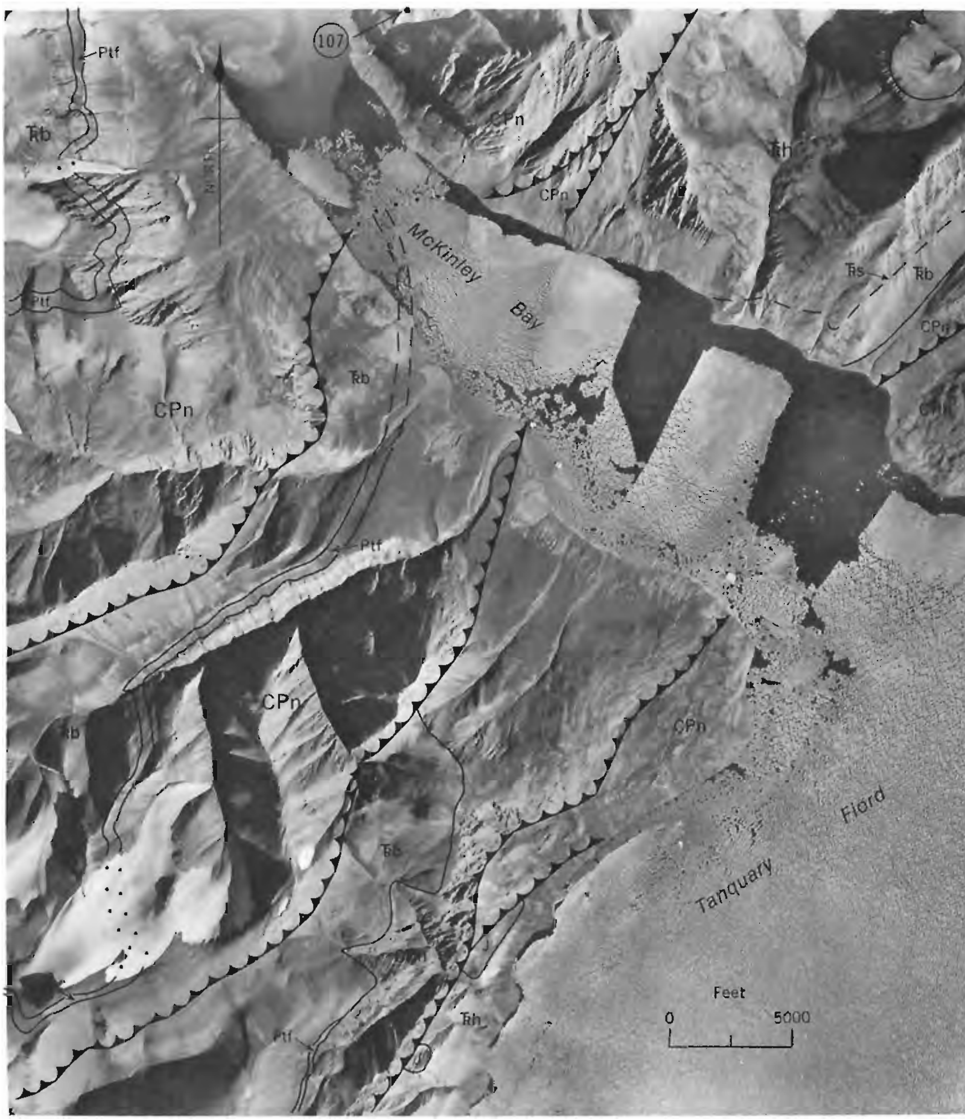


A16676-73

PLATE XXIV. Vertical aerial photograph of East Cape and vicinity on the northeast side of Cañon Fiord in western Ellesmere Island. Photograph illustrates well the weathering characteristics and topographic expressions of various Carboniferous and Permian Formations. Dark coloured units of rock in Tanquary Formation and Sabine Bay Formation are sills. A dyke that cuts Assistance Formation may be seen near centre of photograph. Crossed hammers mark approximate centre of traverse along which was measured section 71 in Figure 9. Solid star is positioned on Bjorne Formation immediately to left of type section of Trold Fiord Formation which is illustrated as section 72 in Figure 9. Geology by R. Thorsteinsson and E. T. Tozer. CPa, Antoinette Formation; Pmb, Mount Bayley Formation; Pt, Tanquary Formation; Ps, Sabine Bay Formation; Pa, Assistance Formation; Ptf, Trold Fiord Formation; Trb, Bjorne Formation, Lower Triassic; Trs, Schei Point Formation, Middle and Upper Triassic; Trh, Heiberg Formation, Upper Triassic; and Q, Quaternary.

A16706–75

PLATE XXV. Vertical aerial photograph of environs of Mount Bridgman in Sawtooth Range, western Ellesmere Island. Crossed hammers are positioned in approximate centre of traverse along which was measured section 56 in Figure 7. Geology by R. Thorsteinsson and E. T. Tozer. CPan, Antoinette Formation; Pmb, Mount Bayley Formation; Pt, Tanquary Formation; Ps, Sabine Bay Formation; Pa, Assistance Formation; Ptf, Trold Fiord Formation; Trb, Bjorne Formation, Lower Triassic; Trs, Schei Point Formation, Middle and Upper Triassic; Trh, Heiberg Formation, Upper Triassic; J, Jurassic formations; Ki, Isachsen Formation, Lower Cretaceous; Kc, Christopher Formation, Lower Cretaceous; Kh, Hassel Formation, Upper Cretaceous; Kk Kanguk Formation, Upper Cretaceous; and Te, Eureka Sound Formation, Tertiary.



A16691–164

PLATE XXVI. Vertical aerial photograph of thrust-faulted mountains in environs of McKinley Bay and Tanquary Fiord in northern Ellesmere Island. Note the distinctly bedded character of Nansen Formation that results from alternating units of hard limestone, and softer units of quartzose sandstone and siltstone. The clastic rocks reflect proximity of this region to the shoreline of the Sverdrup Basin. Note also pinch-out of Trold Fiord Formation in southeastern part of region. Arrow points to locality where *Schwagerina hyperborea* (Salter) was collected in upper 20 feet of Nansen Formation. Geology by R. Thorsteinsson and E. T. Tozer. CPn, Nansen Formation; Ptf, Trold Fiord Formation; Trb, Bjorne Formation, Lower Triassic; Trs, Schei Point Formation, Upper Triassic; Trh, Heiberg Formation, Upper Triassic; and J, undivided Jurassic strata. The significance of the uncommonly thin Schei Point section in this region is discussed by Tozer (1963d, p. 6).

A16760-194

PLATE XXVII. Vertical aerial photograph of much faulted area on the east coast of Bjorne Peninsula in southwestern Ellesmere Island. Crossed hammers mark locality of a Lower Permian, ammonoid fauna collected in the Assistance Formation and described by Nassichuk, Furnish and Glenister (1965, p. 8). The crossed hammers are also located near centre of traverse along which was measured section 52 of Figure 7. Cc, Canyon Fiord Formation; CPbc, Belcher Channel Formation; Pa, Assistance Formation; and Pd, Degerböls Formation.

INDEX

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