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GEOLOGY OF AMUND RINGNES, CORNWALL, AND HAIG-THOMAS ISLANDS, DISTRICT OF FRANKLIN

H.R. BALKWILL

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Preface

Sverdrup Basin in the northwestern part of the Canadian Arctic Archipelago encompasses 310 000 km^2, more than half of which is covered by water. There has been intermittent subsidence in the area since early Carboniferous time and at its centre the basin is more than 9000 m thick. It is filled mainly with sandstone and shale but in its basal part includes some carbonates and evaporites. Exploration for hydrocarbons, commenced in 1969, resulted in the discovery of major gas pools on northern Melville Island, King Christian Island and western Ellef Ringnes Island. Although no active oil or natural gas seeps were noted during the fieldwork on which this report is based, and although the only boreholes that have been drilled have been dry, the area includes several possible reservoir horizons and continues to attract the interest of exploration companies.

This report presents surface and subsurface bedrock data and stratigraphic and structural interpretations for the very thick succession of Mesozoic rocks exposed in the south-central part of Sverdrup Basin and relates these to a conceptual model for its evolution. Both the data and the new concepts presented will be of assistance to those engaged in assessing Canada's oil and natural gas resources. Although submitted for publication in 1979, production problems have delayed the release of this report until this year although parts were earlier placed on Open File.

Ottawa, March 1983

R.A. Price
Director General
Geological Survey of Canada

Préface

Le bassin Sverdrup, occupant la partie nord-ouest de l'Archipel arctique canadien, englobe 310 000 km^2 dont plus de la moitié repose sous les eaux. Un mouvement de subsidence intermittent s'y poursuit depuis le début du Carbonifère et le bassin atteint, en sa partie centrale, une épaisseur de 9 000 m. Constitué surtout de grès et de schiste argileux, la partie basale, par contre, renferme également des carbonates et des évaporites. Les travaux de recherche des hydrocarbures, entrepris en 1969, ont mené à la découverte d'importants gisements de gaz au sud des îles Melville et Roi-Christian, et à l'ouest de l'île Ellef Ringnes. Bien qu'aucun suintement actif de pétrole ou de gaz naturel n'ait été noté au cours des travaux sur le terrain ayant servi à la compilation du présent rapport, et quoique les trous de sondage effectués se soient avérés stériles, la région renferme néanmoins quelques horizons pouvant contenir des réservoirs et suscite toujours l'intérêt de sociétés d'exploration.

Le présent rapport comprend des données relatives à la surface et au sous-sol de la roche en place ainsi que l'interprétation stratigraphique et structurale de la présence de l'épaisse série de roches mésozoïques affleurant dans la partie sud-centrale du bassin Sverdrup; il réussit également à relier ces interprétations à un modèle conceptuel établi en vue d'illustrer l'évolution de la série. Les données et les nouveaux concepts avancés ne peuvent que s'avérer utiles aux scientifiques chargés de l'évaluation des ressources canadiennes en pétrole et en gaz naturel. Bien que le rapport ait été soumis en 1979, des problèmes de production ont retardé sa publication jusqu'à maintenant; néanmoins, certaines sections avaient auparavant été versées au dossier public.

Ottawa, mars 1983

R.A. Price
Le directeur général de la
Commission géologique du Canada

CONTENTS

Figures

GEOLOGY OF AMUND RINGNES, CORNWALL, AND HAIG-THOMAS ISLANDS, DISTRICT OF FRANKLIN

Abstract

Amund Ringnes, Cornwall, and Haig-Thomas islands are in the south-central part of the Sverdrup Basin, a large pericratonic depression in the Canadian Arctic Archipelago containing upper Paleozoic, Mesozoic, and Cenozoic marine and nonmarine sedimentary rocks. Strata exposed on those islands, and penetrated by drillholes, consist of alternating thick successions of sandstone, siltstone, and shale, ranging from possibly Middle Triassic to Upper Cretaceous; the exposed succession is about 5000 m thick. Sediments forming those terrigenous clastic rocks were transported to the basin mainly from source terrains south and east of the basin margin. Gabbro dykes and sills have intruded Mesozoic rocks on both Amund Ringnes and Cornwall islands; radiometric ages for the intrusions range from about 144 Ma to about 117 Ma. The intrusive rocks reach progressively higher in the stratigraphic succession toward the basin depocentre; this and other considerations lead to the suggestion that phases of mafic intrusion accompanied accelerated rates of crustal subsidence and sedimentation.

Isolated remnants of upper Paleocene to middle Eocene sandstones lie with angular unconformity on Mesozoic strata on central Cornwall Island and south-central Amund Ringnes Island, demonstrating Late Cretaceous and early Tertiary uplift and erosion of at least 3600 m of strata along the crest of a northwestward-plunging regional element called Cornwall Arch.

A huge piercement complex composed mainly of Mississippian and Pennsylvanian evaporitic rocks, has intruded M ~ozoic strata on northern Amund Ringnes Island. The complex is part of a regional array of structures that were generated by halokinetic processes, perhaps beginning as early as Triassic.

No active oil or gas seeps were observed on Amund Ringnes, Cornwall, or Haig-Thomas islands. Small sulphurous deposits on Amund Ringnes Island may have been generated partly by emanations of natural gas.

Four exploratory wells were drilled on, or adjacent to, Amund Ringnes Island; all of the wells were dry. One well has been drilled on Cornwall Island. The lower part of the Mesozoic and upper part of the Paleozoic succession in parts of the region have been buried deeply, intruded widely by mafic dykes and sills (which have caused local alteration of the sedimentary rocks), uplifted by Tertiary tectonism, and breached deeply by erosion, thus diminishing the probabilities of large hydrocarbon pools.

Résumé

Les îles Amund Ringnes, Cornwall, et Haig-Thomas se trouvent au sud du centre du bassin de Sverdrup, dans une vaste dépression péricratonique de l'archipel Arctique canadien, contenant des roches sédimentaires marines et non marines d'âge paléozoique supérieur, mésozoique, et cénozoique. Les couches exposées sur ces îles, et traversées par des trous de forage, sont constituées d'épaisses successions alternées de grès, siltstone, argile litée, dont l'âge s'échelonne probablement entre le Trias moyen et le Crétacé supérieur; la succession exposée a environ 5000 m d'épaisseur. Les sédiments qui forment ces roches clastiques terrigènes ont été transportés jusque dans le bassin, après avoir été arrachés principalement à des terrains situés au sud et à l'est du rebord du bassin. Des dykes et sills de gabbro sont intrusifs dans des roches mésozoiques à la fois sur les îles Amund Ringnes et Cornwall; l'âge des intrusions, tel que déterminé par analyse géochronologique, se situe entre 144 Ma et 117 Ma environ. Les roches intrusives atteignent des niveaux de plus en plus élevés de la succession stratigraphique à mesure qu'on se rapproche de l'axe de sédimentation du bassin; cette considération et d'autres nous suggèrent que les phases d'intrusion mafique ont concordé avec un rythme accéleré de sédimentation et de subsidence de la croûte terrestre.

Des vestiges isolés de grès dont l'âge s'échelonne entre le Paléocène supérieur et l'Eocène moyen reposent en discordance angulaire sur des strates mésozoiques au centre de l'île Cornwall et au sud du centre de l'île Amund Ringnes, ce qui indique qu'au Crétacé supérieur, et au début du Tertiaire, il y a eu soulèvement et érosion d'au moins 3600 m de strates, le long de la crête d'un élément régional plongeant vers le nord-ouest, que l'on appelle l'arc de Cornwall.

Un immense complexe de percement composé principalement de roches évaporitiques d'âge mississippien et pennsylvanien est intrusif dans des strates mésozoiques du nord de l'île Amund Ringnes. Le complexe de percement fait partie d'un réseau régional de structures qui ont été engendrées par des processus halocinétiques qui se sont peut-être manifestés dès le Trias.

On n'a pas observé de suintements actifs de pétrole ou de gaz dans les îles Amund Ringnes, Cornwall, ou Haig-Thomas. Ouelques petits gisements sulfureux de l'île Amund Ringnes doivent peut-être en partie leur existence à des émanations de gaz naturel.

On a foré quatre puits d'exploration sur l'île Amund Ringnes, ou à proximité; tous les puits étaient secs. La tranche inférieure de la succession mésozoique et la tranche supérieure de la succession paléozoique d'une partie de la région ont été profondement enfouies, et traversées par un grand nombre de dykes et sills mafiques (qui ont pu provoquer une altération locale des roches sédimentaires), puis soulevées au cours des évènements tectoniques du Tertiaire, et profondément entaillées par l'érosion, ce qui réduit les probabilités de rencontrer d'importantes nappes d'hydrocarbures.

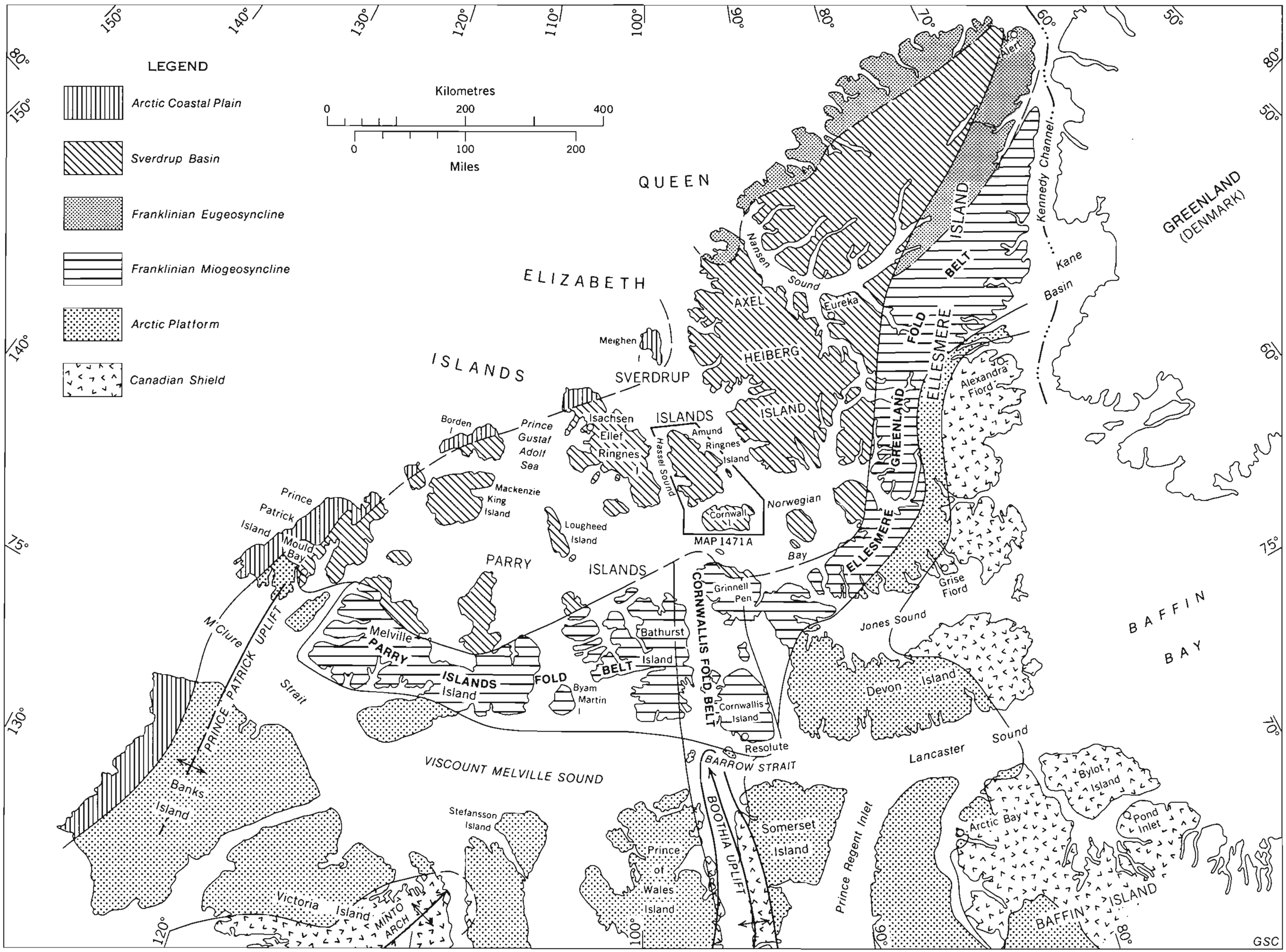

Figure 1. Geological provinces, Queen Elizabeth Islands and environs, Canadian Arctic Archipelago (after Thorsteinsson and Tozer, 1970); Amund Ringnes, Cornwall and Haig-Thomas islands within heavy border.

INTRODUCTION

Location and access

Amund Ringnes Island (about 4530 km^2) and Cornwall Island (1860 km^2) are near the geographic centre of the Queen Elizabeth Islands of the Canadian Arctic Archipelago (Fig. 1); the islands are separated by the shallow waters of narrow Hendriksen Strait. They, along with Haig-Thomas Island, a few kilometres off the southeastern coast of Amund Ringnes Island, have common tectonic and stratigraphic attributes; it is useful and convenient, therefore, to discuss their geology in one paper, rather than separately. There are neither communities nor maintained airstrips on these islands, and activities in the region are customarily directed from Resolute on southern Cornwallis Island (Fig. 1).

Geological field work is restricted to July and August, because the islands are snow-covered from September to late June. Runoff occurs usually in late June and early July; at this time, and also after prolonged rainfall, the ground surface becomes saturated and, in many places, it is hazardous for fixed-wing aircraft to attempt landings. Rough-graded airstrips, prepared at exploratory well locations and geophysical camps, deteriorate rapidly from the actions of permafrost and mass-wasting. Some parts of the terrain, where sandstone is the dominant rock type, allow landings by light aircraft during July and August, but helicopter transportation is the most satisfactory means of access for geological investigation.

Souter (1969) provided a general review of the Arctic climate and its impact on human activities. Modern floras of the Canadian Arctic Archipelago were described comprehensively by Porsild (1964), and modern vertebrate faunas by Snyder (1957). Because vegetation generally is very sparse and is absent locally, there are very few native animals.

Exploration

Amund Ringnes Island was discovered in 1900 by Gunerius Isachsen and Sverre Hassel, members of the Norwegian Polar Expedition, and was revisited by them in 1901 (Sverdrup, 1904); they named the island for Amund Ringnes, a Norwegian brewer and co-patron of the expedition. D.B. MacMillan (1918) touched the southern shore of the island in 1916, the same year in which Vilhjalmur Stefansson (1921) travelled down its western coast. Inspector A.H. Joy (Royal Canadian Mounted Police) traversed part of the island in 1929.

Sir Edward Belcher (1855) discovered and named Cornwall Island (for the Duke of Cornwall) in 1852, during his search for Sir John Franklin. The island was visited next by D.B. MacMillan in 1916 (MacMillan, 1918). Constable R.W. Hamilton (Royal Canadian Mounted Police) traversed part of the island in 1932 while searching for H.K.E. Krueger, a German geologist and leader of the 1929 German Arctic Expedition, who disappeared in 1930 after leaving Meighen Island (Fig. 1). Thorsteinsson (1961) provided a fascinating account of the disappearance and search for Krueger, who indicated, in a note left in a cairn on Meighen Island, that he intended to proceed to Cape Sverre on northernmost Amund Ringnes Island; no evidence has been found that Krueger reached Cape Sverre, and there is no further knowledge of Krueger's fate.

Haig-Thomas Island was named for David Haig-Thomas, who travelled by sledge from Greenland to Amund Ringnes Island in the spring of 1939, and who commented on the cheerless Arctic landscape in a note deposited at Cape Ludwig: "Well, this is a nice sort of place to try and survey. I will leave it to you brother---go ahead with the good work and say what is land and what is ice."

Geological work

A.W. Norris (1963a,b) conducted the first geological exploration of Amund Ringnes Island in 1955, during a reconnaissance of part of the Canadian Arctic Archipelago by the Geological Survey of Canada (Operation Franklin; Fortier et al., 1963). The most recent phase of geological interest in the island resulted from considerations of the hydrocarbon potential. Geological reports by petroleum companies and consultants are on file with the Department of Indian and Northern Affairs. Three exploratory wells have been drilled on Amund Ringnes Island: data from Panarctic Central Dome H-40, Panarctic Gulf West Amund I-44, and Imperial Panarctic Union PPL East Amund M-04 wells, and also from Sun Gulf Global Linckens Island P-46 well, located on Linckens Island on a very low mudflat, about 18 km west of Slime Peninsula, are included in this report. Mobil Cornwall O-30 was abandoned in October, 1979; data from that well remain confidential at the time of writing. The well was drilled after Map 1471A was printed; its location, not indicated on Map 1471A, is 77°29'47"N, 94°38'58"W.

The first systematic observations of Cornwall Island were made also in 1955, by Operation Franklin geologists, D.J. McLaren (1963) and H.C. Greiner (1963).

This report was written in 1976, based on field work carried out mainly in 1972, but also on brief investigations in 1971, 1973, and 1974. Brief, but greatly informative traverses of Cornwall Island were made in 1979 while the writer undertook field work for Panarctic Oils Ltd. Observations made at that time prompted some changes in the text and the addition of Figure 13. Data and interpretations are based on ground traverses, aerial observations from helicopters, aerial photo interpretations, and examination of well samples, cores and geophysical logs. Geophysical data, other than logs, are not available for publication; this lack weakens the interpretations of structure and regional stratigraphy.

Acknowledgments

Collection of outcrop and subsurface data, biochronological determinations, and chemical analyses of a succession of rocks about 5000 m thick, spanning Upper Triassic to Eocene, is necessarily the collaborative effort of many scientists. For parts of this report, the writer has acted only as compiler of data and ideas obtained by colleagues working on related projects, but the originators of many observations, and most ideas, are forgotten. For those reasons, the editorial "we" and "us" are used liberally and justifiably.

K.J. Roy acted as assistant party chief in 1972 and 1973, and made valuable stratigraphic observations, particularly in traverses of Jaeger River, Cornwall Island, and Stratigrapher and Structural rivers, Amund Ringnes Island. Some of the stratigraphic concepts developed in this paper are his. D.G. Wilson traversed part of western Cornwall Island in 1974. Ongoing studies by A.F. Embry have greatly elucidated Sverdrup Basin regional stratigraphy, to the point that parts of the Jurassic succession traversed in 1979 were perceived in entirely different fashions from previously.

Biochronological determinations of collections from 1971 to 1974 were made by W.W. Nassichuk, H. Frebold, J.A. Jeletzky, E.T. Tozer, W.S. Hopkins, Jr., J.H. Wall, and W.V. Sliter; paleontologists from Robertson Research (Canada) Limited made determinations of material collected in 1979. X-ray mineralogical determinations were made by A.E. Foscolos. Excellent assistance in the field was provided by R. Carrington and D. Chow in 1972, and by D. Chow, G. Howard, M. Bustin, D. Haden and G. Ward in 1973.

Helicopter support for the project was supplied by Liftair International in 1972 and by Dominion-Pegasus Helicopters in 1973. The abilities and initiative of T. Cafferty and S. Smith (pilots), and M. Craster and P. Korotyszyn (engineers) contributed greatly to the success of the field programs, as did superb cooking by L. Herchak. G.D. Hobson, F.P. Hunt, and personnel of the Polar Continental Shelf Project assisted field logistics.

A.F. Embry (Geological Survey of Canada), and D.C. Waylett and A.R. Bleakney (Panarctic Oils Ltd.) accompanied the writer in 1979. Panarctic Oils Ltd. (Calgary, Alberta) released data resulting from 1979 field traverses for inclusion within this report.

D.G. Cook and F.G. Young reviewed the manuscript, and provided many helpful suggestions.

The writer also acknowledges gratefully the continuing advice and direction contributed by R. Thorsteinsson.

PHYSICAL FEATURES

Physiography

Amund Ringnes, Cornwall, and Haig-Thomas islands are in the eastern part of the Sverdrup Lowland (Bostock, 1970, p. 18, Map 1254A), a region of low relief developed mainly on poorly to moderately consolidated, slightly deformed Mesozoic rocks. Roots (1963, p. 523 - 526) recognized four physiographic divisions on these islands; Roots' divisions are slightly modified in Figure 2 and the following paragraphs.

(1) A lowland plain characterizes southern Amund Ringnes Island and eastern and western parts of Cornwall Island, with general elevations less than 60 m; the region is widely veneered by Quaternary deposits and alluvium (Fig. 3). Details of the dominantly shaly bedrock are obscure, except in the cutbanks of some rivers and creeks, although broad structural elements are evident in the gently dipping strata. The lowland plain is drained by low-gradient consequent streams, the lower parts of which have wide, braided flood plains. There is a change in gradient, or nick point, on many of the stream beds at elevations of about 10 to 15 m above sea level. The valleys are straight and narrow and actively eroded for variable distances just below the nick points and, at the coast, the valleys broaden to fan deltas with braided distributaries. Upstream from the nick points, the gradients flatten slightly and the valleys broaden and are aggraded; some of these valleys contain small lakes, such as those near Cape Aberdeen and that east of Fog Bay. The nick points and the upstream aggraded valleys are probably relicts that mark an earlier stand of sea level to which the stream gradients were once adjusted.

Low, curved, beach ridges have been raised in places along the southwestern coast of Amund Ringnes Island, and the northern and eastern coasts of Cornwall Island. There are also short straight ridges near present sea level that are remnants of pack ice thrust.

(2) A rolling and scarped lowland forms a distinctive topographic style on the gently to moderately dipping sandstone and shale of central and northern Amund Ringnes Island and Haig-Thomas Island. The rolling surface is interrupted locally by cuestas with low but steep scarps, developed on moderately dipping, very resistant gabbro dykes and sills, and on moderately resistant sandstone intervals. Tributary streams generally are well adapted to the underlying structure but, in some places, the trunk streams are superposed on structure, probably as a result of post-Pleistocene emergence from previous marine levels. Elevations in this region reach a maximum of about 150 m above sea level.

(3) A dissected low upland, with elevations generally between 150 and 300 m above sea level, has been formed on an elongate piercement dome[1] and neighbouring gabbro

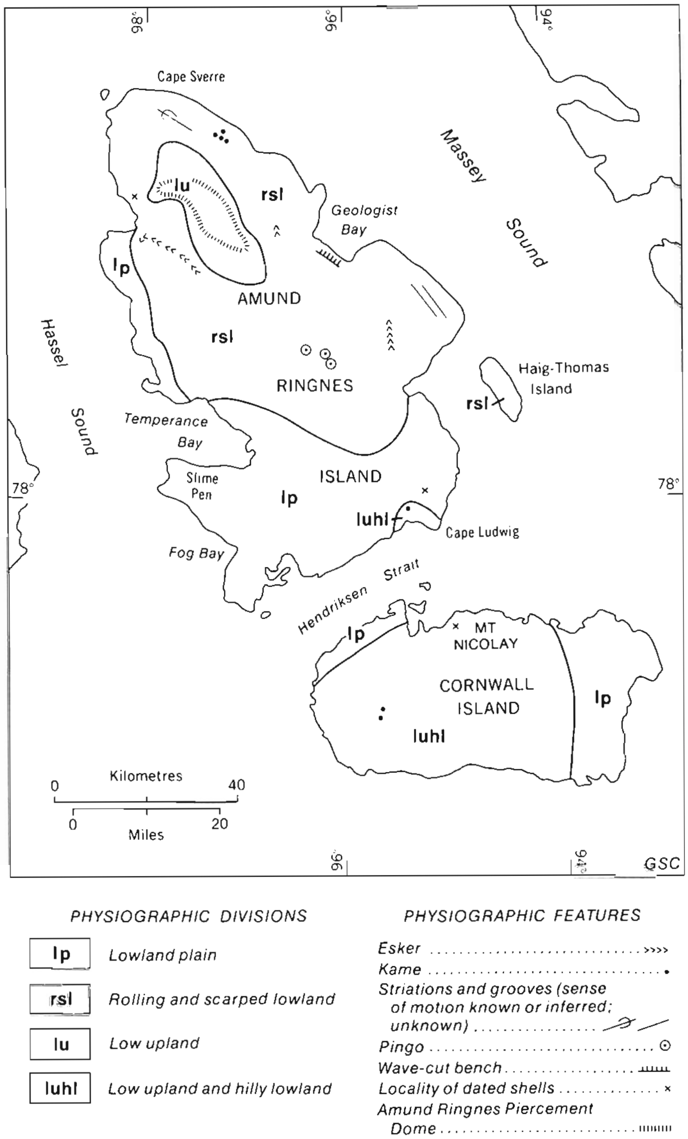

Figure 2. Physiographic divisions and glaciation features, Amund Ringnes, Cornwall and Haig-Thomas islands (partly after Roots, 1963, p. 523).

dykes and sills in north-central Amund Ringnes Island. The highest place on the island, at an elevation slightly more than 300 m above sea level, is at the summit of a thick, gently dipping gabbro dyke about 6 km north of the piercement dome.

The piercement dome is composed mainly of gypsum and anhydrite rocks, which in the arid Arctic climate are not weathered quickly; and the interior of the dome is protected further from erosion by a lag veneer of extraneous gabbro blocks, emplaced with evaporites during diapirism. Consequently, the rocks of the piercement dome, like others of the Arctic Islands (Gould and de Mille, 1964), tend to remain topographically high in contrast to surrounding terrains developed on poorly cemented, more easily eroded sandstone and shale. Drainage within the dome is radial, but assumes an annular pattern adjusted to structure around the periphery of the dome.

(4) A low upland and hilly lowland, developed mainly on slightly to moderately dipping sandstone, includes most of central and western Cornwall Island, and the low but

[1] North Cornwall Dome of Gould and de Mille (1964); here called Amund Ringnes Piercement Dome as originally named by Norris (1963 a).

Figure 3. View westward across lowland plain, southern Amund Ringnes Island near Cape Ludwig. Approximate crest of northward-plunging Cornwall Arch delineated by strike and dip symbols. Js: Savik Formation; Ja: Awingak Formation; JKd: Deer Bay Formation; Ki: Isachsen Formation; Kc: Christopher Formation; Kh: Hassel Formation; Kk: Kanguk Formation; Ke: Eureka Sound Formation. NAPL photo T402L-58.

conspicuous hill at Cape Ludwig. The greatest elevation in this terrain is at the peak of Mount Nicolay, about 330 m above sea level. Mount Nicolay resists erosion because it is nearly surrounded by a swarm of hard gabbro sheets and dykes, and because of the local silica cementation of Heiberg Formation sandstones. This physiographic region is drained by streams that have dendritic patterns.

Sedimentary rocks on Amund Ringnes, Cornwall, and Haig-Thomas islands generally are very poorly consolidated, but the rate of erosion is low: from September to June the ground surface is frozen, inhibiting almost all erosion; in the remaining two to three months, the level of permafrost is within one-half metre of the surface, which inhibits mass-movement other than solifluction creep. Furthermore, the amount of precipitation in the Queen Elizabeth Islands is very small: records are not available for Amund Ringnes Island, but the average is about 10 cm per year on neighbouring Ellef Ringnes Island (Stott, 1969, p. 2). Most of the erosion takes place during the period of runoff in late June and early July.

The general character of sea-floor physiography in the Ringnes Islands was investigated first by the Polar Continental Shelf Project (Canada, Department of Energy, Mines and Resources) in 1960 and 1961 (Pelletier, 1962). During this investigation, Horn (1963) studied submarine physiography of Hassel and Massey sounds along broadly spaced profiles. He observed that the inter island waterways are characteristically U-shaped in profile, that submarine rises and troughs tend to parallel the northwest structural grain of the region, and that troughs commonly consist of several small basins, the bottoms of which exceed the general depth of the continental shelf to the north. These characteristics led Horn to conclude that the inter-island waterways are relict fluvial valleys, greatly modified by glacial scour. Nearshore marine sediments lie in a zone from 2 to 5 km wide along the coastline and consist mainly of muddy sand and silt. Offshore bottom muds are silty clay.

Hendriksen Strait seems to be shallow. Sandy islands in the strait, off the northern shore of Cornwall Island, are in a location that suggests they are underlain by sandstone of the Heiberg Formation. There are other small islands near Amund Ringnes Island; the Sun Gulf Global Linckens Island P-46 well was drilled on a mudflat-island, barely above sea level, that is part of a broad, very shallow platform southwest of Slime Peninsula, and a similar mudflat-island was observed about 5 km offshore from the mouth of Stratigrapher River. The surface of the latter has an area of about 1200 m^2 and is slightly above sea level. Ridges and fluting indicate that ice moves back and forth across the mudflat. Cobbles and boulders of various rock types (including granite gneiss) are scattered randomly on the muddy surface. The island seems likely to be an emerged deposit of glacial gravel, perhaps similar to nearby glacial deposits on land. Two gravel-veneered, small islands lie in the channel between Haig-Thomas and Amund Ringnes islands.

Two other accumulations of rocks lie offshore from eastern Amund Ringnes Island. One of these is about 10 km north of Geologist Bay, and is about 500 m^2 in area; it consists of angular blocks of pale green-grey augen gneiss. The other accumulation lies between Amund Ringnes Island and Haig-Thomas Island, and consists entirely of angular blocks of dark maroon to dark green, partly flow-brecciated rhyolite or latite. First impressions were that the accumulations of rocks, which are completely alien to any known bedrock in the region, are islands. However, in 1958, R. Thorsteinsson (pers. com., 1976) noticed a field of rocks of the same type as the augen gneiss at Geologist Bay, between Meighen and Axel Heiberg islands. This allows the possibility that the two observations were of the same rocks, that the rocks rest on the surface of the ice, and that they drifted southward about 150 km in 15 years (or more likely, in one of the those rare years when there was widespread breakup of the inter-island pack ice). The nearest outcrops of comparable rocks are the lower Paleozoic and (?)older metamorphic and volcanic rocks on northernmost Ellesmere Island (H.P. Trettin, pers. com., 1975). Regardless of whether the masses of rock rest on the ice or lie as shallow islands on a bathymetric prominence, they probably were derived originally from calving glaciers along the northern coast of Ellesmere Island, and rafted by pack ice southwestward to Massey Sound.

Glaciation

Grooves and striations, interpreted to be the result of glaciation, were observed at three widely separated localities on Amund Ringnes Island (Balkwill, 1974; Fig. 2): (1) spectacular grooves are developed in moderately well cemented sandstone of the Isachsen Formation (Lower Cretaceous) at an elevation of about 150 m above sea level in the southeastern part of the island; (2) delicate striations are inscribed in a polished surface of a basalt flow in the lower part of the Hassel Formation (Lower and Upper Cretaceous) at an elevation of about 60 m above sea level near the northeastern coast; and (3) there are striations in well cemented sandstone at the northern rim of Amund Ringnes piercement dome, at an elevation of about 230 m above sea level. All of the grooves and striations strike northwestward; chatter marks associated with the striations at locality 2 indicate northeastward ice motion.

Striated erratics of diverse size and lithology (including, in order of abundance: quartzite, limestone, gabbro and other mafic rocks, gneissic rocks, and pink granite) are distributed widely as isolated clasts over the island. A single large block of granite was found at the summit of Amund Ringnes Piercement Dome at an elevation of about 245 m above sea level.

Sinuous, partly dissected gravel deposits, several kilometres long and a few metres high, form esker-like ridges on bedrock in at least two places on Amund Ringnes Island (Fig. 2). Boulders and cobbles in the crudely stratified gravel are of varied lithology and size, but all are moderately well rounded and most are well rounded. Sand and finer grained parts of the matrix have been winnowed from the surface of the deposits, so that a lag veneer of large clasts effectively protects the ridges from further erosion.

There is a small, rounded gravel hill in western Cornwall Island, and several rounded to conical, kame-like knolls of nonstratified gravel lie on bedrock near the northeastern coast of Amund Ringnes Island. A similar deposit of gravel forms a small peak at the summit of the highest point in the southern part of Amund Ringnes Island, a hill near Cape Ludwig, 131 m high (Fig. 2). The latter deposit contains Cretaceous palynomorphs (identified by W.S. Hopkins, Jr.), probably derived by glacial erosion of Cornwall Island.

A measure of postglacial marine incursion may be provided by Quaternary marine molluscan shells. Shells are distributed widely on the coastal lowland plain in southern Amund Ringnes Island and eastern and western Cornwall Island. Barnacle shells (*Balanus* sp.) collected by pilot N. Bentley, at an elevation of about 35 m in the northwestern part of Amund Ringnes Island (Fig. 2), yielded a radiocarbon age of 8430 ± 170 yr. B.P. (GSC 1391); barnacle shells (*Balanus* sp.) collected from the bedrock surface near Cape Ludwig, at an estimated elevation of 30 m, yielded a radiocarbon age of 7710 ± 120 yr. B.P. (GSC 1973). The highest occurrence of shells on Cornwall Island is near Mount Nicolay, at an elevation of about 97 m. A collection of these shells yielded a radiocarbon age of 9030 ± 250 yr. B.P. (GSC 2417). All determinations were made by the Radiocarbon Laboratory, Geological Survey of Canada (W. Blake, Jr., pers. com., 1973, 1974, 1977).

The general arrangement of striated bedrock and glacially derived gravels lying on bedrock indicates that the gross topographical profile of Amund Ringnes Island---a central rounded upland, flanked by rolling lowlands and lowland coastal plains---existed prior to the most recent phase of glaciation. The surface of the island lacks abundant evidence of ice scour probably because the bedrock is poorly indurated and solifluction is very active. The apparent absence of glacial till seems surprising, in view of the probable susceptibility of local bedrock to erosion by ice.

Pingos

Pingos are rare in the central part of the Queen Elizabeth Islands, but there is a cluster of well developed pingos in the central part of Amund Ringnes Island (Fig. 2). The pingos are on a nearly flat, featureless plain that lies uniformly about 60 m above sea level, and are developed in moderately well indurated shales of the Savik Formation (Jurassic). The largest pingo is about 7 m high and 80 m wide; it has a small central depression, and a shallow peripheral sink, occupied by an annular drainage system. Shales within the pingos are chaotically disrupted. A shallow pit was dug in the disrupted shales, but ground ice was not observed.

The pingos apparently are of the closed-system type (Muller, 1959). There is no apparent reason to suppose that they developed in response to a groundwater regime with a directed hydraulic head, because they are on a featureless plain, about 8 km from any significant uplands, and they are at the crest of a broad, periclinal, structural culmination, with very gentle limbs (2 - 4°) that dip away from the pingos.

STRATIGRAPHY

Regional setting

Amund Ringnes, Cornwall, and Haig-Thomas islands are in the south-central part of the Sverdrup Basin (Fig. 1). The basin is an elongate pericratonic depression containing a succession of marine and nonmarine rocks, which range from Lower Carboniferous to Tertiary (Thorsteinsson and Tozer, 1970; Plauchut, 1971; Trettin et al., 1972; Balkwill, 1978); these strata are superimposed on Paleozoic rocks that were deformed during the mid-Paleozoic Ellesmerian Orogeny. The Sverdrup Basin succession is mainly concordant in the axial region, but there are unconformities along the eastern, southern, and northwestern margins that record gentle uplift and truncation. Although the depocentre migrated from time to time, the thickest part of the succession (about 12 000 m) is preserved in the region of western Axel Heiberg Island and north-central Amund Ringnes Island. Gabbro dykes and sills---not younger than early Late Cretaceous, and in some places considerably older---are important constituents of the succession in the depocentral region. Sverdrup Basin rocks were folded, faulted, and epeirogenically uplifted during a succession of tectonic phases, collectively called the Eurekan Orogeny, which may have extended from latest Cretaceous through Miocene (Balkwill et al., 1975). As a result, Paleogene and Neogene, partly syntectonic, alluvial deposits lie unconformably on Mesozoic and older rocks within and adjoining the basin.

Upper Paleozoic strata of the Sverdrup Basin include carbonate rocks, terrigenous clastic rocks and evaporites, which are exposed in places around the basin margin, notably in north-central Ellesmere Island (Thorsteinsson, 1974; Davies and Nassichuk, 1975). As a result of halokinetic and tectonic mobilization, the evaporites locally intruded the overlying upper Paleozoic and Mesozoic rocks in axial parts of the basin, where they now form the cores of piercement structures (Gould and de Mille, 1964).

Table of Formations

ERA	SYSTEM OR SERIES	FORMATION OR MAP-UNIT		RANGE IN OUTCROP THICKNESS Metres (Feet)	LITHOLOGY
CENOZOIC	RECENT	*Alluvium*		0-10? (0-30?)	Silt: clayey, sandy, with sand and gravel
	RECENT OR PLEISTOCENE	*Marine deposits*		0-30? (0-100?)	Clay: silty, sandy unconsolidated; with silt, sand and minor gravel
	PLEISTOCENE	*Glacial-fluvial gravel*		0-10 (0-30)	Gravel: rounded, striated, pebbles, cobbles, boulders, in silty sand matrix
	Regional unconformity				
	EOCENE AND PALEOCENE	*Unnamed Paleocene/ Eocene ss*		18 (60)	Sand: buff and yellow-buff; minor silt, clay; partly carbonaceous
	Regional unconformity				
MESOZOIC	UPPER CRETACEOUS	*Eureka Sound Formation*		300 (980)	Sandstone: buff-grey; minor siltstone; lignite
		Kanguk Formation		270-360 (890-1180)	Shale: dark grey, dark green-grey and black; partly silty; partly glauconitic sandstone; tuffaceous clay beds in lower part
	UPPER AND LOWER CRETACEOUS	*Hassel Formation*		450 (1475)	Sandstone: buff, light grey, light green, and orange; minor shale; minor coal; locally glauconitic in lower part; local basalt flows
	CRETACEOUS AND OLDER (radiometric ages)	*Gabbro dykes and sills*		1-45 (3-150)	Gabbro: dark green-grey; partly diabasic; intrudes strata to level of Savik Fm, Upper Mbr on Cornwall Island; may locally intrude strata to level of Hassel Fm basalt flows on Amund Ringnes Island
	Intrusive contact				
	LOWER CRETACEOUS	*Christopher Fm*	Kcu	475 (1560)	Upper informal member - Shale: dark grey; slightly silty; red-brown nodules; some calcareous sandstone beds in upper part
			Kcl	400-485 (1310-1590)	Lower informal member - Shale: dark green-grey to dark grey; very silty; large buff concretions; glauconitic sandstone at top
			Kc		Undivided Christopher Formation - Shale: dark grey and dark green-grey; buff concretions
		Isachsen Fm		530-1030 (1740-3380)	Sandstone: buff and grey; dark brown siltstone; dark grey shale; very thin beds of coal
		Unconformity on eastern Cornwall Island			
	LOWER CRETACEOUS AND UPPER JURASSIC	*Deer Bay Formation*	JKdE	180-270 (590-885)	Informal member E - Shale: dark grey; silty; buff concretions; sandstones near top
			JKdD	0-30 (0-100)	Informal member D - Sandstone: buff; locally glauconitic
			JKdC	240-360 (790-1180)	Informal member C - Shale: dark grey; silty; partly sandy
			JKdB	0-10 (0-30)	Informal member B - Sandstone: green-grey; glauconitic
			JKdA	0-330 (0-1080)	Informal member A - Shale: dark grey; silty
			JKd	635 (2085)	Undivided Deer Bay Formation - Shale: dark grey to dark green- grey; red-brown and buff concretions; silty; partly sandy
	UPPER JURASSIC	*Awingak Formation*		250-570 (820-1870)	Sandstone: lower part is medium grey, very fine grained, clayey; grades upward to sandstone: light buff, medium to coarse grained; grades upward to sandstone: buff and red-brown; grades upward to sandstone: partly coaly on Cornwall Island, with shale beds on Amund Ringnes Island
		Ringnes Formation		240-330 (790-1085)	Shale: dark grey; silty; abundant very large buff-yellow concretions; local very thin beds of sandstone
	UPPER (?), MIDDLE AND LOWER JURASSIC	*Savik Formation*	Jsu	0-140 (0-460)	Upper Shale Member - Shale: dark grey; silty; local sandstone
			Jsj	12 (40) (Amund Central Dome H-40)	Jaeger Member - Sandstone: medium green; glauconitic; partly phosphatic
			Jsl	228 (750) (Amund Central Dome H-40)	Lower Shale Member - Shale: dark grey-green; pyritic
	MIDDLE AND LOWER JURASSIC	*Jaeger Formation*	JjD	135-230 (445-755)	Informal member D - Sandstone: buff and red-brown; partly phosphatic
			JjC		Informal member C - Shale: light green
			JjB		Informal member B - Sandstone: buff and red-brown; partly pebbly
			JjA		Informal member A - Sandstone: light grey, very clayey
	LOWER JURASSIC	*Borden Island Formation*		0-65 (0-215)	Sandstone: buff and red-brown; partly pebbly; ferruginous
	LOWER JURASSIC AND UPPER TRIASSIC	*Borden I Fm and Heiberg Fm (Upper Member)*		180 (590)	Sandstone: buff-grey, fine grained
		Heiberg Fm (Upper Mbr)		420-620 (1380-2035)	Sandstone: light buff; partly coaly
	UPPER TRIASSIC	*Heiberg Fm (Lower Mbr)*		350-600 (1150-1970)	Sandstone: buff-grey, medium brown, and grey-green; partly calcareous; with intercalated shale: dark grey to dark green- grey; silty; sandy
	UPPER AND (?) MIDDLE TRIASSIC	*Blaa Mtn Fm*		750 (2460)	Shale: dark grey-green and dark grey; very silty; thin to thick grey-green sandstones
	Intrusive contact				
	PENNSYLVANIAN AND MISSISSIPPIAN (age of parent rk)	*Diapiric intrusions*			Gypsum, anhydrite, limestone, dolomite, and gabbro

GSC

In contrast to the upper Paleozoic succession, with its thick and widespread evaporite and carbonate facies, the Mesozoic rocks of the basin consist almost entirely of terrigenous clasts. Triassic, Jurassic and Early Cretaceous (Neocomian) marine limits of the basin seem to have been about the same as the modern outline (Fig. 1) because rocks of those ages tend to be in alluvial, deltaic, or littoral facies along the eastern and southern basin margins (such as at Cornwall Island), and dominantly in marine shale facies northward (as in northern Amund Ringnes Island). Early Cretaceous (about Aptian) deposition transgressed beyond the earlier boundaries of the basin, and marked a significant change in the tectonic-depositional regime of the Canadian Arctic Archipelago. This change ended the life of the Sverdrup Basin as a distinct depositional entity, with approximately defined limits, and began a phase in which the basin was an actively subsiding element impressed on a broad, far-ranging continental shelf system that extended through the Arctic Archipelago to the northern Interior Plains of the Canadian mainland.

Rocks exposed on Amund Ringnes, Cornwall, and Haig-Thomas islands, and penetrated by drillholes (Table of Formations), consist principally of a conformable succession of Mesozoic terrigenous clastic rocks. These comprise alternating intervals of sandstone, siltstone and shale, which range from possibly Middle Triassic to Upper Cretaceous; this succession is about 5000 m thick. Much of the sequence is exposed because of the great regional structural relief and, except on the coastal lowland plains (Fig. 2), there is little surficial material and almost no vegetation.

Stratigraphic data from outcrops are supplemented by those from four exploratory wells that have been drilled on or near Amund Ringnes Island (Table 1). The deepest well, Panarctic Amund Central Dome H-40, penetrated about 11 030 ft (3364 m)[1] of Mesozoic strata, and bottomed probably in Triassic shale of the Blaa Mountain Formation or Blind Fiord Formation (Fig. 4).

Lithofacies, faunas, and sedimentary structures indicate that a marine basin persisted for long periods of time in the region of northern Amund Ringnes Island, in which pelite-dominated sediments, comprising the Blind Fiord, Blaa Mountain, Savik, Ringnes, Deer Bay, Christopher, and Kanguk formations, accumulated. Episodic northward marine withdrawal from the entire region is recorded by very thick, arenite-dominated intervals of alluvial, deltaic and littoral facies comprising the Heiberg, Isachsen, and Hassel formations, and structurally concordant Upper Cretaceous beds of the Eureka Sound Formation. Intermittent Jurassic marine regression northward from Cornwall Island and the southern part of Amund Ringnes Island is represented by arenaceous rocks comprising the Jaeger and Awingak formations, a tongue of sandstone in the Deer Bay Formation, and by unconformities at the base of some of these units. These sandstone intervals are thick and prominent at the basin margin (Cornwall Island), but they thin northward, and grade northward progressively to glauconitic sandstone, glauconitic siltstone, and nodular silty shale in a succession dominated by marine shale. Unconformities in the succession of eastern Cornwall Island, not observed elsewhere in the mapped areas, indicate that a recurrently active tectonic-stratigraphic hinge, here called Cornwall Island Hinge, existed through east-central Cornwall Island.

The Mesozoic succession, in the northern part of Amund Ringnes Island, was intruded diapirically by two huge masses of evaporite rocks, derived from deeply buried upper Paleozoic strata. Gabbro dykes and sills intruded Mesozoic rocks on both Cornwall and Amund Ringnes islands. Mafic intrusions rise to progressively higher stratigraphic levels from south to north; that is, they cut Lower Jurassic rocks on Cornwall Island (at the basin margin), Upper Jurassic rocks (Deer Bay Formation) in southern Amund Ringnes Island, and Albian (uppermost Lower Cretaceous) or Cenomanian (lowest Upper Cretaceous) rocks near Cape Sverre, northern Amund Ringnes Island.

Isolated remnants of upper Paleocene to middle Eocene carbonaceous arenites lie with angular unconformity on Mesozoic strata at several places on central Cornwall Island and central Amund Ringnes Island. These remnants occur in such a way as to demonstrate that Upper Cretaceous rocks, and underlying older parts of the conformable Mesozoic succession, were folded and faulted, greatly uplifted and eroded deeply during the interval from latest Cretaceous through early Tertiary.

The reader is alerted to the following important stratigraphic qualifications:

- Map 1471A was printed in 1979, before 1979 field traverses on Cornwall Island. These traverses, and subsequent biochronological determinations, revealed important stratigraphic details that were not known previously---and which were not indicated on Map 1471A or recorded in the original text. The new data indicated that some map units could be correlated with formations other than those displayed on Map 1471A, and that some additional units could be mapped.

Table 1. Well data, Amund Ringnes Island (to 31 December, 1976)

WELL NAME	LOCATION	DATE		GR. ELEV.	K.B.	T.D.	STATUS
		Spudded	Completed	Feet (Metres)	Feet (Metres)	Feet (Metres)	
Panarctic Central Dome H-40	78°19′28″N 96°15′50″W	1970-11-10	1971-04-25	207 (63.1)	224 (68.3)	11 030 (3361.9)	Dry and abandoned
Panarctic Gulf West Amund I-44	78°23′04″N 97°50′16″W	1972-03-30	1972-04-21	50 (15.2)	60 (18.3)	3137 (956.2)	Dry and abandoned
Sun Gulf Global Linckens Island P-46	77°45′47″N 97°45′26″W	1973-03-03	1973-05-08	1 (0.3)	21 (6.4)	6008 (1831.2)	Dry and abandoned
Imperial Panarctic Union PPL East Amund M-05	78°24′48″N 95°04′24″W	1973-05-30	1973-08-13	254 (77.4)	282 (85.9)	8193 (2497.2)	Dry and abandoned

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[1] For approximate distances, elevations and thicknesses, a metric conversion factor of 1 ft = 0.3 m is used in this paper; for more precise measurements, as in boreholes, a conversion factor of 1 ft = 0.305 m is used.

- Map 1471A could not be reprinted. To attempt to relate the map (and some other figures) to revisions consequent to 1979 data the following approach is taken: the rocks are described in terms of the boundaries indicated on the map; sections have been added to the text, specifying appropriate revisions; a map (Fig. 13) has been added to show revised boundaries in eastern Cornwall Island.

Each of the following sections begins with descriptive stratigraphy of the rocks, followed by interpretations of sedimentary environments. Stratigraphic age assignments from paleontological determinations are presented in the Appendix.

Local stratigraphy

Mississippian and Pennsylvanian

Otto Fiord Formation and other rocks comprising diapirs

Nomenclature. Thorsteinsson (1974, p. 26) gave the name Otto Fiord Formation to about 300 m of intercalated anhydrite and limestone at Hare Fiord (Ellesmere Island, Fig. 5). Lateral equivalents of these rocks have been considered for some time as the deeply buried source for evaporite-cored diapirs in the central part of the Sverdrup Basin (Fortier, 1963a, p. 518; Gould and de Mille, 1964, p. 724; Davies and Nassichuk, 1975).

Distribution. Gypsum, with random blocks of anhydrite, limestone, dolomite and gabbro, forms the surface of the large Amund Ringnes Piercement Dome[1] (surface area about 35 km^2) and the eastern and southern rim of a nearby unnamed dome adjacent to Andersen Bay[2]. Also, narrow dykes and sills of gypsum (Figs. 6a, b), which transect country rocks around the periphery of the domes, probably emanated from deeper parts of the intrusive mass. There are no piercement domes on Cornwall Island.

Lithology. By far the most prevalent rock type in the domes is massive and foliated, finely to coarsely crystalline gypsum, which forms a matrix for included random blocks of limestone, dolomite, gabbro and anhydrite. Gypsum ranges from white to dark grey; most is dull medium grey but, near some contacts with basic igneous rocks, it is red, pink, orange, yellow and indigo, from oxidation of finely dispersed crystals of magnetite and pyrite. Foliated gypsum, resulting from colour banding or, in some places, textural change from coarse sugary material comprising light bands, to very finely crystalline material comprising darker bands, is particularly apparent near the boundaries of the domes. Foliation bands range in width from about 1 mm to several centimetres. Large, colourless, transparent tabular plates of selenite are present locally.

Gypsum comprising tabular dykes near the domes (Fig. 6) is light to medium grey, finely to coarsely crystalline, and distinctly foliated. Some foliation is imparted by layers of contrasting texture and some is the result of thin bands rich in very small crystals of black magnetite.

Widespread, conspicuously dark-weathering masses of mafic igneous rocks, intensely frost shattered as felsenmeer, cap the southern and central parts of Amund Ringnes Piercement Dome. No gabbro was observed in the dome adjacent to Andersen Bay. The gabbro is fresh, hard, dark grey-green, finely to coarsely crystalline and partly diabasic. In almost all places, the blocks lack aphanitic borders that might suggest chilled margins of intrusive bodies, indicating that the blocks have been transported by diapirism. An exception is a large, linear mass of gabbro that parallels the western border of the dome; locally this body has aphanitic margins, and the adjacent gypsum is distinctively coloured, in some places brick red and in others grey-brown. The size and linearity of this body, combined with its textural relationships, suggest (Gould and de Mille, 1964, p. 730) that it may be intrusive into the gypsum, rather than a block transported by diapiric movement.

R.G. Blackadar (reported by Norris, 1963a, p. 543) examined thin sections of specimens of the mafic rocks. A specimen collected near the eastern margin of the dome had the following minerals:

	per cent	
Andesine	39.4	
Clinopyroxene	0.9	
Magnetite	4.1	
Amphibole	32.1	
Sericite	1.6	
Chlorite	20.4	(clinopyroxene altered
Apatite	0.1	to amphibole)
Quartz	0.1	
Pyrite	0.3	

Diabasic gabbro collected near the western edge of the dome had the following composition:

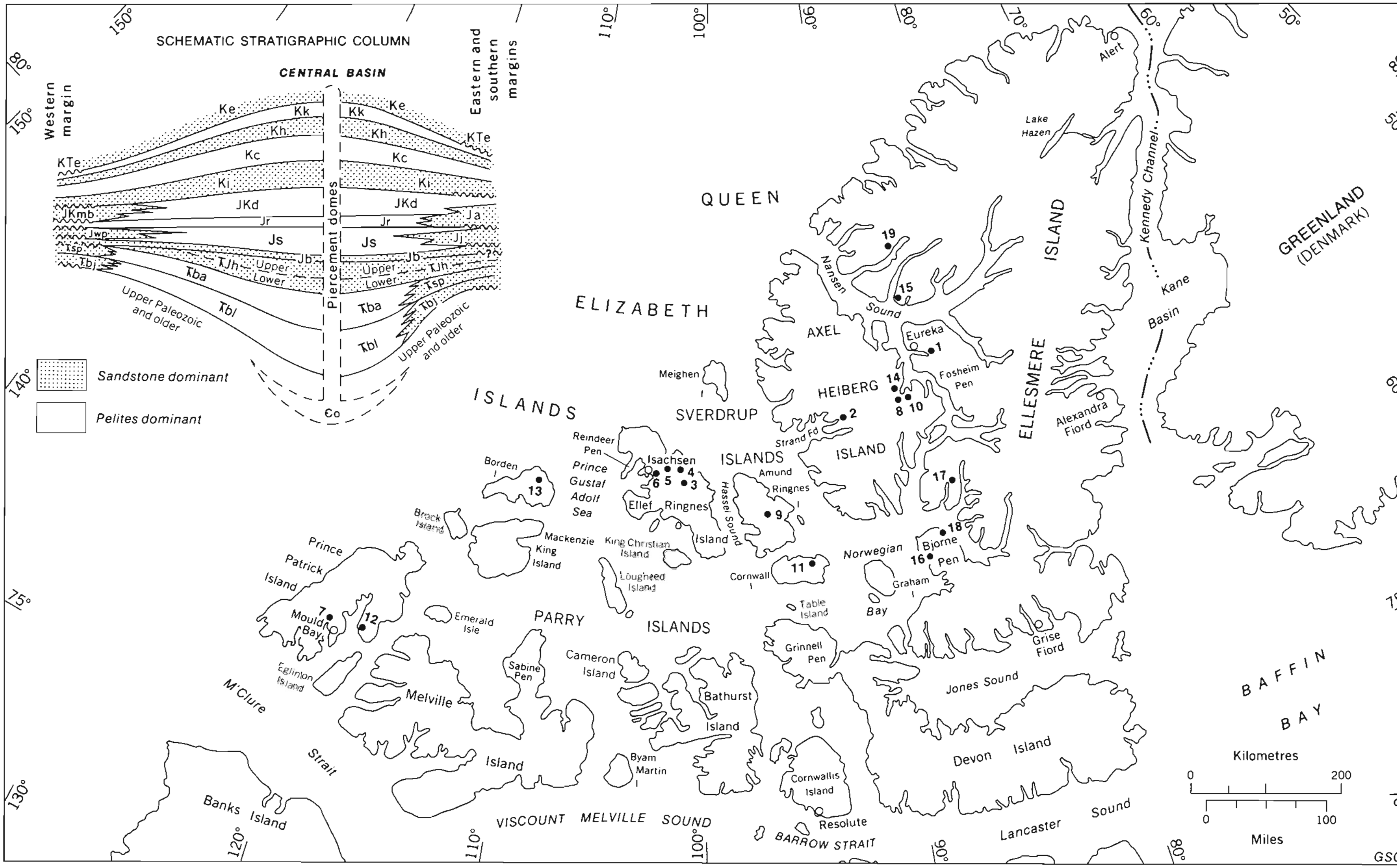
	per cent	
Plagioclase	13.7	
Magnetite	15.0	
Amphibole	41.9	(clinopyroxene altered
Colourless amphibole (?)	0.4	to amphibole)
Sericite	21.4	
Carbonate	0.3	
Quartz	3.8	
Chlorite	3.5	
Apatite	trace	

The mineral composition of these rocks is approximately the same as mafic dykes and sills in other parts of Amund Ringnes Island, leading Blackadar to conclude that the igneous rocks were derived from a common source.

In contrast to the hard, fresh gabbro composing most of the mafic igneous blocks, there are a few small (less than 5 m across) masses of igneous material in the central part of the dome in which ferromagnesian minerals are altered completely to soft, light green chlorite.

Limestone and dolomite blocks and large masses lie in a matrix of gypsum at the margins of the domes. There are small (less than 10 m) blocks of dark grey-brown, fetid, microcrystalline to coarsely crystalline limestone at the eastern margin of the dome of Andersen Bay, and a noteworthy block of dark grey-brown, finely to coarsely crystalline limestone enclosed in irregularly foliated gypsum, along the southern shore of Andersen Bay. The rock is fetid and very porous (vuggy and intercrystalline porosity), and black carbon lines the vugs; small irregular masses of free sulphur are present nearby in the enclosing gypsum. By far the largest masses of carbonate rocks are at the southern and western margins of Amund Ringnes Piercement Dome. That at the southern margin lies as a felsenmeer hill, extensive enough to delineate on the geological map (Map 1471A). Those rocks have a distinctly brecciated appearance, not observed in other occurrences of carbonate rocks; angular, randomly oriented, but lithologically homogeneous, fragments of laminated (silty), very finely crystalline, medium grey-brown, limy dolomite are set in a dark grey-brown, microcrystalline to coarsely crystalline limestone matrix. The rocks are moderately fractured and the fractures are filled partly with white to clear sparry calcite; leaching of calcite has developed good fracture porosity in some surface exposures. The rocks have a strong fetid odour. Individual clasts composing this extensive mass of brecciated rocks are lithologically alike, but the overall fabric lacks any semblance of sorting or preferred clast orientation. The size of the carbonate mass and continuity of its internal fabric

[1] North Cornwall Dome of Gould and de Mille, 1964.
[2] New name accepted by the Canadian Permanent Committee on Geographical Names, November 28, 1973.



INDEX TO TYPE SECTIONS

1. KTe: Eureka Sound (Troelsen, 1950)
2. Kk: Kanguk (Souther, 1963)
3. Kh: Hassel (Heywood, 1957)
4. Kc: Christopher (Heywood, 1957)
5. Ki: Isachsen (Heywood, 1957)
6. JKd: Deer Bay (Heywood, 1957)
7. JKmb: Mould Bay (Tozer, 1956)
8. Ja: Awingak (Souther, 1963)
9. Jr: Ringnes (Balkwill *et al.*, in press)
10. Js: Savik (Souther, 1963)
11. Jj: Jaeger (Greiner, 1963)
12. Jwp: Wilkie Point (Tozer, 1956)
13. Jb: Borden Island (Tozer and Thorsteinsson, 1964)
14. ŦJh: Heiberg (Souther, 1963)
15. Ŧba: Blaa Mountain (Troelsen, 1950)
16. Ŧsp: Schei Point (Tozer, 1963)
17. Ŧbl: Blind Fiord (Tozer, 1961)
18. Ŧbj: Bjorne (Tozer, 1963)
19. Ꞓo: Otto Fiord (Thorsteinsson, 1974)

Figure 5. *Approximate locations of Mesozoic type sections or reference localities for formations referred to in text, with schematic stratigraphic column (Mesozoic), Sverdrup Basin.*

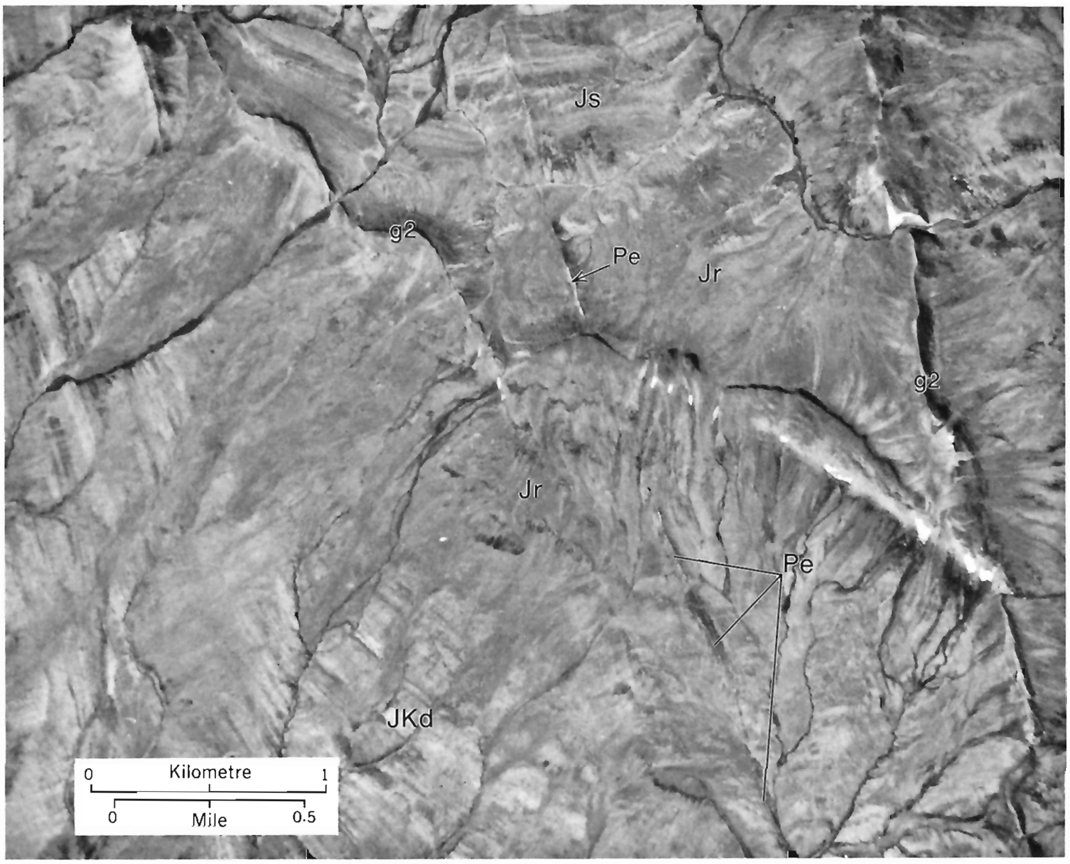


Figure 6a. Vertical air photograph showing Savik (Js), Ringnes (Jr), and Deer Bay (JKd) formations, crossed by gypsum dyke (Pe), and by mafic dykes and intrusive sheets (g2), near southern margin of Amund Ringnes Piercement Dome. Arrow indicates location and direction of view of Figure 6b. Part of NAPL photo A16748-26 (enlarged).

Figure 6b. Gypsum dyke and hard pelitic hornfels (Ringnes Formation), near southern margin of Amund Ringnes Piercement Dome. GSC 199242.

are such as to suggest that the carbonate rocks were brecciated before diapiric transport, perhaps by solution collapse, and later emplaced diapirically as a huge, discrete block.

Large blocks of fetid, partly fossiliferous limestone, as much as 25 m thick, are enclosed in gypsum near the western margin of Amund Ringnes Piercement Dome. The limestone is medium to dark grey-brown, weathers medium brown, and is very finely crystalline; the rocks are considerably fractured and have a sparry calcite fracture filling.

Random, fractured, angular to rounded blocks, usually less than several metres wide, of medium blue-grey anhydrite compose about 5 per cent of the surface of the domes. The anhydrite is dominantly very finely crystalline, with some very coarse gypsum crystals. Some hand specimens display a severely distorted nodular-mosaic fabric which, according to G.R. Davies (pers. com., 1974), may indicate a relict diagenetic fabric, deformed by tectonism. At the contacts with the enclosing gypsum matrix, anhydrite has altered to very finely crystalline gypsum, and fractures in the anhydrite blocks are filled by white, very finely crystalline gypsum.

Contacts. Gypsum and enclosed blocks are in diapiric fault contact with quartzose sandstones (Borden Island Formation and Upper Member Heiberg Formation, undivided) at the northern and southern boundaries of Amund Ringnes Piercement Dome, and with the Savik, Ringnes, Deer Bay and Isachsen formations at various places along the flanks. Foliation in gypsum and stratification in adjacent country rocks is vertical and, in a general way, structurally concordant in many places, but in others the gypsum is intricately convoluted adjacent to steeply dipping country rocks. For reasons discussed previously, the limestone breccia at the southern limit of the dome is believed to have resulted from deep, in-place solution and collapse, and is not likely to be a product of diapiric crushing nor a primary sedimentary breccia. The contact between the limestone and adjacent sandstone, therefore, is a diapiric fault contact.

The eastern and southern rims of the dome at Andersen Bay are in diapiric fault contact with the Deer Bay Formation.

Savik, Ringnes, and Deer Bay shales adjacent to the southeast-trending gypsum dyke near the southern limit of Amund Ringnes Piercement Dome are bleached to medium grey (from their typical dark grey and black hues) and are hard and brittle from alteration to pelitic hornfels (Fig. 6). There are abundant, small (less than 1 mm) pyrite porphyroblasts in the hornfels. The altered zones on either side of the dyke are about 3 m wide. These relationships may indicate that hot, mobile gypsum intruded and thermally altered the adjacent shales, or that hydrothermal solutions entered the rocks through fractures provided by pre-existence of the dyke. Gypsum dykes near the northern and western margins of the dome lack such relationships with adjacent shales.

Age and correlation. Partly from interpretation of subsurface data, Meneley et al. (1975) proposed the existence of three major, upper Paleozoic facies terrains in the axial part of Sverdrup Basin (Fig. 7). Amund Ringnes Island is in the west-central part of a large, eastern, evaporite-dominated terrain, a condition which probably determined the structural style of piercements and related structures on that island. Davies and Nassichuk (1975) proposed a depositional model to account for the distribution of Sverdrup Basin evaporites and related facies. They concluded that the evaporites are submarine in origin, rather than being of the sabkha type, and were confined to the structural and depositional axis of a subsiding basin.

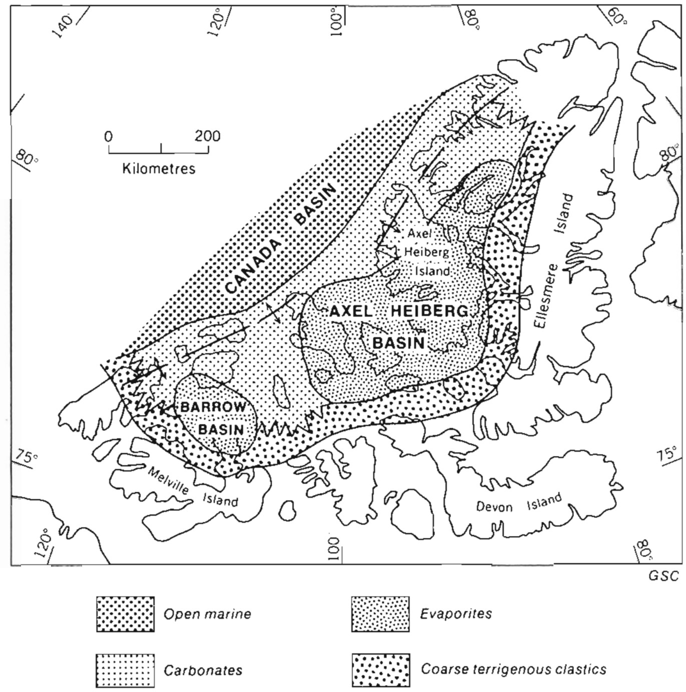


Figure 7. Lower Pennsylvanian lithofacies, Sverdrup Basin (from Meneley et al., 1975, Fig. 2).

Gould and de Mille (1964, p. 745) suggested that mafic rocks in the core material of the domes are of two ages. Radiometric ages for samples collected from mafic intrusions in Mesozoic rocks on Amund Ringnes and Cornwall Island range from 117 Ma to 144 Ma (see Mafic Intrusions). They reported a radiometric age of 200 ± 75 Ma from a sample collected within Amund Ringnes Piercement Dome.

Stott (1969, p. 11 - 16) presented a comprehensive review of the stratigraphy of gypsum, anhydrite and limestone comprising piercement domes on Ellef Ringnes Island. He concluded that the source beds for the diapirs in the Sverdrup Basin are deeply buried equivalents of Carboniferous and Permian rocks exposed on Ellesmere Island. The evaporites are considered presently to be correlative with Upper Mississippian to lower Middle Pennsylvanian anhydrites, now called the Otto Fiord Formation (Thorsteinsson, 1974); and the exotic limestone blocks were derived largely from Mississippian and Lower Pennsylvanian rocks (W.W. Nassichuk, pers. com., 1976). The lithologies of piercement rocks on Amund Ringnes Island are similar to the diapirs described by Stott; moreover, limestone blocks in Amund Ringnes Piercement Dome contain Early Pennsylvanian (Morrowan) faunas (GSC loc. C-22183)[1]. Therefore, it seems reasonable to conclude that evaporites and fossiliferous limestones composing piercement structures on Amund Ringnes Island were derived from deeply buried, upper Paleozoic rocks. The unfossiliferous carbonate rocks may be part of the same succession.

Fresh gabbro inclusions in Amund Ringnes Piercement Dome are mineralogically similar to dykes and sills that are widespread in Lower Cretaceous and older sedimentary rocks on the island and, in large part, are likely to be derived from mafic rocks contemporaneous with that assemblage, disrupted and transported upward from deeper levels through the mechanism of diapirism.

[1] Paleontological reports are given in the Appendix for all fossil localities cited in the text and noted on the geological maps.

Lower(?), Middle and Upper Triassic

Blind Fiord and Blaa Mountain Formations

Nomenclature. Tozer (1961, p. 11; 1963c, p. 384) introduced the name Blind Fiord Formation for Lower Triassic green and grey siltstone at Blind Fiord, Ellesmere Island (Fig. 5). At the type section, the formation rests paraconformably on Permian rocks and is overlain, abruptly but conformably, by Middle Triassic Blaa Mountain strata. The Blind Fiord Formation grades from siltstone at the type section to sandstone of the Bjorne Formation at the eastern and southern basin margins (Thorsteinsson and Tozer, 1970, p. 576).

Troelson (1950, p. 74) applied the name Blaa Mountain Formation to Triassic shale, siltstone, and sandstone in the Blue (Blaa) Mountains of western Ellesmere Island (Fig. 5). Tozer (1961, 1963a, b) described the stratigraphy of the formation, which in the eastern part of Sverdrup Basin is divisible into five informal members, which are, from the base upward: 'lower shale', 'lower calcareous', 'middle shale', 'upper calcareous', and 'upper shale'. From the type region, the formation thins, becomes sandier toward the eastern and southern margins of the basin, and grades to sandstone-dominated strata composing the Schei Point Formation (Tozer, 1963b, p. 78). At its type locality, the Blaa Mountain Formation lies abruptly, but conformably, on green and grey siltstone and shale of the Lower Triassic Blind Fiord Formation, and is gradational upward into sandstone and shale composing the Lower Member of the Heiberg Formation.

Clear distinction of the Blaa Mountain and Blind Fiord formations is difficult in the thick assemblage of pelitic rocks in the subsurface of central Sverdrup Basin; strata below sandstone and shale in the Lower Member of the Heiberg Formation in Amund Central Dome H-40 well, therefore, are assigned to an undivided unit that includes those two formations (Fig. 8).

Distribution and thickness. Surface rocks assigned to the Blaa Mountain Formation are poorly to moderately well exposed in cutbanks of creeks over a wide area of Cornwall Island where they form the deeply eroded core of the northward-plunging Cornwall Arch (Map 1471A). The base of the formation is not exposed; the lowest exposed part of the succession is near the coast between Cape O'Brien and Pell Point. The Mobil Cornwall 0-30 well was spudded in those rocks. The top of the formation was mapped at the base of the lowest prominent sandstone interval of the intercalated sandstone and shale succession comprising the Lower Member of the Heiberg Formation. (Individual sandstone beds near the base of the Heiberg Formation are discontinuous, so that in regional mapping the interformational boundary is imprecise.)

Based on regional dip and outcrop width, the surface thickness of the Triassic pelitic succession on southern Cornwall Island is estimated to be about 750 m (Fig. 4, Sec. I-J). The Central Dome H-40 borehole penetrated about 1975 m of silty shale and minor amounts of sandstone, extensively intruded by mafic sills and dykes, below the Lower Member of the Heiberg Formation (Fig. 8). Of that succession, about 360 m are within the Blaa Mountain Formation, based on the ages of enclosed palynomorphs, and the remainder in strata equivalent to the Blind Fiord Formation. The presence of this thick Triassic succession of pelitic strata, together with thick surface sections (Thorsteinsson and Tozer, 1970, Fig. X-10) and regional subsurface data (Meneley et al., 1975) provided evidence for vigorous subsidence and deposition in the axial part of Sverdrup Basin during Early to early Late Triassic.

Lithology. Strata assigned to the Blaa Mountain - Blind Fiord formations in south-central Cornwall Island consist principally of dark green-grey to dark grey, thinly laminated clayey siltstone, and silty to very silty, well indurated, papery[1] shale. Intercalated with the shale are intervals comprising about 20 per cent of the total succession, and up to 10 m thick, consisting mainly of light to medium green-grey, very fine to fine-grained, micaceous, carbonaceous, and glauconitic quartzose sandstone. Prominent bedding laminations are imparted by bedding-parallel, randomly oriented micaceous and carbonaceous fragments. Some intervals have very low angle cross-laminations. The sandstones have poor to fair intergranular surface porosity. In a typical sandstone-dominated succession, individual sandstone beds are generally 2 m or less in thickness, and are separated by thinner beds of dark green-grey siltstone and shale, comparable in lithology to the thick shale intervals composing most of the formation. Results of X-ray mineralogical analyses of some samples of the succession are presented in Table 2.

Marine molluscs, particularly *Monotis* sp., are abundant in some beds, especially near the top of the succession in south-central Cornwall Island (for example at GSC loc. C-22236), where the dominant lithology in a succession several metres thick is dark green-grey, thin-bedded, sandy, bioclastic limestone composed mainly of broken *Monotis* shells. (At this intriguing locality, the uppermost Blaa Mountain rocks closely resemble calcareous sandstones of the Schei Point Formation of some other parts of Sverdrup Basin, but the enclosed faunas are dated by E.T. Tozer as late Norian, whereas rocks at the Schei Point type section contain Anisian to Karnian faunas. No strata of this type were observed in western Cornwall Island, and we know of no other surface localities where Norian rocks display this facies, but it seems unlikely that the occurrence is unique, so that care should be exercised in subsurface formational assignments of Triassic calcareous sandstones.)

The Blaa Mountain and Blind Fiord formations are intruded in central Cornwall Island and in the subsurface (Fig. 8) by many gabbro sills and dykes, described in a following section. Wall rocks adjacent to the intrusions are bleached light grey to white, and are altered over widths of a few metres to a few tens of metres to partly spotted, hard, pelitic hornfels, or to hard, nonporous metaquartzite, particularly well displayed in chip samples from Central Dome H-40 and East Amund M-05 wells.

Contacts. Sandstone beds are thicker and more abundant toward the top of the Triassic pelitic succession, which has a gradational contact with overlying strata of the Lower Member of the Heiberg Formation. The contact at surface (Map 1471A) and in boreholes (Figs. 8, 9) is placed at the level at which sandstone becomes the dominant rock type. (In some places, this is an indefinite boundary because some sandstone intervals in the lowermost parts of the Heiberg Formation are not continuous over great distances.) This is consistent with Souther's (1963, p. 432) delineation of the Blaa Mountain - Heiberg contact at the Heiberg Formation type section, but differs from the contact placement on a preliminary map of Cornwall Island released previously (Balkwill, 1975). (On the latter, the contact was placed at the base of the lowest sandstone containing Norian macrofossils; such placement confused lithostratigraphy with biochronology, and is changed here.)

Age and correlation. The youngest macrofaunas collected from the Blaa Mountain Formation in the eastern part of Sverdrup Basin are late Karnian. The oldest macrofaunas are in most places Anisian, although some beds in the northwestern part of the basin, included in the Blaa Mountain Formation, are latest Early Triassic (Thorsteinsson and Tozer, 1970, Fig. X-10 and p. 578).

[1] Bedding and splitting terms used in this paper are those of McKee and Weir (1953).

Table 2. Results of X-ray diffraction analysis of randomly selected bedrock samples from Amund Ringnes and Cornwall islands. Analysis by A.E. Foscolos, Geological Survey of Canada

FORMATION	LITHOLOGY	Layer Silicates: Chlorite	Illite	Kaolinite	Kaolinite and/or Chlorite	Mixed layers	Silicates: Quartz	Feldspars	8.49 or 9.08 Å Peak	Carbonates: Calcite	Dolomite	Siderite	Sulphates: Gypsum	Jarosite	Alunite	Pyrite	γCaSO4	pH	Total
AMUND RINGNES ISLAND																			
KANGUK	Shale		10		6	15	44	10					11	4				3.80	100
	Shale		13	13		16	27	7					9	15				2.85	100
	Shale		6	6		11	47	6					16	6	2			4.00	100
HASSEL	Sandstone		11	52			37											5.70	100
	Sandstone		11		6	2	40	41										8.60	100
CHRISTOPHER	Shale		13		12	11	37	26								1		8.20	100
	Shale		9		19	26	35	4						5	2			4.85	100
	Shaly sandstone		3		5	2	31	23		33	2					1		8.60	100
	Sandstone		10		14	17	38	7					12		2			5.40	100
	Sandstone		13		18	7	41	14							36	4		7.10	100
DEER BAY	Silty shale		12		14	6	52	7					6	3				5.50	100
	Silty shale		13		16	10	43	4					10	4				3.15	100
	Silty shale		14		14	11	53	4						3	1			3.85	100
	Silty shale		16		9	5	50	10			3	1	3		2	1		7.70	100
	Silty shale		15		8	8	49	4					10	5			1	3.65	100
	Silty shale		18		10	5	50	8					4	4	1			4.15	100
	Silty shale		12	12		10	45	15			3	3				2		7.40	100
RINGNES	Shale		16			3	41	4			1	1	28	5	1			4.25	100
	Shale		15		11	6	50	4			4	5	3		2			7.70	100
SAVIK	Shale		11		14	14	42	3					8	8				3.10	100
	Shale		14		15	11	55	5										7.45	100
	Shale		13		12	15	54	4							2			7.85	100
	Shale		13		8	9	42	7	3	13	5							8.30	100
CORNWALL ISLAND																			
SAVIK	Shale		8	15		4	56	17										3.30	100
	Shale		12	19		5	59	5										5.90	100
	Shale		15	25		7	44	2			2			4			1	3.55	100
	Shale		11		15	4	61	5							2	2		6.00	100
BLAA MOUNTAIN	Silty shale		15		13	7	41	22	2									6.80	100
	Silty shale	13	13			7	50	14				2				1		8.20	100

GSC

Macrofossils were collected at several localities in the upper part of the shale-dominated succession mapped as the Blaa Mountain Formation (Map 1471A, Fig. 4). All of the collections are dated by E.T. Tozer as Norian (see Appendix); the collection from GSC locality C-22237 was dated as middle Norian but the others were assigned to the late Norian. They are thus considerably younger than any previously reported collections from rocks assigned to the Blaa Mountain Formation. If the Blaa Mountain and Heiberg formations are to be divided lithologically on the basis of shale or sandstone dominance as Souther (1963) originally proposed, then the thick interval comprising shale with Norian macrofossils on Cornwall Island must be assigned to the former, while recognizing that they are coeval with a large part of the Lower Member of the Heiberg Formation at Buchanan Lake and other parts of eastern Sverdrup Basin. (No new name is given at this time to the Norian shales.) No macrofossils were observed in the region southward from the head of Jaeger River to Pell Point.

Palynomorphs below a level of 1738 m in Amund Central Dome H-40 indicate an Early Triassic age for those strata (Robertson Research (North America) Limited, 1973). No obvious change in lithology was observed in chip samples at that level to provide a lithological basis for separating the pelitic succession into the Blaa Mountain and Blind Fiord formations.

Tozer (1961, p. 13 - 18) demonstrated that the Blaa Mountain Formation in the eastern part of Sverdrup Basin thins and becomes increasingly sandy and calcareous toward the margin of the basin. Where calcareous sandstone is dominant, he referred the rocks to the Schei Point Formation. There is a thin sequence comprising strata of the Schei Point Formation at Table Island, immediately south of Cornwall Island (Fig. 5), with Anisian to Karnian faunas (Tozer, 1961, p. 14, 15). Those sandstones, which are the youngest Sverdrup Basin Triassic rocks south of Cornwall Island, may be equivalent to some part of the undated shales composing the lower exposures of the pelitic succession in south-central Cornwall Island. At Table Island, the Schei Point beds are underlain by Bjorne Formation sandstones (Tozer, op. cit.), which may be coeval with the Lower Triassic pelitic beds deep in Amund Central Dome H-40 (Fig. 8).

Tozer (1970, p. 633 - 635) called attention to distinct contrasts between pelagic faunas and benthonic shallow-water faunas in Triassic rocks of Arctic and western Canada; the pelagic faunas provide no evidence to indicate that the Sverdrup Basin Triassic faunal province was isolated from other provinces. Further, Tozer noted that a taxonomic diversity gradient exists from south to north, and speculated that the faunally less diverse Arctic Triassic seas were cooler than those of the Canadian Cordillera.

Interpretation. Regional stratigraphy of central and eastern Sverdrup Basin indicates that large amounts of Triassic pelites were derived from the eastern and southeastern margins, with intermittent contributions from the northern margin (Thorsteinsson and Tozer, 1970, p. 578). From paleocurrent and petrographic studies, Trettin and Hills (1966) concluded that large amounts of Lower Triassic clastic detritus prograded northeastward into the western part of Sverdrup Basin through a re-entrant near northwestern Melville Island. The very thick succession of Blaa Mountain and Blind Fiord pelites grades eastward and southward to much thinner successions of Bjorne Formation sandstone, and calcareous, partly coquinoid Schei Point sandstone present, for example, at Table Island (Fig. 5) (Tozer, 1961 p. 13 - 23). Also, new evidence, cited in the previous section, shows that the diachronous facies boundary between Blaa Mountain shales and Lower Heiberg sandstones and pelites is younger (late Norian) at Cornwall Island than at other positions along the basin margin, indicating that a probable Late Triassic basin re-entrant existed there.

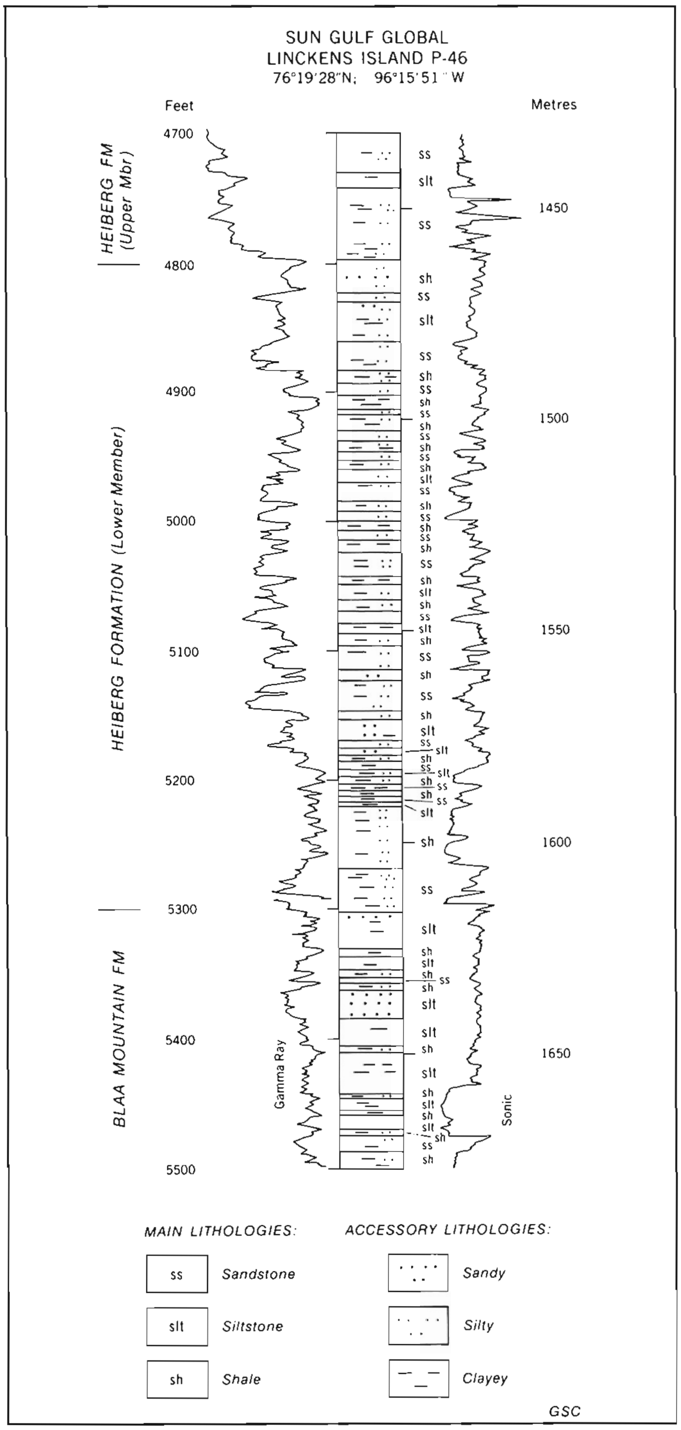


***Figure 9.** Lithology, gamma ray and sonic curves, Sun Gulf Global Linckens Island P-46 well between 4700 and 5500 feet (76°19'28"N, 96°15'51"W).*

Along with the explosive rate of basinward thickening and abrupt change in lithology, there are other indications that the transition from the Bjorne and Schei Point shelf regime to the Blind Fiord - Blaa Mountain basinal regime was abrupt and accompanied by a significant increase in bathymetric slope. The lithology, minor sedimentary structures, and association of glauconite and carbonaceous detritus (see Selley, 1976) suggests that parts of the Blind Fiord - Blaa Mountain succession may be products of turbidite deposition. Furthermore, near the headwaters of Jaeger River, shale and sandstone are folded in a nonsystematic array of flexural-flow folds, which are likely products of soft-sediment deformation. The folds have amplitudes that range erratically from several centimetres to several metres, and wave lengths ranging from about a metre to a few tens of metres, but some of which are large enough to be delineated on the geological map. The axial traces of the folds are northeasterly to easterly, about orthogonal to the crest of the regional structural grain of Cornwall Island. There are no similarly oriented folds on Cornwall or Amund Ringnes islands. Although the axial traces are approximately perpendicular to the presumed (northward) direction of glacial movement, it seems unlikely, for the following reasons, that they are products of ice-thrusting: the Triassic pelitic rocks are better indurated and presumably less susceptible to ice-induced deformation than more weakly indurated nearby strata of the Deer Bay and Savik formations, which display no comparable folds; there are no flutes, striations or other vestiges of Pleistocene glacial modifications of the landscape in the neighbourhood of the folds; and more convincing, large convolute sandstone rolls are intercalated with shale, indicating that at least some beds in the succession were deformed before they were indurated. Other mesoscopic folds and related structures, with styles indicative of soft-sediment, slope-induced lateral flow, were observed in a cored interval of Blaa Mountain sandy pelites about 2025 m below the top of Panarctic Tenneco et al. King Christian N-06 well, eastern King Christian Island (Balkwill and Roy, 1977). In summary, the folds in south-central Cornwall Island, like those in the N-06 core, probably developed from lateral down-slope plastic flow of relatively poorly compacted sediments.

The rate of accumulation for the Blind Fiord - Blaa Mountain pelites, at least for the well established thicknesses in the east-central part of the basin, is greater than for other Mesozoic pelitic formations (Sweeney, 1977). This condition, with the structural attributes presented in the foregoing paragraphs, suggests that the pelites accumulated on a rapidly subsiding basin floor, with influential bathymetric relief. In contrast, all younger marine pelites display characteristics of accumulation on smooth, shallow bathymetric surfaces that lacked appreciably inclined slope transitions from adjacent basin-marginal regimes.

Triassic pelitic rocks in the axial part of the Sverdrup Basin are on the order of 3000 m thick (Thorsteinsson and Tozer, 1970). Combined with several hundred metres of upper Paleozoic strata (Thorsteinsson and Tozer, op. cit.), the load of Triassic rocks almost certainly was sufficient to initiate halokinetic migration of upper Paleozoic evaporitic rocks and early stages of diapirism. Some possible consequences of Triassic sedimentation patterns on the timing and style of diapirism are discussed in a following section on structural geology.

Upper Triassic

Heiberg Formation (Lower Member)

Nomenclature. Souther (1963, p. 432) gave the name Heiberg Formation to a rock succession 1600 m thick, at Buchanan Lake, Axel Heiberg Island (Fig. 5). He distinguished a Lower Member, consisting of alternating units of sandstone and shale, the upper beds of which contain abundant Norian marine pelecypods; and an Upper Member, consisting mainly of carbonaceous and coaly sandstone, which generally lacks macrofossils other than plant fragments. At the type section, the Lower Member of the Heiberg Formation lies gradationally on a shale-dominated succession assigned to the Blaa Mountain Formation; Souther placed the Heiberg - Blaa Mountain boundary at the level at which sandstone is more abundant than shale.

Distribution and thickness. Sandstone and shale assigned to the Lower Member of the Heiberg Formation are poorly to moderately well exposed in cutbanks of creeks near Cape O'Brien, and along Jaeger River. The transition from upper parts of the Lower Member to sandstone of the Upper Member is fairly well exposed along sharply incised creeks immediately south of Mount Nicolay.

From dip measurements and outcrop distribution, the Lower Member of the Heiberg Formation is estimated to be about 225 m thick on central Cornwall Island. [This figure is considerably less than the thickness given in an earlier preliminary map of Cornwall Island (Balkwill, 1975) because of repositioning of the Blaa Mountain - Heiberg contact on Map 1471A for reasons given in the foregoing section.] The member thickens northward to the Central Dome H-40 well, where it is about 490 m thick, including about 120 m of mafic intrusive rocks.

Lithology. The Lower Member of the Heiberg Formation consists of very fine to medium-grained (but mainly fine-grained), green-grey to buff-grey quartz sandstone, and medium to dark green-grey, sandy, thinly laminated siltstone and shale. These rock types are present as repeated, coarsening-upward cycles, ranging from several centimetres to a few metres in thickness. Individual sandstone beds tend to be thicker and more abundant upward in the succession, and the attendant siltstone and shale intercalations thinner and sandier. The cyclic, coarsening-upward aspect of the member is aptly illustrated by borehole log curves (Fig. 9). The sandstone beds have good intergranular porosity in most outcrops, but chip samples show that many subsurface levels of the succession are cemented with silica.

Lower Heiberg sandstone beds are partly parallel-laminated (with carbonaceous flakes on some bedding surfaces) and partly cross-stratified, with small low-angle trough sets. Abundant trails resembling *Didymaulichnus* (F.G. Young, pers. com., 1976) were observed on some brick-red, clay parting surfaces in the section along Jaeger River. There also, some of the sandstone beds contain rounded, discoidal, grey and red-brown shale clasts (probably intraclasts), about 2 to 3 cm in diameter, and some very irregular, deep red-brown, ironstone partings. Fragments of red shale and ironstone are present in chip samples from the Lower Member of the Heiberg Formation in the Linckens Island P-46 borehole.

Contacts. The base of the Lower Member of the Heiberg Formation was mapped as the level in the intercalated sandstone-shale succession comprising upper Blaa Mountain - Lower Heiberg strata at which sandstone is more abundant than siltstone and shale. This is consistent with Souther's (1963) original definition of the two formations, but differs from the contact as mapped previously by Balkwill (1975). North and south of Jaeger River, this contact is delineated easily at the base of a buff sandstone bed, 30 m thick, below which are dominantly dark grey-green shales. The contact is less obvious in the west-central part of the island where Lower Heiberg sandstone units are discontinuous along strike and the boundary depicted on the geological map is thus an approximation. The top of unit Trhl was mapped at the uppermost level of green-grey shales and siltstones, above which are buff sandstones of unit TrJhu. In some places, as at Mount Nicolay, this contact is marked topographically by a local break in slope. In boreholes, the contact is marked by prominent shifts in gamma ray, and other geophysical log profiles (Fig. 8).

Age and correlation. Macrofossil collections from rocks on Cornwall Island assigned to the Lower Member of the Heiberg Formation were dated by E.T. Tozer as late Norian (GSC loc. C-26625). McLaren (1963, p. 530) collected late Norian pelecypods near the top of rocks he assigned to the Lower Member at Mount Nicolay. At Cornwall Island, and probably in the subsurface of Amund Ringnes Island, the contact between shale-dominated Lower Heiberg strata is considerably younger than in eastern parts of Sverdrup Basin; on Axel Heiberg and Ellesmere Islands, Lower Heiberg beds are as old as early Norian, and Blaa Mountain shales are not younger than Karnian.

Interpretation. The Lower Member of the Heiberg Formation consists of repeated coarsening-upward cycles of shale, siltstone and sandstone, partly represented in geophysical log profiles by upward-flaring curves (Fig. 9). The succession contains relatively abundant marine pelecypods (chiefly *Monotis* sp.), local trails and burrows, and some small to medium low-angle sets of trough cross-strata. These intercalated lithologies appear to represent sands and muds deposited in relatively shallow water adjacent to a large delta or delta complex that prograded northward to northwestward, and overwhelmed the marine environment, resulting in delta plain and other nonmarine deposits of the Upper Member. Sandstone beds with red shale partings and intraclasts are suggestive of temporary emergence and agitation, and redeposition at or near the strandline, possibly in interdeltaic tidal flats. No contorted bedding or other indicators of soft-sediment lateral flow were noted in Lower Heiberg strata.

Upper Triassic and Lower Jurassic

Background

Nomenclature, age and correlation of the interval comprising Upper Triassic and Lower Jurassic arenaceous rocks lying between upper Norian marine beds of the Lower Member of the Heiberg Formation and lower Toarcian sandstones and coeval shales (Jaeger and Savik formations, see Figs. 5, 10) present some of the most problematic aspects of Sverdrup Basin stratigraphy. The problems have more than academic interest because the upper part of that sandstone succession is a natural gas reservoir at western Ellef Ringnes Island, King Christian Island, and northern Melville Island (Fig. 5). Reasons for distinguishing three lithologic units---Heiberg Formation Upper Member, Borden Island Formation, and Borden Island Formation - Heiberg Formation Upper Member (undivided)---for rocks comprising this interval on Cornwall and Amund Ringnes islands are dictated by the following regional conditions.

(1) Souther (1963, p. 433) named the Heiberg Formation at Buchanan Lake, Axel Heiberg Island, and divided it into a Lower Member consisting of sandstone and shale, with Norian macrofossils at the top, and an Upper Member of sandstone with some coal, and lacking marine macrofossils. As defined by Souther, the Upper Member included sandstone beds to the base of Savik Formation shales.

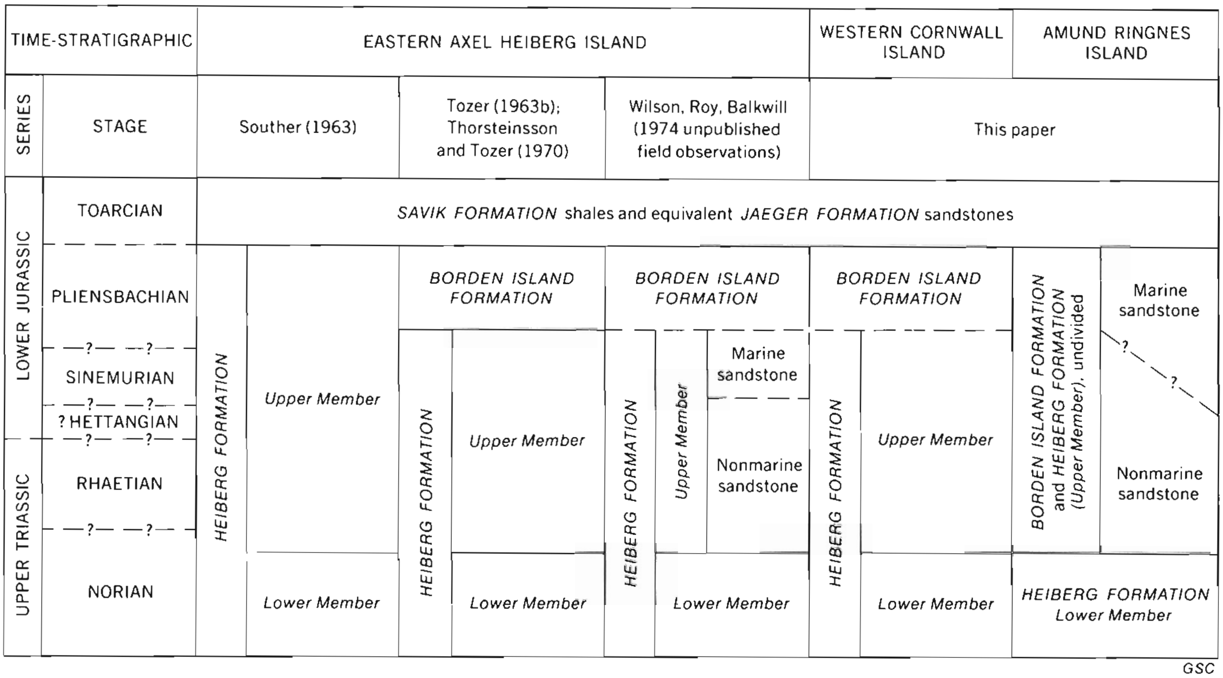


Figure 10. Upper Triassic and Lower Jurassic nomenclature, eastern and south-central Sverdrup Basin. Dashed contacts are considered approximate or uncertain.

(2) Tozer and Thorsteinsson (1964, p. 121) introduced the term Borden Island Formation for about 60 m of glauconitic sandstone and thin beds of red ferruginous sandstone at Borden Island, near the northwestern rim of Sverdrup Basin (Fig. 5). At the type section, the formation lies disconformably on the Schei Point Formation (containing Karnian macrofossils), and is overlain conformably by grey shales of the lower part of the Savik Formation, which contain Toarcian faunas (Thorsteinsson and Tozer, 1970, Figs. X-10, X-12). The writer, with R.A. Rahmani, T.P. Poulton and J.T. Tan, examined and sampled the Borden Island Formation type section in 1977 (Rahmani and Tan, 1978). The formation consists of three parts. At the base there is ferruginous, silty sandstone, in paleotopographic depressions developed on the Schei Point Formation; the age of the basal sandstones is not known. Above those beds lies an upward-coarsening interval of shale, siltstone and sandstone, with late Sinemurian ammonites. The upper part consists of an upward-coarsening interval of shale and sandstone, containing Pliensbachian to early Toarcian palynomorphs (Tan, 1979).

Sinemurian and Pliensbachian parts of the Borden Island Formation crop out at several places around the western margin of Sverdrup Basin. In wells drilled there, a basal, ferruginous shale and sandstone interval is commonly developed. Embry (pers. com., 1980) suggests that the basal interval represents part of the Hettangian Stage, present only in deeper parts of the basin, and overstepped toward the basin margins by younger Lower Jurassic rocks. Further, he suggests that the three parts of the Borden Island Formation in western Sverdrup Basin represent depositional responses to eustatic sea level fluctuations in the Hettangian, Sinemurian and Pliensbachian ages of the Early Jurassic.

(3) A few years after Souther's field work at Buchanan Lake, Tozer studied Triassic and Jurassic rocks in the eastern part of the Sverdrup Basin and noted that there is a thin, but widespread, unit of buff sandstone with thin red ferruginous beds, lying below Savik Formation shales and above light-coloured Heiberg Formation sandstones. Because of the lithologic similarity of the red-weathering sandstones to rocks in the type section of the Borden Island Formation and their position below Savik shales, he assigned them---including 51 m of sandstone at the top of Souther's type section of the Heiberg Formation---to the Borden Island Formation, and assumed that the rocks are Sinemurian in age. Moreover, he inferred that Upper Heiberg sandstones immediately below the red-weathering Borden Island beds are entirely nonmarine and more likely to be Triassic than Jurassic (Tozer, 1963b, p. 16, 17, Table 1; Thorsteinsson and Tozer, 1970, p. 579). Subsequent maps (Thorsteinsson, 1971a) distinguished the interval containing red-weathering sandstones as the Borden Island Formation.

K.J. Roy, D.G. Wilson and the writer examined Upper Heiberg - Borden Island relationships at several localities in the eastern part of Sverdrup Basin (including the Heiberg Formation type section) in 1974, and observed that:

(a) Individual red-weathering beds in the succession mapped as the Borden Island Formation are discontinuous laterally. In many places, red sandstones are extensively bioturbated and partly glauconitic; the red colouration of some beds may have been diagenetically produced by oxidation of iron in glauconitized fecal pellets. The base of the interval and, consequently, its thickness also vary erratically from place to place, depending on the local stratigraphic level of the lowest observed red-weathering bed. (At Buchanan Lake, for example, there are a few thin red, ferruginous beds tens of metres below the top of the dominantly massive-bedded, buff sandstones of the Upper Member of the Heiberg Formation.)

(b) In many places there are buff sandstones in the upper part of the Heiberg Formation (i.e. below the red and buff, recessive sandstones commonly mapped as the Borden Island Formation), which contain abundant *Ophiomorpha*-like burrows and other trace fossils, and low-angle cross-strata, and lack coal, thus appearing to be at least partly marine shoreface deposits. There is no observable discordance between these probable marine sandstones and the buff and red sandstones above, or the partly coaly Heiberg sandstones below. The general stratigraphic succession is: buff-coloured, probably nonmarine Heiberg sandstones; buff, bioturbated, probably marine Heiberg sandstones; and buff and red, fossiliferous Borden Island sandstones. This succession seems to be concordant and gradational. Upper Heiberg beds on Ellesmere Island contain fossil plants of the same flora as is present in Rhaetic rocks of East Greenland (T. Delevoryas, Univ. Texas, pers. com. to D.G. Wilson, 1976); and palynomorphs in Upper Heiberg sandstones on Cornwall Island are considered tentatively Rhaetian to Early Jurassic by Robertson Research (North America) Limited (see Appendix). However, no diagnostic Hettangian faunas or floras have been reported from any part of the succession.

(c) Buff and red Borden Island sandstones contain marine fossils in many places. The most common faunas, *Lingula* sp. and *Meleagrinella* sp., are of no value for detailed age determination, but diagnostic Pliensbachian macrofossils [*Amaltheus* aff. *A. stokesi* (Sowerby); H. Frebold, pers. com., 1975] have been collected from several localities near the base of the buff and red sandstones. Thus far, no Sinemurian macrofossils have been collected from any rocks in eastern Sverdrup Basin.

From the foregoing, as well as from observations of the Upper Heiberg - Borden Island interval on Cornwall Island and the Ringnes islands, cited in following sections, it is concluded that the uppermost Heiberg - Borden Island interval along the eastern and southern margins of Sverdrup Basin constitutes first-order Early Jurassic marine transgression toward the southern and eastern basin margins. This tendency was interrupted by recurrent regression, with deposition (and some oxidation) of ferruginous sands. In western Sverdrup Basin, the base of Jurassic rocks is widely marked by red shale or red sandstone. In the Ringnes islands, the Triassic-Jurassic boundary is not obvious, lithologically, given the data available at this time. Biochronological determinations, by Robertson Research (Canada), of well cores and chip samples submitted by Panarctic Oils Ltd., indicate the boundary is at or near the base of the thick sandstone succession comprising the Upper Member of the Heiberg Formation (of Souther's nomenclature).

The preceding observations and comments illustrate some of the difficulties in distinguishing, in surface exposures, the Borden Island Formation of original definition and previous usage from the uppermost part of the Heiberg Formation. These difficulties are amplified in the subsurface by the limitations imposed by well samples and geophysical logs. Renovation of Upper Triassic - Lower Jurassic stratigraphic nomenclature is vital and should follow a systematic, basinwide sedimentological and biochronological study. For this report, we assigned rocks on Cornwall and Amund Ringnes islands to the Heiberg Formation Upper Member, the Borden Island Formation, or to an undivided map unit combining them for reasons specified in the sections that follow.

Heiberg Formation (Upper Member)

Nomenclature. Over most of Cornwall Island, the rocks delineated on Map 1471A as the Upper Member of the Heiberg Formation compare closely with Souther's original definition of the unit: the rocks are mainly buff sandstones, with a few beds of siltstone and shale and some thin intercalated coal beds; they lie conformably on Lower Heiberg siltstones and sandstones. At western Cornwall Island there is a thin lens of red, sideritic, pebbly sandstone near the top of the Upper Member. The lenticular bed has Sinemurian or Pliensbachian brachiopods.

Distribution and thickness. Quartzose, partly coaly sandstone assigned to the Upper Member of the Heiberg Formation forms an arcuate outcrop belt across central and northern Cornwall Island. The sandstone forms the prominent hill called Mount Nicolay where, adjacent to gabbro sheets, it is cemented by quartz. The unit is thickest (about 620 m) along Jaeger River; in southwestern Cornwall Island, it is about 260 m thick (Fig. 4, Sec. A-B).

Lithology. The Upper Member of the Heiberg Formation lacks marine macrofossils (except for the lens of Borden Island - like red sandstone included in the uppermost part of the unit in southwestern Cornwall Island) and is composed almost entirely of partly cherty quartz sandstone with a few thin units of dark grey shale and siltstone, and very minor amounts of coal. The sandstone beds are mainly very light grey to light grey-buff, with local brown and brown-grey beds; they are partly carbonaceous and coaly, with carbon detritus on bedding surfaces, small coalified logs and root traces, and some hard, lustrous coal beds no more than a few centimetres thick. The sandstone beds range in thickness from very thin to massive, and are partly cross-stratified by small to large, high-angle tabular and trough sets. Foresets in the section measured by Wilson face northwestward; random observations of the unit in other parts of Cornwall Island indicate that this is the dominant facing direction of large cross-strata. Details of bedding fabric commonly cannot be seen because of the friable nature of the unit in many outcrops.

The sandstone is poorly cemented in most outcrops on Cornwall Island and, in many places, lies as undulating terrains of loose sand. Exceptions are at Mount Nicolay, where the sandstones are cemented with quartz, adjacent to thick gabbro sheets, and an area of hoodoo development in west-central Cornwall Island, where the sandstones are erratically cemented not far from a network of mafic dykes and sills.

Contacts. Light-coloured sandstone comprising the Upper Member of the Heiberg Formation contrasts with darker hues of the interbedded sandstone and shale succession comprising the Lower Member. At Mount Nicolay, this contact is marked also by a break in slope.

In western Cornwall Island, the Upper Heiberg coaly sandstone grades upward to buff sandstone with a lens of red sandstone containing Sinemurian or Pliensbachian brachiopods. In this area, the top of the Heiberg Formation was mapped at the base of an overlying, continuous bed of red sandstone (also with Sinemurian or Pliensbachian brachiopods), and the lens of red sandstone is included as a local marker in the Upper Heiberg.

Age and correlation. Regional conditions applying to the age and correlation of the Heiberg Formation Upper Member were presented in the foregoing review of Upper Triassic and Lower Jurassic stratigraphy. Throughout Cornwall Island, late Norian bivalves [*Monotis ochotica* (Keyserling)] are abundant in uppermost beds of the Lower Member of the Heiberg Formation, as at GSC locality C-26625. The fossiliferous strata are overlain concordantly by nonfossiliferous Upper Member sandstones, lacking marine macrofossils. Samples of carbonaceous and shaly Upper Heiberg rocks were collected by D.G. Wilson and K.J. Roy and examined by paleontologists of Robertson Research (North America) Limited, who tentatively considered a sample about 130 m above the base of the unit at Jaeger River to be Rhaetian (GSC loc. C-30132). A tentative ?Jurassic age was assigned to collection C-30135, about 210 m above the base of the Upper Heiberg at Jaeger River.

As mapped on western Cornwall Island, uppermost beds of the Upper Heiberg Member are upper Sinemurian, or lower Pliensbachian, because they contain a lens of sandstone with diagnostic brachiopods [*Cirpa* cf. *C. fronto* (Quenstedt)] identified by D.V. Ager (GSC locs. C-26620, C-26636). Palynomorphs, tentatively considered Late Triassic, were collected about 40 m below the top of the Upper Member in southwestern Cornwall Island (GSC loc. C-37148).

Interpretation. Sandstone composing map unit TrJhu is part of a major Late Triassic - Early Jurassic regressive-transgressive depositional episode. Strata in the lower part of the unit overlie abruptly intercalated marine sandstone, siltstone and shale which, from lithological and faunal evidence, seem to be delta front deposits. The abruptness of the transition suggests that the succeeding delta and fluvial systems prograded rapidly, with a great influx of sand derived from a lithologically mature, arenaceous, partly cherty terrain. Strata comprising most of the Upper Heiberg interval are composed dominantly of fine-grained sandstone. There are few shale or siltstone beds, fining-upward cycles, or other characteristics usually associated with a large meandering channel system. Therefore, the strata are more likely to be products of a huge braided fluvial complex, rather than those of a single large river. Phases of increased discharge are indicated by scour channels with pebble lenses, and intraclast beds. Some of the very well sorted, fine-grained, clean sandstone units may have been deposited by wind.

Foreset beds tend to face northwestward. Deltaic progradation may have been directed northwestward from the large basin re-entrant near Graham Island. The succession in eastern Cornwall Island is considerably thicker than it is in western Cornwall Island or in wells to the north and west. Preservation of the particularly thick succession of alluvial sandstone required active syndepositional subsidence.

If there is an observable change in the character of the nonmarine rocks, signalling the end of the lower, regressive fluvial phase, and the beginning of the fluvial part of the upper, transgressive phase, it is not presently apparent to us. The lens of red, fossiliferous (Sinemurian-Pliensbachian) sandstone in southwestern Cornwall Island marks the lowest evidence of transition to Jurassic marine conditions. This lens is coarser grained than adjacent beds, and may be an upper shoreface relict of local, relatively high energy, such as a storm berm. Regional marine inundation of the Upper Heiberg alluvial plain in the region of western Cornwall Island is marked by the continuous interval of red, fossiliferous, coarse-grained sandstone, mapped by us as the base of the Borden Island Formation.

Revision. A few hundred metres north of Jaeger River, very poorly exposed beds of light grey shale (unit Jbsh of Figure 13), a few metres thick, were discovered in 1979. The shales lie abruptly and conformably on Heiberg sandstones; they contain Sinemurian or Pliensbachian palynomorphs [Robertson Research (Canada) report to Panarctic Oils, 1979] and are therefore correlative with part of the Borden Island Formation of western Sverdrup Basin. Figure 13 depicts the Heiberg - Borden Island contact based on the foregoing revision. Contacts and thickness given in Figures 4, 8 and 12 and Table of Formations should be revised accordingly.

Borden Island Formation

Nomenclature. Some of the history of Borden Island nomenclature was reviewed in a previous section. In western Sverdrup Basin, where the formation was first named, it consists of ferruginous marine sandstones and shales; those rocks are now known to range from Sinemurian---and possibly Hettangian---to lower Toarcian (Tan, 1979; Embry, pers. com., 1980). In 1972-74 traverses, red sandstones with Sinemurian or Pliensbachian fossils at western Cornwall Island were mapped as the Borden Island Formation (Fig. 11); the formation was not recognized in eastern Cornwall Island (Map 1471A). Traverses and biochronological determinations in 1979 revealed that rocks indicated as units JjA and JjB contain Sinemurian (?) - lower Toarcian palynomorphs and are equivalent to part of the Borden Island Formation of western Sverdrup Basin (Fig. 13). The type section of the Jaeger Formation (at Jaeger River, eastern Cornwall Island) includes unit JjB, which creates confusion in the interpretation of this section.

Distribution and thickness. Westward-dipping, red fossiliferous sandstone, assigned to the Borden Island Formation on Map 1471A forms the crest of a low ridge in the southwestern part of Cornwall Island (Fig. 11). From southwestern Cornwall Island, the formation thins northward to about 30 m because of lithofacies changes: some red sandstone units forming the lower part of the Borden Island interval grade laterally to buff sandstone, from which fossils were not collected, but which nonetheless may be marine. The buff sandstone is not obviously distinguishable from sandstone in the Upper Member of the Heiberg Formation, and so was mapped with that unit.

Lithology. Rocks mapped (Map 1471A) as the Borden Island Formation on Cornwall Island consist of alternating fining-upward dark- and light-coloured sandstone intervals, about 1 m or less thick. Dark red-brown and yellow-brown rocks constitute about 30 per cent of the total succession, and light-coloured rocks about 70 per cent; but, because the dark beds are moderately well cemented with brown limonite, they tend to form a dark veneer over the softer, light-coloured sandstones (Fig. 11), giving a false surface impression of the real lithology of the formation.

Sandstone at the base of each interval is dark red-brown, locally grading to yellow-brown, fine to very coarse grained, very pebbly, and partly fossiliferous. About two thirds of the pebbles are light buff or light grey chert, and the rest are dark grey or red-brown; some pebbles have dark grey or brown cores and light-coloured weathering rinds. Most pebbles are less than 1 cm long, and are well rounded. Bimodal quartz and chert sand with limonite cement forms the matrix for the pebbly intervals, which are concentrated at the bases of wide (tens of metres), shallow channels. Siderite cement was not noted in surface beds, but is abundant in some well samples (D.G. Wilson, pers. com.).

The light-coloured sandstone beds are pale grey to pale buff and partly yellow-buff, very fine to medium grained, but dominantly fine grained, and poorly cemented. Observations of sedimentary structures are largely precluded by the great friability of the rocks. As a generalization, the lithology of the light-coloured sandstone closely resembles that of the sandstone in the Upper Heiberg Member, except for the presence of intercalated red-brown pebbly beds.

Age and correlation. Ammonites in the Borden Island Formation in western Sverdrup Basin range in age from early Sinemurian to late Pliensbachian (Frebold, 1975). Palynomorphs at the type section are Sinemurian to early Toarcian (Tan, 1979). Based partly on palynological evidence, Embry (pers. com., 1980) suggests that the lower part of the formation in central areas of the basin is Hettangian.

Brachiopods were collected in southwestern Cornwall Island from basal beds of the succession mapped (Map 1471A) as the Borden Island Formation (GSC loc. C-26623). The collection contained the rhynchonellid *Cirpa* cf. *C. fronto* (identified by D.V. Ager, University College of Swansea), which indicates a late Sinemurian or early Pliensbachian age for the strata. (The same diagnostic fauna was collected from a lens of red sandstone included in the Upper Heiberg Member at GSC loc. C-26623.)

Interpretation. Along the eastern and southern margins of Sverdrup Basin (including Cornwall Island), the Borden Island Formation, distinguished by its red, fossiliferous, pebbly sandstone intercalations, represents initiation of regional Early Jurassic marine trangression. The formation overlies

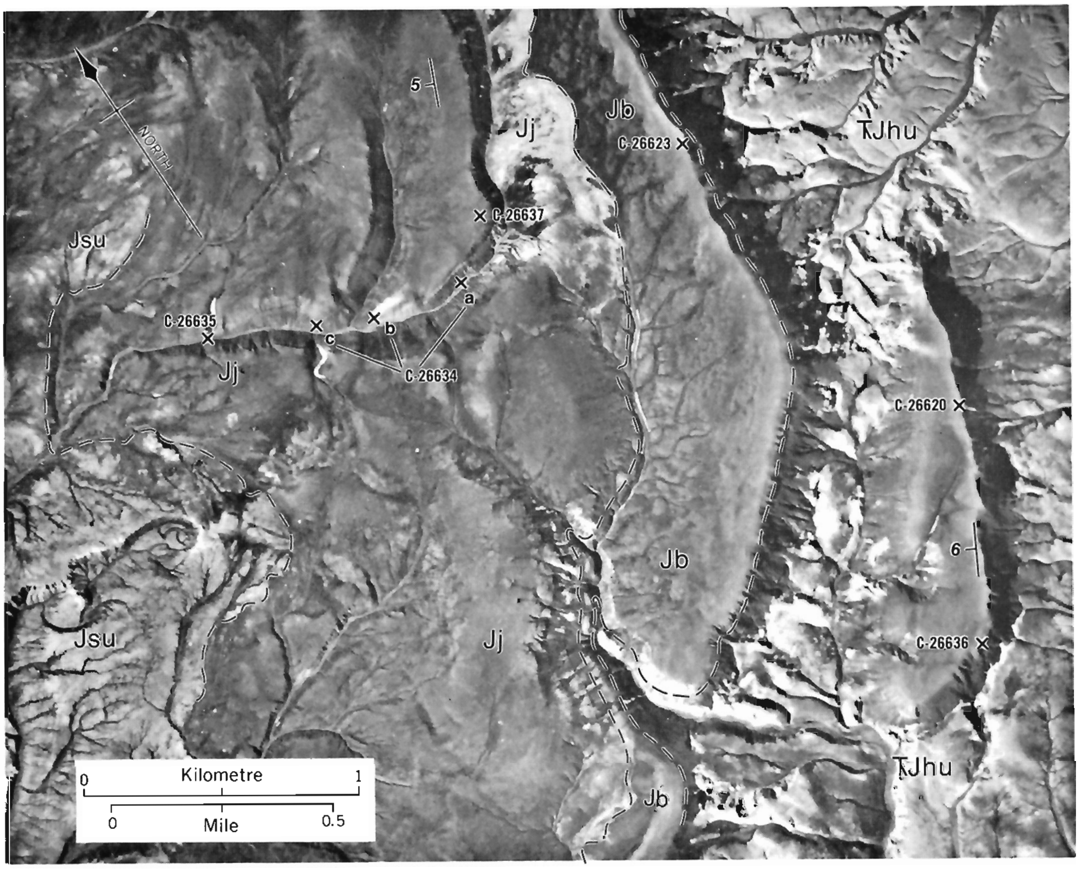


Figure 11. Stratigraphic relationships, southwestern Cornwall Island. TrJhu: Heiberg Formation, Upper Member; lens of red-weathering sandstone at sites of fossil collections C-26636 and C-26620; Jb: Borden Island Formation; Jj: Jaeger Formation; Jsu: Savik Formation, Upper Shale Member. Age assignments of faunal collections as follows: C-26636, C-26620 and C-26623 late Sinemurian to early Pliensbachian; C-26634a early Toarcian; C-26634b middle Toarcian; C-26634c late Toarcian (tentative); C-26637 middle Toarcian; C-26635 middle or late Toarcian (see Appendix). Part of NAPL vertical air photograph A16193-91 (enlarged).

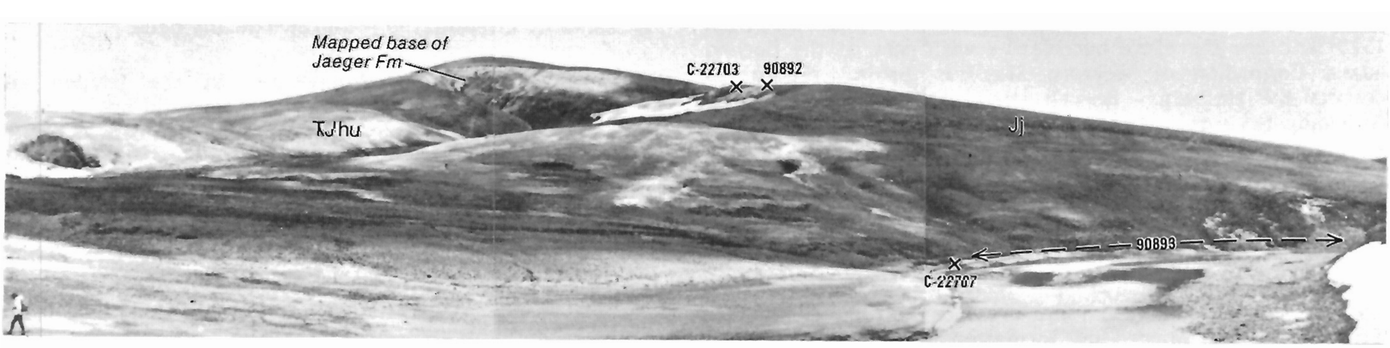


Figure 12. View northeastward of the Upper Member of the Heiberg Formation (TrJhu) and Jaeger Formation (Jj) at Jaeger River, Cornwall Island. Strata dip about 10-12 degrees eastward (to right in photo). GSC fossil localities: C-22707 early Bajocian; 90893 early Bajocian; C-22703 Toarcian; 90892 early Bajocian. Note light-coloured, nonfossiliferous sandstones stratigraphically above lower fossil collections (see text). GSC 199243.

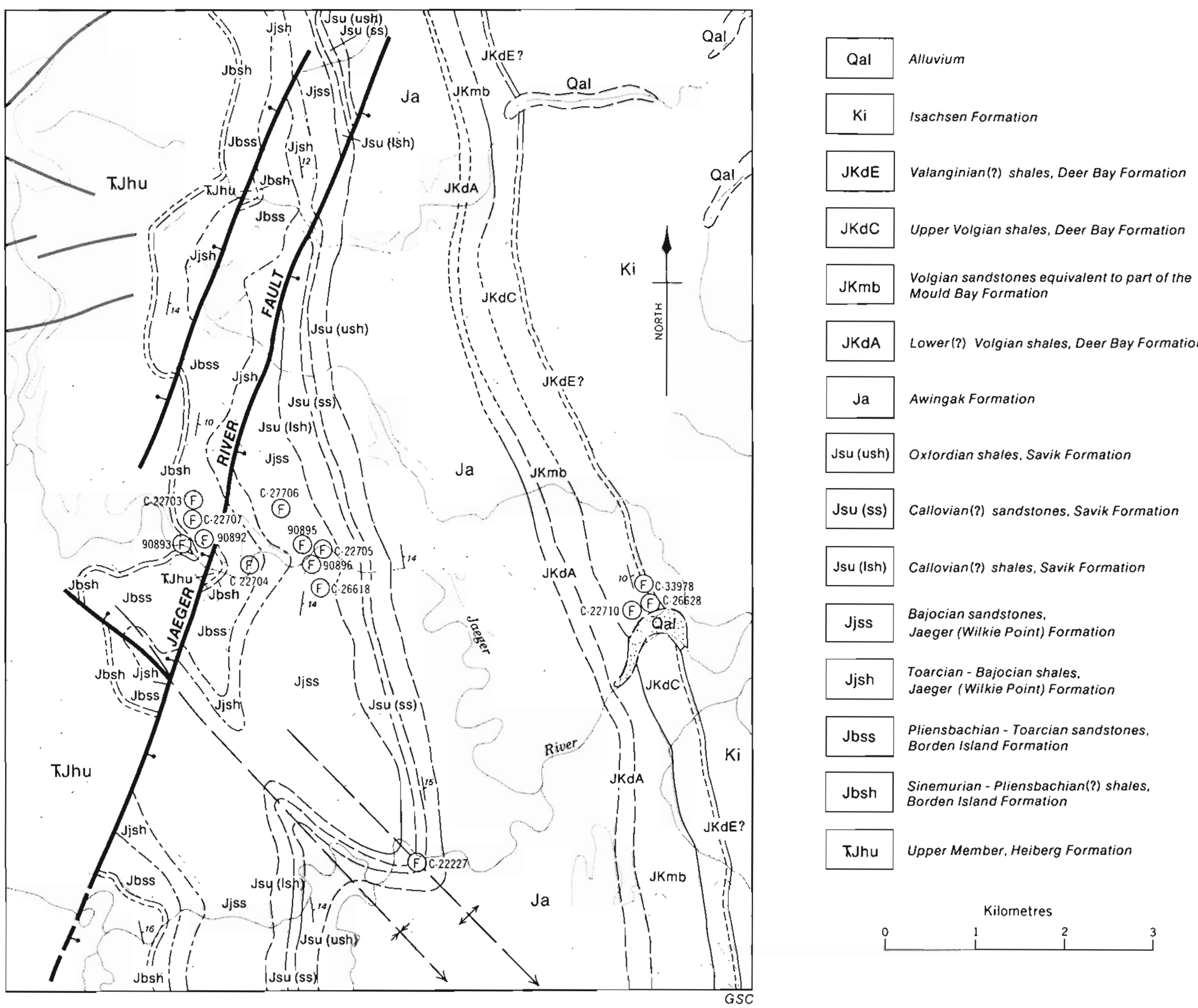


Figure 13. Revised (1980) geological map, Jaeger River area, eastern Cornwall Island. Compare with Map 1471A.

the Heiberg Upper Member sandstone, which likely was deposited on a coastal plain, and underlies pebbly and shaly Jaeger Formation sandstone, which is marine throughout.

The presence of intercalated, fossiliferous chert-pebble lenses, as channel lag in the sandstones, requires intermittent marine conditions of high energy, which might be produced by storms on upper shoreface tracts.

Because iron pigments in the Borden Island Formation are confined to thin, intercalated, discontinuous layers, and there are insignificant amounts of iron-bearing detrital grains, we favour the premise that pigmentation resulted from in-place diagenesis. The red beds contain fossils and, in some places, abundant *Ophiomorpha*-like burrows, whereas the intercalated buff beds seem to be barren of fossils and other biogenic traces. This suggests that preferential localization of iron oxide pigment in the red beds resulted from oxidation after early diagenetic biodegradation, perhaps from alternation of glauconitized fecal matter, or iron-enhancement of pore-waters and precipitation following animal decomposition.

Revision. A thin, very poorly exposed interval of green-grey shale (unit Jbsh of Figure 13) lies on the Heiberg Formation at Jaeger River. The shale contains Sinemurian to Pliensbachian palynomorphs; green-grey shales composing map unit JjA on western Cornwall Island contain palynomorphs considered as "post-early Pliensbachian to pre-mid Toarcian" [Robertson Research (Canada) Limited report to Panarctic Oils Limited, 1979]. The green-grey shales are overlain by sandstones depicted on Map 1471A as unit JjB of the Jaeger Formation. The oldest macrofaunas in unit JjB are early Toarcian; the basal beds can therefore be Pliensbachian.

Unit JjB and the underlying shales (JjA of western Cornwall Island, and the shales at Jaeger River) are approximately coeval with the Pliensbachian - lower Toarcian beds forming the top of the Borden Island Formation of western Sverdrup Basin (Tan, 1979).

Greiner (1963) placed the base of the type section of the Jaeger Formation at the base of sandstones composing unit JjB. The name "Jaeger Formation" has precedence over "Borden Island Formation" which was defined later (Tozer and Thorsteinsson, 1964). Despite that, regional correlation would be improved if units JjA and JjB were assigned to the Borden Island Formation, and the base of the Jaeger Formation (or some newly named formation) was placed at the base of unit JjC (Fig. 13).

Borden Island Formation and Upper Member Heiberg Formation (undivided)

Nomenclature. Grey sandstone adjacent to Amund Ringnes Piercement Dome and in the subsurface of Amund Ringnes Island is assigned to a collective map unit (TrJhub) because it has some attributes in common with both the Borden Island Formation and Heiberg Upper Member, but lacks other important aspects considered typical of those units.

Distribution and thickness. Nearly vertical beds of quartz-cemented sandstone assigned to map unit TrJhub form resistant rims at the northern and southern margins of Amund Ringnes Piercement Dome. The sandstone is structurally concordant beneath Savik Formation shale, and a complete Savik succession seems to be present; there seems to be little likelihood that the sandstone comprises exotic masses faulted diapirically against Savik shale. The exposed thickness of the unit at each of these localities is about 180 m, but at each locality the lower contact is in fault (or intrusive) juxtaposition with diapiric material comprising the dome. Thicknesses of the unit in drillholes are given in Figure 8.

Lithology. The sandstone comprising map unit TrJhub is light to medium buff-grey, and weathers medium grey; no red or brown beds were observed. The rocks are very thin to thin bedded and partly cross-stratified as small-scale, low-angle sets. Some beds near the base of the section at the northern rim of the dome contain angular, tabular shale clasts in a matrix of very fine grained sandstone; the shale clasts are up to 2 cm long and are very light grey, appearing to be bleached. Some beds near the top of the sandstone succession have abundant cylindrical burrows, perpendicular to bedding; the burrows are about 4 to 5 cm wide and 3 to 4 cm long.

The sandstone ranges from very fine grained to medium grained, but is dominantly very fine grained (grain mode about 0.10 mm). The sand grains are very well sorted, mostly angular and composed almost entirely of quartz, with about 5 per cent accessory grains of feldspar, chert, sericite flakes, rounded tourmaline grains, and carbonaceous grains. Cuttings from subsurface levels of the unit contain grains of light grey to white, powdery, tripolitic chert, which impart a spotted appearance to the rock chips. Such grains are not apparent in surface samples of the Heiberg Upper Member on Cornwall Island, presumably because the soft, powdery chert is weathered easily at the surface. The rocks are moderately to well cemented with silica, and this quality contrasts them with other quartzose sandstones on Amund Ringnes Island, except those adjacent to gabbro sheets at Mount Nicolay.

The texture and composition of the sandstone assigned to map unit TrJhub categorizes them as mature quartzarenites.

Contacts. Unit TrJhub is in diapiric fault contact with gypsum and diapirically transported limestone blocks at the northern and southern rims of Amund Ringnes Piercement Dome. Beds at the upper contact are concordant with shales assigned to the Savik Formation (undivided), although the contact is covered everywhere with talus derived from the resistant cemented sandstone which forms a rampart above the soft shale. The contact is abrupt, and apparently conformable in wells and is prominently marked by conspicuous deflections on log curves (Fig. 8).

Age and correlation. No diagnostic macrofossils were collected from rocks assigned to map unit TrJhub. Oldest macrofaunas collected above the sandstones (GSC loc. C-22232) were assigned an early Bajocian age by Frebold. From palynological studies, Robertson Research (North America) Limited (1973) suggested that Upper Triassic strata might be indicated by a form attributable to *Aratrisporites* that is present at a level of 1110 feet (339 m) in the Amund Central Dome H-40 well. On that basis, most of the strata assigned to unit TrJhub in that well would be Upper Triassic. Other diagnostic Triassic forms were noted in samples from between 1230 and 1290 feet (375-393 m) (*Lunatisporites* sp. and aff. *Ovalipollis ovalis*).

The sandstone at the piercement dome closely resembles upper parts of a sandstone interval at Reindeer Peninsula, northwestern Ellef Ringnes Island (Fig. 5), which Stott (1969) mapped as the Borden Island Formation; only the lower parts of that thick succession may have any red sandstone beds, and they yielded a collection of early Sinemurian ammonites.

Thus, map unit TrJhub partly resembles the Heiberg Upper Member because it comprises light-coloured quartz sandstone that is distinctively fine grained and well sorted; but the strata lack coal beds typical of the Heiberg Member at Cornwall Island. The upper beds of unit TrJhub are burrowed extensively and seem to be marine, which is a diagnostic attribute of the Borden Island Formation. However, they lack red beds and pebble lenses which distinctively characterize the basin-marginal facies of that formation. They resemble, more closely than any other unit we have seen, the marine beds at the top of the Upper Heiberg Member on eastern Axel Heiberg Island (Fig. 10).

Sandstone adjacent to the piercement dome lies in a midbasin position, about equal distances from Cornwall Island and Reindeer Peninsula. At Cornwall Island the Upper Heiberg is thick and the Borden Island Formation is thin. At Reindeer Peninsula, the Upper Heiberg (in the strict sense) is not exposed and it may be very thin or absent, whereas the Borden Island Formation (in the broad sense) is very thick.

From the foregoing, it is concluded that the sub-Savik sandstone at Amund Ringnes Piercement Dome and underlying most of Amund Ringnes Island may include midbasin facies of both the Upper Member of the Heiberg Formation and the Borden Island Formation but we have insufficient data at present to separate the strata meaningfully.

Interpretation. Interpretation of the Late Triassic - Early Jurassic deposition of the southern and central parts of Sverdrup Basin is summarized essentially in the choice and naming of the three map units discussed in the foregoing sections. The term Heiberg Formation Upper Member is applied here to quartz sandstone lacking marine macrofossils and containing some coal beds, which probably was deposited by rivers and wind, initially as part of a vigorously prograding delta system, and later on a broad coastal plain. This seems to be a proximal facies, thickest along the eastern and southern margins of the basin. A thin succession of sandstone strata in western Cornwall Island was assigned to the Borden Island Formation because it is partly red and pebbly, and contains late Sinemurian or early Pliensbachian macrofossils. Approximately similar rocks on the northwestern rim of the basin contain Sinemurian macrofossils. That facies seems to be lacking in rocks of the midbasin; instead, there are vertically burrowed sandstone beds adjacent to Amund Ringnes Piercement Dome. Because of uncertain correlations at the latter, the rocks there have been assigned to the undivided Upper Member of the Heiberg Formation and Borden Island Formation.

Lower and Middle Jurassic

Jaeger Formation

Nomenclature. Greiner (1963, p. 535, 536), following his 1955 reconnaissance traverse of Jaeger River, eastern Cornwall Island (Fig. 5), introduced the name Jaeger

Formation for partly pebbly, partly glauconitic, and fossiliferous sandstone occurring there. He estimated that the type section is about 300 m thick; but part of that section is repeated by normal fault (Map 1471A), and the actual stratigraphic thickness of the formation there is about 230 m.

Along the eastern margin of Sverdrup Basin, a thin but mappable sequence of shale separates Jaeger sandstone from underlying beds. Tozer (1963b, p. 21, 22) recognized that this shale is a tongue of the lower part of the Savik Formation of eastern Axel Heiberg Island, and that Jaeger sandstone occurs as a wedge that thins basinward and grades laterally to Savik shale. Consequently, he named the wedge of sandstone the Jaeger Member of the Savik Formation. Tozer's nomenclature is followed here: Jaeger Formation is retained for Cornwall Island, where lower Savik shale is not mappable continuously; and Jaeger Member (of the Savik Formation) is applied to the northward-thinning wedge of sandstone in the subsurface of southern Amund Ringnes Island (Figs. 4, 14).

Distribution and thickness. On eastern Cornwall Island, the Jaeger Formation (units JjB, JjC and JjD of Map 1471A) consists of two resistant sandstone intervals, with an intervening recessive shale interval, which altogether form a sinuous, eastward-dipping strike ridge (Fig. 12). An unfaulted section of the formation south of Jaeger River, measured and examined by K.J. Roy (pers. com.), is about 230 m thick. The formation forms part of a similar ridge that crosses western Cornwall Island (Fig. 11). Based on graphic measurements, the formation (units JjA, JjB, JjC and JjD of Map 1471A) is estimated to be about 165 m thick in a moderately well exposed, unfaulted section in southwestern Cornwall Island (site of fossil collection C-26637 and nearby collection sites).

The Jaeger Formation thins abruptly northward because of its lateral facies transition to Savik Formation shale. At Linckens Island P-46, the Jaeger interval (Jaeger Member) is about 37 m thick; in East Amund M-05, it is about 40 m thick; and it is barely discernible in Central Dome H-40 as very fine grained glauconitic sandstone and siltstone intercalations between depths of about 250 and 290 feet (75 and 87 m) (Fig. 8). The boundary between the Jaeger Formation and the Savik Formation was arbitrarily delineated at Hendriksen Strait (Fig. 4, Sec. I-J).

Lithology. There are important contrasts in the character of the Jaeger Formation on eastern and western Cornwall Island. The stratigraphically lowest part of the formation (map unit JjA) on the western side of the island consists of light grey and light green-grey clayey sandstone and sandy shale. Those soft rocks comprise a recessive, mainly covered, but apparently conformable succession above ferruginous-cemented Borden Island sandstone; their thickness is on the order of a few tens of metres. The recessive basal interval is the lowest of a strongly to weakly developed four-part internal aspect of the Jaeger succession on western Cornwall Island. Red, quartzose sandstone (map unit JjB) lies above the recessive basal beds. The sandstone beds are overlain by recessive, light grey, shaly sandstone (map unit JjC), which is increasingly shaly northward from central western Cornwall Island. The upper beds of the Jaeger Formation are composed of glauconitic and phosphatic partly red, quartzose sandstone (map unit JjD).

In contrast with the foregoing, basal beds of the type section of the Jaeger Formation in eastern Cornwall Island consist of ridge-forming pebbly sandstone (map unit JjB), which overlies buff sandstone included within the Heiberg Formation Upper Member. The Jaeger-Heiberg contact was mapped at the base of the lowest continuous level of red-weathering pebble beds (Map 1471A). The lower interval (map unit JjB) of eastern Cornwall Island is overlain by light grey-green recessive shale (map unit JjC) and the upper Jaeger interval (map unit JjD), which consists of glauconitic and phosphatic sandstone, completing the three-part internal division of the formation that prevails in eastern Cornwall Island.

The interval on western Cornwall Island (informally designated on Map 1471A as JjA) consists of partly fossiliferous, soft, light grey and partly light green-grey, parallel-bedded, very clayey sandstone, which becomes increasingly silty and shaly northward. The interval lacks the brown and red ferruginous cement that characterizes parts of the Borden Island Formation below and the sandstone of map unit JjB above, so it presents a colour contrast as well as a topographic contrast (Fig. 11).

Sandstone comprising informal unit JjB in western Cornwall Island is mainly medium grey-green and yellow-buff, but is covered extensively by a red-brown

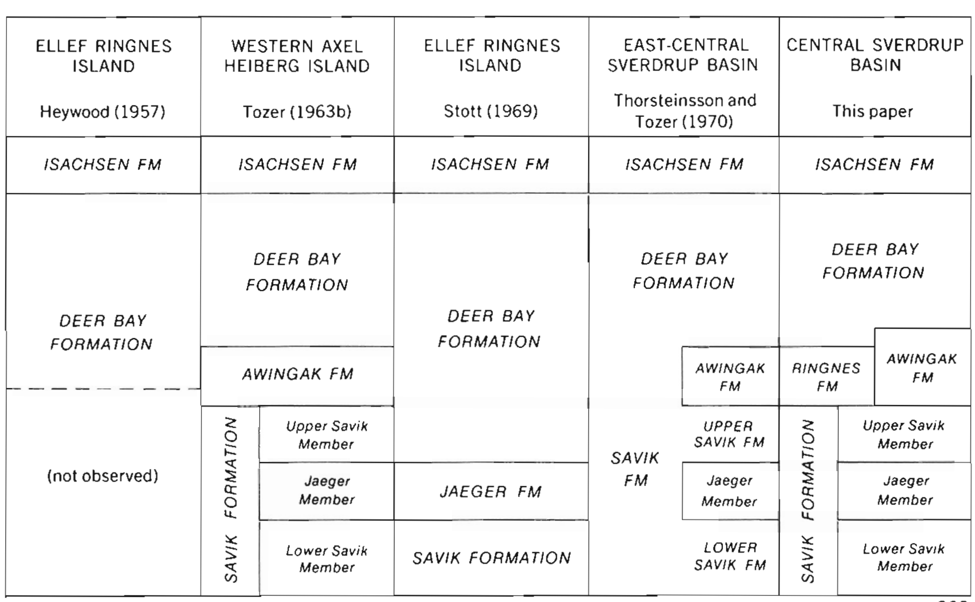


Figure 14. Nomenclature of Toarcian to Valanginian rocks, central and eastern Sverdrup Basin.

weathering veneer. The sandstone is composed dominantly of fine-grained, subangular quartz and light buff chert grains; also present are some thin lenses of light buff, and light grey chert granules and, locally, some thin intervals of dark brown, fine- to medium-grained phosphate pellets. Some beds contain abundant belemnite guards and sparse, moderately to poorly preserved ammonites. The basal few metres of the lower Jaeger interval on eastern Cornwall Island (map unit JjB) are conspicuously pebbly and red-brown. The pebbles, mainly well rounded, consist of light grey and light buff, dark grey, pink, and red-brown chert. The matrix for the pebbly beds is very fine to coarse-grained, siderite- and limonite-cemented quartzose sand. The remainder of interval JjB, which is about 40 to 50 m thick, consists of alternating lithologies: thin intercalated beds of red-brown, pebbly, partly phosphatic (as fine pellets), very porous sandstone, with ammonites and abundant trails, as well as plant stem impressions and small fragments of silicified wood, alternate with thicker intervals of fine- to coarse-grained, parallel-bedded and flaggy, poorly cemented, light grey and yellow-buff quartz sandstone, which seem to lack macrofaunas.

Map unit JjC is recessive and forms a saddle in both western and eastern parts of Cornwall Island. The succession is a few tens of metres thick and consists of light green-grey, slightly to moderately silty and sandy shale, with some very thin, red-brown siltstone beds. The shale contains appreciable amounts of expansive (montmorillonitic) clay and, as a result, the most impressive outcrop characteristic of this interval is its capacity for water retention: in some places the wet clays are so tenaciously sticky that foot traverses become exercises in absurdity. The succession is less shaly in southwestern Cornwall Island and, locally, is present only as elongate thin lenses in a sandstone-dominated succession.

The upper part of the Jaeger Formation (informal map unit JjD) is the thickest and most consistently developed. The succession consists mainly of parallel-bedded, light to medium grey, very fine to medium-grained, very porous quartzose sandstone. There are also units consisting of medium grey-green, glauconitic sandstone and rust-brown weathering, limonite-cemented, sandy siltstone with abundant dark brown, medium- to coarse-grained, ovate phosphate pellets, which on weathered surfaces commonly are leached completely, leaving ovate moulds. Belemnite guards are fairly abundant, and ammonites and abundant trails on bedding surfaces are present.

Contacts. Shaly sandstone and sandy shale assigned to the informal Jaeger map unit JjA (western Cornwall Island) are soft and recessive and, consequently, the contact with rocks mapped as the Borden Island sandstone is covered. There is no obvious physical evidence, however, to indicate an angular discordance along the contact. Basal pebbly Jaeger strata (map unit JjB) lie paraconformably on Upper Heiberg coaly sandstone in eastern Cornwall Island.

The Jaeger sandstone succession thins northward from Cornwall Island and grades progressively northward to very fine grained glauconitic sandstone, as at Linckens Island P 46; to glauconitic siltstone, as at Central Dome H-40; and ultimately to shale that is not distinguishable from the remainder of the Savik Formation, as at Amund Ringnes Piercement Dome (Fig. 8). Proximal development of this transition is through thickening of the lower shaly part of the succession (map unit JjA). Thus, even in southern Amund Ringnes Island, as indicated by lithologies in Linckens Island P-46, a concordant, well developed interval of shale, assigned to the Lower Savik Member, separated Jaeger Member sandstone from underlying older sandstone (Fig. 4).

In both western and eastern Cornwall Island, the Jaeger Formation is overlain abruptly and conformably by dark green-grey, recessive shale of the Upper Savik Member. Southward from Jaeger River, the lowermost beds of the Awingak Formation truncate the Upper Savik shale, so that Awingak and Jaeger sandstone units are in paraconformable contact in southeastern Cornwall Island.

Age and correlation. The Jaeger Formation contains moderately abundant molluscan faunas. Oldest faunas (GSC locality C-26634) collected from Cornwall Island are *Harpoceras* aff. *H. exaratum* (Young and Bird), which indicate an early Toarcian age or, more precisely, the *Exaratum* Subzone of the *Falcifer* Zone (see Frebold, 1975, for a review of Early Jurassic ammonites of Arctic Canada).

In ascending order, faunas collected above the *Harpoceras* level include: *Dactylioceras* cf. *D. commune* (Simpson) of the middle Toarcian *Bifrons* Zone; and *Peronoceras spinatum* (Frebold), tentatively assigned by Frebold to the lower part of the upper Toarcian. Frebold (op. cit., p. 11) reported that *Hildaites* sp. was collected by Greiner along Jaeger River, which establishes the presence of lower Toarcian beds in the lower part of Greiner's type section of the Jaeger Formation in eastern Cornwall Island. Other collections of Toarcian faunas were made from map unit JjB at GSC localities C-22703, C-22704, C-26637 and C-26626.

The stratigraphically highest faunas that we collected from the Jaeger Formation are from GSC locality C-26618, about 50 m from the top of the formation, and those were identified by Frebold as *Pseudolioceras* aff. *P. m'clintocki* (Haughton), and assigned a probable early Bajocian (Aalenian) age. Early Bajocian faunas were collected also from map unit JjD in northwestern Cornwall Island (GSC loc. C-26633).

Collections of *Leioceras opalinum* (Reinecke) and *Pseudoleioceras m'clintocki* (Haughton) were made at GSC localities C-22707 and 90893 (Map 1471A, Figs. 8, 12). Those fossils are early Bajocian and must be exotic "float" (possibly distributed by marine processes during the high stand of postglacial marine submergence) inasmuch as they lie well below the stratigraphically lowest level of Bajocian rocks. Similarly, collection 90892 is considered exotic. Greiner (1963) collected a loose early Callovian ammonite below the top of the formation at Jaeger River prompting speculation that the top of the formation at Jaeger River might be Callovian (Thorsteinsson and Tozer, 1970, Chart IV). We suggest that the fossil is exotic, derived probably from shales lying on the Jaeger Formation, because the youngest in situ fossils collected from the Jaeger Formation anywhere on Cornwall Island are early Bajocian and the shales above the formation carry early Callovian ammonites on nearby Amund Ringnes Island.

The Jaeger Formation is coeval with a large part of the mainly glauconitic sandstone succession in the western and northwestern parts of Sverdrup Basin called the Wilkie Point Formation (Tozer, 1956, p. 18). Stott (1969) assigned some sandstones at Reindeer Peninsula, Ellef Ringnes Island (Fig. 5) to the Jaeger Formation. It can be demonstrated from well information (Fig. 8) that the well developed Jaeger sandstone succession of Cornwall Island thins northward and grades to shale, and that it does not cross this part of the basin directly to the coeval sandstone at Reindeer Peninsula. Therefore, it is more appropriate to assign the sandstone strata at Reindeer Peninsula to the Wilkie Point Formation, because they can be shown to be part of the western basin-marginal sandstone facies.

Interpretation. The Jaeger Formation is a succession of sandstone and shale, mainly or entirely marine, along the eastern and southern margins of Sverdrup Basin, which becomes thinner toward the basin depocentre because of lateral gradation of sandstone to shale. Fossiliferous, glauconitic, pelletal and pebbly sandstone composing informal units JjB and JjD closely resemble Borden Island strata, and may be products of comparable environments (i.e. slowly accumulated sands and lag gravels of beaches and other littoral regimes.)

The shales of informal map units JjA and JjC seem to be products of very low energy conditions, compared with the partly pebbly sandstones of intervals JjB and JjD. Intermixing of high- and low-energy environments is common in coastal barrier regimes. Low-energy environments may lie landward (as lagoons and coastal bays) or seaward (as lower shoreface tracts) from the coastal barriers (Davies et al., 1971). Indications are that intervals JjA and JjC are products of the former because nonabraded lycopod megaspores are abundant, and dinoflagellates are absent; modern lycopods are not tolerant of marine conditions (A.R. Sweet, pers. com., 1976). Episodic sand influx to the quiescent tracts might be barrier washover products of coastal storms, or responses to increased fluvial discharge. The characteristic light grey-green colour of the shaly intervals indicates that the regimes were stable or very slowly subsiding and did not emerge to levels of subaerial accretion and oxidation.

Sporadic, but nonetheless characteristic, occurrences of phosphate pellets and nodules in fossiliferous, burrowed parts of the Jaeger sandstones are significant indicators that a widespread, shallow, warm, marine environment prevailed in Early Jurassic and part of Middle Jurassic time in the region of Cornwall Island and southern Amund Ringnes Island. Phosphatic nodules have been reported also from the Wilkie Point Formation at several widespread localities in the western part of the basin. According to Blatt et al. (1972), Late Tertiary and Quaternary marine phosphorites occur in warm climates between the fortieth parallels, commonly on sides of basins where phosphate-rich waters upwell adjacent to shallow shelves. Moreover, such realms are known to be nutrient rich, with high productivity of organisms (mainly phytoplankton), which incorporate the phosphate into their tissues. The associations of phosphatic rocks, retarded sediment accumulation, organic matter, and their possible implications for hydrocarbon genesis in the Lower and Middle Jurassic interval, are discussed in sections on economic geology.

Revision. For reasons cited in the paragraphs dealing with the Borden Island Formation, units JjA and JjB can be correlated with the upper part of that formation of western Sverdrup Basin. If restricted to map units JjC and JjD (Jjsh and Jjss of Figure 13), the Jaeger Formation would range from Toarcian to probably lower Bajocian.

Lower, Middle and (?) Upper Jurassic

Savik Formation

Nomenclature. Souther (1963, p. 435) proposed the name Savik Formation for shale at Savik Creek, eastern Axel Heiberg Island (Fig. 5), which overlies abruptly and conformably Borden Island sandstone (uppermost Heiberg Formation of Souther's original definition, Fig. 10) and which grades upward to sandstone of the Awingak Formation. In his original definition, Souther noted: "The shale of the lower half of the formation is dark grey and crumbly...," and "The shale in the upper half of the formation contains a higher proportion of silt. It is hard, brittle, and although very thin bedded and friable, commonly forms bluffs and low broken cliffs." (K.J. Roy and the writer examined the type Savik section in 1974. Our impressions were that there is a lower succession of light to medium greyish green shale, in which the silt content increases upward to culminate in a thin unit of glauconitic sandstone; and that the glauconitic sandstone is overlain conformably by an upper pelite succession consisting of black, shaly siltstone, which is gradational upward into sandstone of the Awingak Formation.) Tozer (1963b, p. 17) applied the names Lower Savik Member and Upper Savik Member to the distinctive pelitic lithologies defined by Souther. Further, he noted that a hiatus probably separates the Lower and Upper Savik at the type section because the youngest faunas collected from the Lower Savik are early Bajocian, and the oldest faunas collected from the Upper Savik are early Oxfordian. Strata of late Bajocian, Bathonian and Callovian ages seem to be absent. Regional biostratigraphy suggests that the mid-Jurassic hiatus is basinwide. From place to place along the basin margins, various of the mid-Jurassic substages are not represented faunally, and nowhere is there macrofaunal evidence of upper Callovian beds. A sub-Oxfordian hiatus, therefore, may be an important biostratigraphic datum in the Sverdrup Basin.

Along the eastern and southern margins of Sverdrup Basin, a wedge of sandstone, becoming thinner basinward, is coeval with part of the Lower Savik shale succession. Tozer (1963b, p. 21, 22) named the wedge of sandstone the Jaeger Member (of the Savik Formation), thus emphasizing that the sandstone wedge is correlative with part of the Jaeger Formation, which was defined by Greiner (1963, defined, p. 535, 536) following a reconnaissance traverse of Jaeger River, eastern Cornwall Island (Fig. 5). Thus, according to present nomenclature, the Savik Formation in the eastern and south-central parts of Sverdrup Basin consists of three members: a Lower Shale Member, Jaeger Sandstone Member, and an Upper Shale Member (Thorsteinsson and Tozer, 1970, Fig. X-12). The top of the formation is chosen where sandstone of the Jurassic Awingak Formation overlies Oxfordian shale (Fig. 14).

Evidence will be presented in following sections to show that, on Amund Ringnes Island, the lower and middle parts of the Awingak Formation grade laterally to Oxfordian-Kimmeridgian shale, characterized by huge mudstone concretions, for which the name Ringnes Formation has been proposed (Balkwill et al., 1977), and that this shale is widespread in axial parts of the basin. On Amund Ringnes Island (and elsewhere in the Sverdrup Basin where the Jurassic succession is dominated by marine shale) an interval comprising dark shale, which is mainly lower Callovian, but also may be partly upper Callovian and lower Oxfordian, lies between Jaeger sandstone beds and the Ringnes Formation (or equivalent Awingak sandstones). To maintain consistency of nomenclature, Balkwill and Roy (1977) proposed that the Savik Formation in the central and western parts of Sverdrup Basin be defined so as to include pelitic strata to the base of concretionary shales of the Ringnes Formation, and that the Upper Shale Member be considered as the pelitic interval between Jaeger sandstones and the Ringnes Formation (Fig. 14). As thus defined, a sub-Oxfordian hiatus lies within the Savik Formation, as it does also at the Savik type section.

In this report, the name Savik Formation is used for the pelite-dominated succession on Amund Ringnes Island. Three members (Lower Shale, Jaeger Sandstone, and Upper Shale) can be delineated in the subsurface and surface of the southern and central parts of the island. Because of northward gradation to shale, the Jaeger Member cannot be mapped with confidence in the northern part of the island, and there the name Savik Formation (undivided) is applied. The sandstone-dominated succession on Cornwall Island, approximately coeval with the Savik Formation, is assigned to the Jaeger Formation.

Distribution and thickness. Recessive shale of the Savik Formation (undivided) is poorly exposed along the northern and southern rims of Amund Ringnes Piercement Dome, at the foot of ramparts formed by steeply dipping, resistant sandstone of map unit TrJhub. The Savik succession, which is presumed to be stratigraphically concordant with the adjacent sandstone and therefore complete, is estimated to be about 300 m thick at those localities.

Jaeger sandstone is present as a very thin marker as far north as the Central Dome H-40 drillhole. The Upper Shale Member is well developed on Cornwall Island, especially on the western flank of the island (Map 1471A), but it becomes progressively thinner and, ultimately, truncated beneath sandstone of the Awingak Formation in the southeastern part of the island. The range of thicknesses of the Savik Formation (and its internal subdivisions) are given in the Table of Formations and Figure 8.

Lithology. In outcrops (Map 1471A), Savik Formation (undivided) shale is dominantly dark grey-green, with some medium green and dusky maroon beds in the lower part. The strata are thinly laminated and papery, and are slightly silty in the lower third of the succession, owing to intercalation of parallel laminations and very thin beds of partly fossiliferous, clayey siltstone. Dark brown and red-brown, small (about 10 - 30 cm long), calcareous ironstone nodules form frost-shattered rubble piles on the surface where these beds outcrop.

The strata between depths of 2865 and 3215 feet (874 - 980 m) in Linckens Island P-46 well are typical of the subsurface development of the Lower Shale Member. These beds consist of medium grey to dark grey, dark green-grey and dark red-brown, partly pyritic, partly glauconitic, and partly phosphatic, slightly to very silty shale. Phosphate is present as dark brown to black, spherical to oblate and partly flattened pellets, ranging in length from about 0.08 to 0.4 mm. The pellets have concentric internal fabrics, most commonly with black outer rinds and dark brown cores. They are contained in medium brown to grey-brown siltstone chips. The entire Lower Savik Member tends to cave, causing much downhole sample contamination.

Upper Savik shale is mainly dark green-grey and is moderately silty, thus contrasting with the typically light green-grey, partly silty shale of the Lower Shale Member. On Cornwall Island, the middle part of the Upper Shale Member contains a thin unit, about 10 m thick, of buff, coarsening-upward, very fine to medium-grained sandstone (unit Jsu(ss) of Figure 13). At the top of the sandstone, on the western side of the island, there is a 1/2 m thick bed of red-brown siderite, overlain by about 4 m of clayey siltstone, and that is succeeded by the uppermost Savik beds consisting of dark grey, silty, pyritic soft shale with very thin light grey tuffaceous clay beds. At Jaeger River the mid-Upper Savik sandstone (unit Jsu(ss) of Figure 13) is overlain abruptly by about 50 m of black silty shale (unit Jsu(ush) of Figure 13) with tuffaceous clay beds. The mid-Upper Savik sandstone beds are absent at Cape Ludwig. There, the dark green-grey shales are separated from the black shales by a thin bed of siderite.

The Jaeger Member is delineated in subsurface sections (Figs. 4, 8) in central and southern Amund Ringnes Island. This succession is about 37 m thick in Linckens Island P-46, and about 40 m thick in East Amund M-05; it is barely discernible in Amund Central Dome H-40, as very fine grained glauconitic sandstone and siltstone intercalations between depths of 250 and 290 feet (76 - 88 m) (Fig. 8).

Contacts. The basal beds of the Savik Formation are covered by slopewash and talus at both the northern and southern rims of Amund Ringnes Piercement Dome, thereby obscuring the contact with sandstones of map unit TrJhub. There are several reasons for concluding that the contact is conformable and abrupt: (1) there is a very abrupt change in topographic expression, which probably reflects a lithologic change from sandstone to shale; (2) the lowest exposed Savik beds are structurally concordant with the nearby steeply dipping sandstones; (3) the approximate thickness of the Savik Formation at both localities is almost the same as that anticipated from regional considerations; and (4) log curves from all wells on the island (Fig. 8) indicate a very abrupt regional subsurface contact.

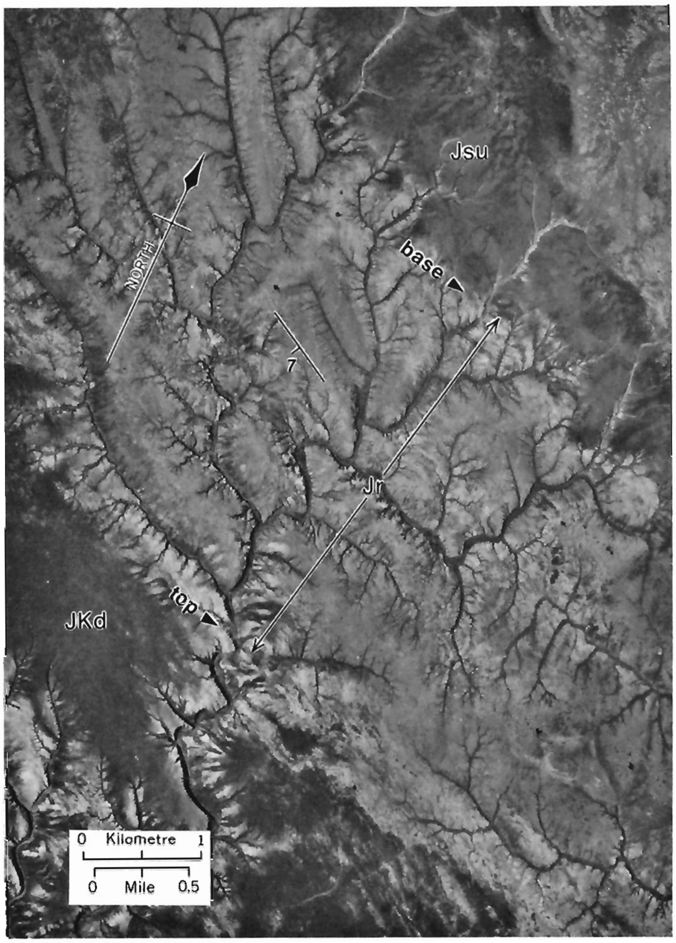


Figure 15. Vertical air photograph of Ringnes Formation (Jr) type section, about 78°17'N by 90°27'W, central Amund Ringnes Island. Jsu: Upper Member of Savik Formation; JKd: Deer Bay Formation (map unit JKdA7). Part pf NAPL photo A16193-20.

The upper part of the Lower Savik Member becomes increasingly silty and sandy upward and is gradational into sandstone of the Jaeger Member. The contact was chosen arbitrarily at the depth of about 2880 feet (878 m) in Linckens Island P-46, at the base of a funnel-shaped deflection in the gamma ray curve (Fig. 8).

Shale of the Upper Savik Member is overlain conformably by the Ringnes Formation in central Amund Ringnes Island (Fig. 15), and by the basal sandstones of the Awingak Formation in southern Amund Ringnes Island and on Cornwall Island, except for the southeastern part where Upper Savik shale is truncated progressively southward beneath Awingak sandstone (Map 1471A).

Age and correlation. Regional macrofaunal evidence for the chronological range of the Savik Formation is as follows (Thorsteinsson and Tozer, 1970, Fig. X-12): beds near the base of the Lower Shale Member have yielded early middle Toarcian faunas (*Dactylioceras commune* Subzone of the *Hildoceras bifrons* Zone; see Frebold, 1975); youngest macrofaunas collected from the Upper Shale Member are early Oxfordian (*Cardioceras* aff. *mirum*), which are from the Savik Upper Shale Member at the type section, Axel Heiberg Island. Late Callovian macrofaunas have not been collected from any strata in the basin, suggesting that there is a basinwide sub-Oxfordian hiatus within the Savik Formation. (Toward the basin margins, all or parts of the

Bathonian and Bajocian stages are absent also.) But Johnson and Hills (1973, p. 187 - 190), following studies of fossil microplankton, suggested that in central parts of the basin the hiatus is not great, because several microfloral taxa continue through an interval about 15 m thick, which broadly separates the Callovian and Oxfordian stages. Furthermore, there is evidence that in some places the Middle Jurassic stages are represented by acutely condensed sections: the writer collected early Bajocian and Bathonian faunas from a physically uninterrupted interval about 2 m thick, near Skarre Fiord, southern Axel Heiberg Island, only about 28 km south of the type section of the Savik Formation.

Stratigraphic levels of Savik macrofaunal collections from Cornwall and Amund Ringnes islands are indicated on Figure 4. Early Bajocian pelecypods (*Oxytoma jacksoni* (Dompeckj)) were collected from Savik shale along the northern rim of Amund Ringnes Piercement Dome (GSC loc. C-22232). The collection was from silty shale in the lower part of the exposed strata, estimated to be about 90 m above the contact with map unit TrJhub. In the same section, early Callovian faunas were collected about 130 m below the top of the Savik Formation, above which the oldest faunas collected are Oxfordian-Kimmeridgian in age, and they lie in the lower part of the Ringnes Formation. Early Callovian faunas were collected below the top of the Upper Shale Member at Cape Ludwig (GSC loc. C-22230) and also about 60 m below the top of the Upper Shale Member in the central part of Amund Ringnes Island (GSC loc. C-26629).

It is important to Savik Formation chronology and correlation that early Toarcian faunas of the *Harpoceras falciferum* Zone (see Frebold, 1975) were collected from the lower part of the Jaeger Formation on Cornwall Island, from a succession of rocks that is increasingly shaly northward. Almost certainly the lower part of the Savik shale succession in the central part of the basin is equally old; the possibility that basal Savik shale beds in the central part of the basin may be as old as Pliensbachian, was suggested in an interpretive discussion of map unit TrJhub.

Thorsteinsson and Tozer (1970, Fig. X-12) summarized regional correlation of the Savik Lower Member with the Wilkie Point Formation, a wedge of basin-marginal sandstone along the western and northwestern rims of the basin, which is approximately coeval with the Jaeger Formation of the southern and eastern margins.

A thin succession of dark green-grey Savik Upper Member shales lies between Wilkie Point sandstone and the Ringnes Formation over wide areas of the western part of the Sverdrup Basin. The shale was included as part of the Lower Member of the Mould Bay Formation by Tozer and Thorsteinsson (1964).

Interpretation. In general, Savik microfaunas are indicative of shallow-marine shelf environments (J.H. Wall, pers. com., 1975).

If the entire Savik Formation on northern Amund Ringnes Island is about 300 m thick, as was inferred from the evidence, it represents relatively slow pelite accumulation (about 20 m per million years) during late Early and Middle Jurassic, and possibly early Oxfordian, compared with other Mesozoic shale assemblages (Fig. 16). This evidence, combined with the condition that coeval marginal sandstones are partly phosphatic and are stratigraphically condensed, indicates that a condition of subdued basin subsidence and diminished sediment supply persisted throughout the Early and Middle Jurassic. (Evidence will be presented in discussion of the Ringnes Formation to show that this condition was prolonged, in some parts of the basin, until Volgian time.)

Revision. The Savik sections on Cornwall Island and at Cape Ludwig were traversed in 1979. Samples of the black, pyritic, tuffaceous shales (unit Jsu(ush) of Figure 13) contain palynomorphs assigned by Robertson Research (Canada) to the mid-Oxfordian. The underlying green-grey shales (unit Jsu(lsh) of Figure 13) contain palynomorphs, which they assigned to the early Oxfordian. We suggest there is a strong likelihood that the green-grey shales are Callovian and not Oxfordian: the green-grey shales contain early Callovian

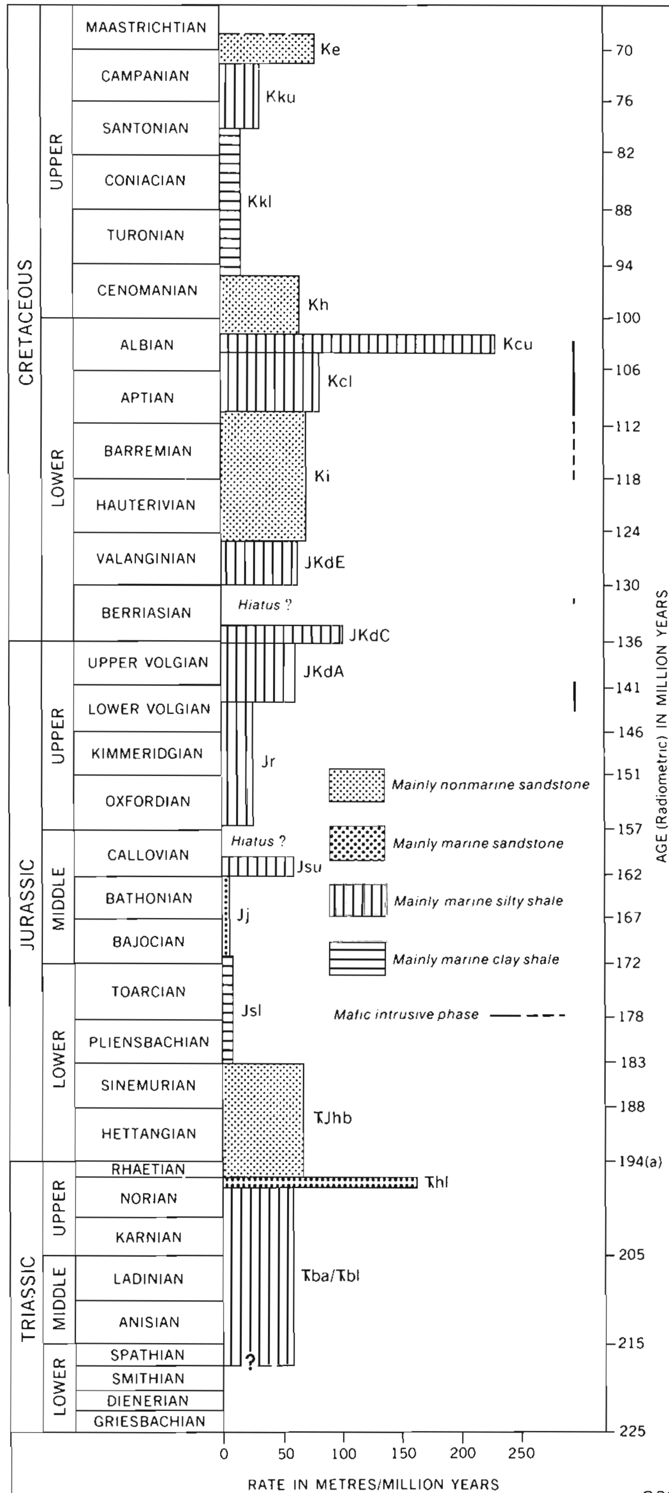


Figure 16. Approximate mean accumulation rates (m/Ma) for Mesozoic rock units, central Amund Ringnes Island. (Radiometric ages for geological stages taken from Douglas, 1970, except (a) which was taken from Hallam, 1975.)

ammonites at Cape Ludwig and near the Amund Central Dome well; the contrast in lithology between the green-grey shales and black shales is striking; and the presence of a sandstone (unit Jsu(ss) of Figure 13) and siderite beds between the shales allows for the possibility of a significant paleoenvironmental change between deposition of the contrasting shales.

On the above basis, the Callovian-Oxfordian boundary may be marked by the siderite bed (possibly a relict soil zone) between the shales at Cape Ludwig, and at the top of the mid-Savik sandstone at western Cornwall Island. From this, the sandstone may be correlative with sandstone beds in western Sverdrup Basin, considered the uppermost part of the Wilkie Point Formation by Tozer and Thorsteinsson (1964).

One thing is certain: existing nomenclature is inadequate to distinguish stratigraphic elements now encompassed by the Savik Formation.

Upper Jurassic

Awingak Formation

Nomenclature. Souther (1963, p. 436, 437) introduced the name Awingak Formation for about 300 m of intercalated sandstone and shale, lying conformably between Savik Formation and Deer Bay Formation shales, at Awingak Creek, Axel Heiberg Island (Fig. 5, Sec. X). The formation has been mapped over wide areas of eastern Sverdrup Basin (see Thorsteinsson, 1971a, b, 1972).

Greiner (1963, p. 536) assigned rocks above the Jaeger Formation on eastern Cornwall Island to the Awingak Formation, but he was unable to examine the section closely. Detailed mapping by the writer in 1972-3 revealed that the lower and middle parts of the Awingak succession of eastern Cornwall Island grade northward to silty shale with abnormally large mudstone concretions, composing the recently named Ringnes Formation (Balkwill et al., 1977); also that the upper Awingak beds are equivalent to the lower part of the long-established Deer Bay Formation (Heywood, 1957). In this report and accompanying map, the name Awingak Formation is applied in areas where more than one half of the interval is sandstone, and the name Ringnes or Deer Bay Formation is applied in areas that are more than half shale.

Distribution and thickness. The Awingak Formation is moderately well exposed along the eastern and western sides of Cornwall Island and at the prominent hill at Cape Ludwig (Map 1471A). The thickest known section of the formation anywhere in the Sverdrup Basin is several miles south of Jaeger River, where the sandstone-dominated succession is about 570 m thick. The formation is about 250 m thick in western Cornwall Island, about 396 m thick at Cape Ludwig, and about 214 m thick in Linckens Island P-46 (Fig. 8). The formation on Cornwall Island and at Cape Ludwig consists of four parts (Ja1, Ja2, Ja3 and Ja4 of Fig. 8); the significantly greater thickness of the formation in southeastern Cornwall Island is a result, largely, of thick development of the uppermost of those parts.

Lower and middle Awingak sandstone grades abruptly northward to the Ringnes Formation and to the lower part of the Deer Bay Formation in the subsurface between Cape Ludwig and the shallow-dipping periclinal dome in the central part of Amund Ringnes Island (Fig. 4).

Lithology. The impressively thick Awingak succession on eastern Cornwall Island consists of four sandstone-dominated parts which, for convenience of discussion, are designated as units Ja1, Ja2, Ja3 and Ja4 (Fig. 8). The depositional conditions and significance of each of these units are interpreted in a following section.

Awingak interval Ja1 is composed of repeated, coarsening-upward cycles of medium grey, partly clayey and silty, and partly carbonaceous, poorly cemented, very fine grained quartzose sandstone. Each cycle consists of very thin to thin, flaggy-weathering beds of very fine grained sandstone, with laminations and partings of clay, silt, and carbonaceous detritus, spaced at intervals of about 1 to 3 cm; the abundance of clay and silt decreases upward, culminating in thin beds of very fine grained sandstone at the top of each cycle. There are about 15 of these cycles at Cape Ludwig, each of which is on the order of 3 to 6 m thick (Fig. 17). Some sandstone beds have thin (less than 2 cm), cross-laminated sets. There are near-vertical burrows in some beds, trails on some parting surfaces, and random small fragments of silicified wood. Macrofossils were not observed in this interval. Interval Ja1 is about 92 m thick at Jaeger River, and about 48 m thick at Cape Ludwig.

Informal unit Ja2 is best exposed in cutbanks of a meander belt of the Jaeger River. The lower part of the unit forms resistant hoodoos at Cape Ludwig (Fig. 17). The interval consists of light buff-grey, fine- to coarse-grained and partly pebbly (but mainly medium-grained), quartz sandstone with thin siltstone intercalations. The rocks are partly cemented with silica, but generally have good porosity in outcrops. Rounded quartz granules and pebbles form thin, discontinuous lenses at the bases of probable scour channels. The strata are partly parallel bedded, and partly cross-stratified, especially at Cape Ludwig, where there are large low-angle sets.

Southward from Jaeger River, sandstones comprising unit Ja1 increasingly resemble those of unit Ja2; in southeasternmost exposures, Awingak sandstone rests directly on Jaeger sandstone.

Awingak beds comprising unit Ja3 are poorly to moderately well exposed at the nose of a plunging anticline south of Jaeger River, and along an unnamed river northeast of Cape Ludwig. At those localities, the interval is about 168 m and 130 m thick, respectively. It consists mainly of buff-grey, fine-grained, parallel-bedded, locally silty and shaly, porous sandstones, a few metres thick, which alternate with thinner beds of medium to dark red-brown, fine- to coarse-grained and pebbly, partly glauconitic, flaggy sandstones with fragments of silicified wood and relatively abundant marine macrofossils. Brown sandstones are continuous for distances of several kilometres; interbedded with the dark grey shale and siltstone beds, they impart a distinctively banded aspect to interval Ja3.

Strata comprising unit Ja4 are about 150 m thick at Jaeger River and, although not well exposed, are seen to consist mainly of repetitive, fining-upward cycles of coarse- to very fine grained, light grey, light grey-buff and yellow-buff, partly silica-cemented but mainly porous, quartzose sandstone. The strata are partly cross-stratified, with medium high-angle trough sets. Where the cycles are complete, the tops consist of dark grey, parallel-laminated, papery, carbonaceous and clayey siltstone and, in some places, thin to very thin beds of black subbituminous coal: but the tops of most cycles are truncated by the basal beds of the succeeding sandstone cycles. Sandstone strata at the top of interval Ja4 contain some very thin beds with rounded quartz and chert pebbles and granules, and some marine macrofossils. Unit Ja4 is considerably less well exposed in western Cornwall Island; it is thinner (about 76 m thick) and generally finer grained than on the eastern side of the island. Rocks assigned to unit Ja4 northeast of Cape Ludwig consist of alternations of buff to tan, platy, parallel-bedded, coarsening-upward beds of very fine to medium-grained sandstone, with marine pelecypods, and some very thin lenses of chert and quartz granules. The sandstone beds are intercalated with, and grade upward from dark grey, parallel-laminated, very silty shale and shaly siltstone.

Figure 17. View northeastward of lower and middle parts of the Awingak Formation at Cape Ludwig, southern Amund Ringnes Island. Jsu: Savik Formation, Upper Member; Ja1: Awingak Formation, informal unit; Ja2: Awingak Formation, informal unit (see text and Fig. 8). GSC fossil locality C-22230 contains early Callovian faunas (see Appendix). GSC 199241.

The foregoing description indicates that there is relatively little lithofacies variation from place to place within units Ja1, Ja2 and Ja3, but that there is considerable lateral variation in the lithofacies character and thickness of unit Ja4. These contrasts can be interpreted in terms of depositional environments and processes, so that an early marine-dominated phase of sedimentation (comprising units Ja1 through Ja3) is distinguishable from a later, fluvially dominated phase which produced unit Ja4.

Contacts. Basal beds of the Awingak Formation conformably overlie very silty Upper Savik shale. The contact was mapped at the base of the lowest observed, very fine grained sandstone of the cyclic sandstones comprising unit Ja1 (Fig. 17). Stratigraphic evidence for differential erosion across Cornwall Island hinge is provided in southeastern Cornwall Island, where sandstones of unit Ja1 become increasingly coarse grained southward, resembling the sandstones of interval Ja2. In the southeasternmost exposures, basal Awingak sandstone rests directly on buff-coloured Jaeger sandstone, and the mapped contact between them was extrapolated from more northerly outcrops.

Strata comprising unit Ja4 are overlain, abruptly and conformably, by dark grey, partly fossiliferous, marine Deer Bay Formation shale. Awingak intervals Ja1 through Ja3 grade mainly or entirely northward to nodular shale comprising the Ringnes Formation, and interval Ja4 grades northward to the lower shale strata of the Deer Bay Formation. These relationships are discussed in following sections.

Age and correlation. The Awingak Formation is sparsely fossiliferous, particularly in the lower part, throughout its regional outcrop extent. Early Oxfordian faunas are present in black shale below basal Awingak sandstone at the type section, eastern Axel Heiberg Island (Tozer, 1963b). Late Oxfordian or early Kimmeridgian faunas were collected about 225 m above the base of the Awingak Formation at the type section (Souther, 1963, p. 437). Faunas collected from the uppermost part of the formation on western Axel Heiberg Island were dated as late Early Volgian (*Buchia piochii* Zone of the Canadian Arctic; see Jeletzky, 1966). The regionally known age range of the formation is, therefore, from possibly early Oxfordian to Early Volgian.

For the report area, probable mid-Kimmeridgian faunas were collected from red-brown pebbly sandstone beds of unit Ja3 near Cape Ludwig (GSC loc. C-22231). Marine macrofossils were collected from unit Ja3 on Cornwall Island also (GSC loc. C-22228), but the faunas, including abundant large *Pecten (Camptonectes)* cf. *praecinctus* Spath, may not be restricted in range to mid-Kimmeridgian.

Late Oxfordian-Kimmeridgian faunas are relatively common in central and northern Amund Ringnes Island, in a shale-dominated succession called the Ringnes Formation (Balkwill et al., 1977). This fact and an interpretation of lithofacies suggest that all or most of the informal intervals Ja1 through Ja3 grade rather abruptly to the Ringnes Formation in the subsurface between Cape Ludwig and the periclinal dome in the central part of the island (Fig. 4). Further, Late Volgian faunas, assigned by J.A. Jeletzky to the *Buchia unschensis* Zone, were collected from the lower (but not lowest) part of the Deer Bay Formation in central Amund Ringnes Island, indicating equivalence of those strata with uppermost beds of Awingak unit Ja4. No faunas of the *Buchia piochii* Zone have been collected from Cornwall or Amund Ringnes islands, but rocks representing that biostratigraphic interval may include some of the nonmarine beds of unit Ja4 on Cornwall Island, and some shales in the lower part of the Deer Bay Formation on Amund Ringnes Island, below strata containing faunas of the *Buchia unschensis* Zone.

Interpretation. Observations of faunas, facies, regional and local geometry, and sedimentary structures indicate that the Awingak Formation represents the proximal sand facies of two phases of clastic progradation into the south-central part of Sverdrup Basin. The principal surges of clastic influx were directed basinward through the regional basin re-entrant localized near Graham Island and southeastern Cornwall Island (Fig. 18). Ringnes Formation shale represents the prodelta apron and distal basin pelitic facies of the first phase of this Late Jurassic regime; and lower Deer Bay Formation shale represents the pelitic facies of the second phase.

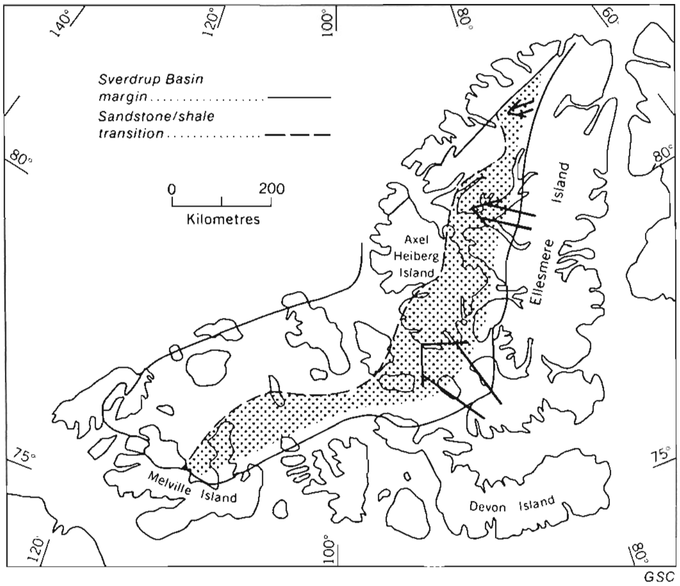


Figure 18. Awingak Formation (Oxfordian - Lower Volgian) sandstone distribution and interpreted progradation directions (arrows), Sverdrup Basin.

Awingak strata of unit Ja1 on Cornwall and southern Amund Ringnes islands consist of repeated, coarsening-upward cycles of very fine to fine-grained, parallel-bedded, bioturbated, clayey and silty sandstone (Fig. 17). This interval is developed consistently along the depositional strike (for example, comparable facies are developed in lower Awingak beds in west-central Ellesmere Island) and it is interpreted as early first-phase progradation into the basin margin by delta-front sands of a regime of small deltas along the southern and eastern margins of the basin (Fig. 18). The overlying sandstone of unit Ja2 is clean, fine to medium grained, partly bioturbated, and has some large sets of low-angle cross-strata. These rocks may represent delta mouth and interdeltaic coastal sand facies. They mark maximum basinward progradation of sand during the first-phase Awingak system. The last part of the first phase of Awingak deposition produced fossiliferous, partly pebbly, partly ferruginous sandstone (unit Ja3), in which there are intercalations of shale basinward, as at Cape Ludwig. Unit Ja3 can be interpreted as representing detritus reworked extensively by marine-dominated processes, with accumulation of pebbly and shelly lag deposits on coastal barriers and offshore parts of the littoral zone that were subjected periodically to waves and currents during coastal storms.

In contrast to the foregoing, the second phase of Awingak delta progradation is represented on Cornwall Island (particularly eastern Cornwall Island) by fining-upward, cyclic repetitions of sandstone, siltstone, shale, and discontinuous thin coal beds. The sandstone has high-angle cross-strata, root casts, shale clasts, scour channels with pebble lenses and, except for the uppermost beds, it lacks marine macrofossils. These strata are interpreted as the meandering channel and delta-plain facies of a single, large, river-dominated delta that prograded northward from the region of eastern Cornwall Island. At Cape Ludwig, this assemblage consists of interlayered, coarsening-upward, cyclic repetitions of sandstone and silty shale, which probably represent the delta-front facies of successive constructive phases of sand deposition. Sandy lobes prograded basinward at positions that shifted laterally from time to time in response to lateral migration of major distributary channels.

The two-phase depositional style of the Awingak Formation is illustrated clearly by log curves and samples from Linckens Island P-46 and East Amund M-05 wells (Fig. 8). Lower parts of log curves are funnel-shaped and slightly serrated in detail, without abundant interdigitations indicative of well developed shale intercalations; those parts of the curves may represent strata deposited as delta-front sheet sands and delta-mouth sands. The top of the lower progradational succession is marked abruptly at 2050 feet (625 m) in Linckens Island P-46 by siltstones and shales comprising the lowest (earliest) lagoonal or marine embayment muds of the late destructional phase. In outcrops at Cape Ludwig and in samples from Linckens Island P-46, these and succeeding shales and pebbly sandstones tend to have abrupt boundaries, indicative of accumulation in circumstances of greatly contrasted energy conditions.

The facies and geometry of the sandstones suggest that major Awingak deltaic progradation was directed northward from a basin re-entrant centred about Graham Island, extending westward to Cornwall Island, and possibly eastward to Bjorne Peninsula (Fig. 18). In his original description of the Awingak Formation, Souther (1963) noted that sandstones (which he speculated might be nonmarine) are the dominant component of the formation in west-central Axel Heiberg Island, whereas there are intercalated sandstones and marine shales in eastern Axel Heiberg Island, including the type section. Combined with foregoing observations of eastward coarsening and thickening of Awingak facies on Cornwall Island, this indicates that the Awingak succession formed a large northward-directed deltaic lobe, the axis of which extended northward from Graham Island to an apex in south-central Axel Heiberg Island (Fig. 18).

Revision. Buff and red-weathering sandstones composing unit Ja3 of the Awingak Formation are overlain by about 30 m of dark grey, silty fissile shale (unit JKdA of Figure 13). The shale beds are very poorly exposed. Samples collected from a narrow gully that enters the north bank of Jaeger River contain "very late Jurassic or very early Cretaceous" palynomorphs [Robertson Research (Canada) report to Panarctic Oils, 1979]. The shales lying above Awingak sandstones (unit JKdC of Map 1471A) contain palynomorphs identified by Robertson Research (Canada) as Early Cretaceous. But unit JKdC contained a fossil tentatively identified as early Late Volgian (GSC locality C-26624, see Appendix). The sandstones composing unit Ja4 of the Awingak Formation are younger than Kimmeridgian and possibly as young as Early Cretaceous. They are broadly coeval with part of a wedge of sandstones assigned to the Mould Bay Formation in western Sverdrup Basin (Tozer and Thorsteinsson, 1964).

Ringnes Formation

Nomenclature. Balkwill et al. (1977) proposed the name Ringnes Formation for a succession of shale, mappable in surface rocks of central and northern parts of Sverdrup Basin. In outcrop, the formation is distinguishable from underlying Savik Formation shale and overlying Deer Bay Formation shale because of the presence of abnormally large (as long as 5 m), light buff weathering, calcitic and sideritic mudstone concretions. The type section of the formation is in central Amund Ringnes Island (Fig. 15).

The Ringnes Formation is a basin-central pelitic lithofacies that occupies the same relative stratigraphic position as the lower and middle parts of the Awingak Formation. Some evidence for this correlation (and for correlating the upper Awingak beds of eastern Cornwall Island with the lower part of the Deer Bay Formation, and not with the Ringnes Formation) was presented in the foregoing discussion of the Awingak Formation, and some is presented in a following section on age and correlation of the Ringnes Formation.

Distribution and thickness. Gently dipping Ringnes Formation shale is distributed in a broad, elliptical outcrop belt in central Amund Ringnes Island. The formation is mappable also on the northern and southern flanks of Amund Ringnes Piercement Dome.

Mudstone concretions constitute only about 5 per cent of the rock volume of the Ringnes Formation, but they are so large and brightly coloured, in contrast with enveloping dark grey shales, that they allow easy delineation of the formation at the surface; however, recognition of the formation in the subsurface is difficult in many drillholes.

The Ringnes Formation is about 330 m thick at the type section (Fig. 15). This section and neighbouring sections in central Amund Ringnes Island are the thickest known at present. They are near the south-to-north facies transition of lower and middle Awingak sandstones to the Ringnes Formation. From these thick sections, the formation thins markedly northward and northwestward: it is about 240 m thick on the north flank of Amund Ringnes Piercement Dome; about 75 m thick on Reindeer Peninsula, northwestern Ellef Ringnes Island; about 50 m thick in the central part of Mackenzie King Island; and about 20 m thick on western Melville Island (Fig. 5).

Lithology. The Ringnes Formation consists of dark grey to black, very silty, slightly sandy, papery shale, with sparse marine macrofaunas, and moderately abundant and varied marine microfaunas. Faunal lists for collections from the formation are contained in Balkwill et al. (1977). The formation is distinguished from the underlying Savik Formation and overlying Deer Bay Formation (both of which consist of dark grey, silty, marine shales) mainly by the presence of randomly distributed, huge (as long as 5 m) ellipsoidal, yellow-buff-weathering, slightly calcitic and sideritic, partly sandy mudstone concretions. The concretions commonly have septarian structure with siderite fracture filling; they undergo extreme frost shattering along those fractures, and at the ground surface lie as conical mounds of rubble. Although the concretions constitute only about 5 per cent of the shale-dominated succession, the mounds of rubble impart a distinctly lighter toned aspect to the landscape than do the adjacent dark Savik and Deer Bay shales, so that the Ringnes Formation can be delineated on aerial photographs (Fig. 15). (Concretions are present in the middle and upper parts of the Deer Bay Formation also, but they are red-brown to medium brown, commonly pyritic, and about one fifth to one tenth as large as Ringnes Formation concretions.) Most of the macrofossils collected from the Ringnes Formation were found in the huge concretions, but only a small percentage of the concretions examined were found to contain fossils.

All of the concretions have similar external forms: they are abnormally large, weather yellow-buff, and have siderite-filled, irregularly patterned septarian rinds. On Amund Ringnes Island, the Ringnes Formation concretions are faintly and irregularly laminated, with laminations imparted by very fine grained quartz sand and silt, fine- to medium-grained carbonized plant fragments and flattened clay intraclasts. Some concretions contain calcitized serpulid worm tubes, and also have vaguely defined burrows normal to the layering.

A.E. Foscolos made X-ray mineralogical analyses of shale samples from the type section. The samples contain about 50 per cent quartz and 5 per cent feldspars; illite is the dominant clay mineral present (about 20 per cent), with lesser percentages of mixed-layer clays and kaolinite; accessory minerals include calcite, siderite, dolomite, and pyrite. Total organic carbon contents of the samples ranges from 2.3 to 3.3 per cent.

The Ringnes Formation is identifiable from sonic logs of many wells because the mudstone concretions impart abrupt, thin, high-velocity responses. The shales enveloping the concretions commonly have lower velocity indices than the underlying Upper Savik shale and overlying Deer Bay shale. Also, chip samples from the Ringnes shales are characteristically black and have a 'sooty' texture; Savik shales are dark green-grey and fissile, whereas Deer Bay shales are green-grey and noticeably silty.

Conditions in the Panarctic Gulf West Amund I-44 well illustrate the difficulties in delineating the subsurface development of the Ringnes Formation. The well was spudded a few hundred metres below the top of the Deer Bay Formation (Fig. 8), at the crest of a large periclinal fold with gentle flanks. The interval between 454 and 619 m K.B. on the gamma ray log may represent the Ringnes Formation. The subdued 'fingers' in the otherwise undistinguished profile may mark intervals of silty mudstone concretions. Chip samples from that interval consist of brownish grey to greyish black micaceous, silty, sideritic, slightly calcareous, papery shale. Sideritic and calcitic components tend to be present in discrete layers, which, from analogy with surface development, may be levels of large mudstone concretions.

Contacts. At the type section, basal beds of the Ringnes Formation---defined as the level of lowest occurrence of dark grey, silty shale with distinctively large, yellow-buff concretions---conformably overlie dark green-grey, slightly silty marine shale of the Upper Member of the Savik Formation. Regionally, the contact is rather abrupt (Fig. 15); locally, it is definable only over an interval of several metres because, at the outcrop scale of observations, the concretions are discontinuous along strike.

The Ringnes Formation is overlain by dark grey silty marine shale of the Deer Bay Formation at the type section, as it is at other localities in the Ringnes Islands. Top of the Ringnes Formation is marked at the uppermost limit of the concretionary shale succession, which at the scale of outcrop observation is vaguely defined over an interval of several metres, but which is mappable on a regional basis (Fig. 15).

The facies transition from lower and middle Awingak sandstones to Ringnes concretionary shale lies in the subsurface between the outcrops at Cape Ludwig and those of the Ringnes Formation type region in central Amund Ringnes Island.

Age and correlation. Marine macrofossils collected from rocks assigned to the Ringnes Formation include pelecypods (mainly the genus *Buchia*), gastropods, and a few ammonoids. Tozer and Thorsteinsson (1964, p. 145) collected ichthyosaur bones from the unit at Mackenzie King Island. Approximate stratigraphic levels of fossil collections from the Ringnes Formation are indicated in Figure 4. Paleontological reports for those collections are included in Balkwill et al. (1977).

Most of the Ringnes Formation is upper Oxfordian to lower Kimmeridgian, as indicated by macrofaunas of those ages contained in collections from GSC localities 81751, C-22199, C-22200, C-22232, C-22234 and C-22251. Early Callovian faunas were collected from Savik Formation shale about 70 m below the base of the Ringnes Formation (GSC loc. C-26629). Early Oxfordian faunas are present in shale above the mid-Jurassic hiatus in the eastern part of Sverdrup Basin (Thorsteinsson and Tozer, 1970, Fig. X-12), so it seems possible that basal Ringnes Formation beds are also lower Oxfordian, and that the sub-Oxfordian hiatus is at or near the contact of the concretionary shale with underlying green-grey Savik Formation shale. Faunas collected at the approximate top of the Ringnes Formation type locality were dated by J.A. Jeletzky as mid-Kimmeridgian to early Early Volgian (GSC loc. C-22222). The oldest collections from the overlying Deer Bay Formation shale are early Late Volgian (zone of *Buchia fischeriana* d'Orbigny sensu stricto; see Jeletzky, 1966).

Identifiable macrofossils were not seen in well cuttings from West Amund I-44. Fragments of prismatic layers of shells, probably from pelecypods, and crinoids and echinoid debris are present sporadically, as are small (1 - 2 mm) pyritized tubes which may be casts of serpulid worm tubes.

Collections of microfaunas from the interval 454 to 619 m K.B. in the West Amund I-44 well tend to support a late Oxfordian to early Kimmeridgian age for most of the Ringnes Formation (J.H. Wall, pers. com., 1975; Balkwill et al., 1977). The foraminifers in the well, which are identifiable or comparable with published species, show a general similarity to those reported from the upper Oxfordian and lower Kimmeridgian of western Siberia.

The foregoing discussion of the Awingak Formation provided macrofaunal and lithostratigraphical evidence to support correlation of lower and middle parts of the Awingak sandstone succession of Cornwall Island and Cape Ludwig with the Ringnes Formation of central and northern Amund Ringnes Island.

Tozer and Thorsteinsson (1964, p. 144, 145) collected late Oxfordian to early Kimmeridgian faunas at Mackenzie King Island from rocks they assigned to an informal shale member in the lower part of the Mould Bay Formation (Tozer, 1956). Those rocks were examined by the writer in 1976; they are lithologically similar to the Ringnes Formation of other parts of the basin, occupy a homotaxial position with it, are at least partly equivalent in age and, therefore, should be assigned to that formation. Ringnes Formation shale with Oxfordian and Kimmeridgian faunas is present also on northwestern Melville Island. Johnson and Hills (1973, p. 193) noted an interval comprising Upper Jurassic shale with huge yellow-weathering concretions at Bjarnasson Island, a small island lying off the northwestern coast of Axel Heiberg Island. Wilson (1976) examined a section of the Ringnes Formation at Ekblaw Lake, northern Ellesmere Island, where the formation is about 42 m thick and consists of dark grey siltstone with huge mudstone nodules. Late Oxfordian or early Kimmeridgian faunas were collected previously from that location (Nassichuk and Christie, 1969).

Interpretation. Ringnes Formation shale, like other thick, marine Jurassic shale successions in the Sverdrup Basin, lacks turbidites, syndepositional slump structures or other indicators that it was deposited on a basin floor that had influential bathymetric relief. Microfaunas from the formation indicate accumulation in shallow-marine conditions (J.H. Wall, pers. com., 1975). Modern serpulid worms occupy a wide range of environments, from near shore to outer shelf (Andrews, 1964) but, because the animals are filter feeders, they thrive best in agitated water and are common in shallow-marine environments, where they commonly form biogenic mounds. Apparently, the rate of Jurassic sedimentation of the basin was about in equilibrium with sediment supply, so that over most or all of the basin the surface of sediment accumulation was never far below sea level. The approximate rate of accumulation of Ringnes beds was relatively slow (about 30 - 35 m per million years) compared with most other Sverdrup Basin pelitic units. Nonetheless, the Ringnes Formation and equivalent Awingak sandstones mark accelerated Late Jurassic Sverdrup Basin sedimentation following a mid-Jurassic hiatus or phase of retarded sedimentation.

Concretions in shale may be syngenetic, diagenetic, or epigenetic. Raiswell (1971) specified criteria for recognizing the age of development of those types. Explanations for the origins of the distinctive Ringnes Formation concretions must account for their abnormally large size and widespread distribution. Balkwill et al. (1977) suggested that the huge concretions owe their form partly to diagenetic cementation, but that their size and distribution could also be partly a result of primary depositional geometry.

Some characteristics of thin sandstone layers intercalated with shale in the upper part of the Ringnes Formation on east-central Amund Ringnes Island suggest that they may have originated as sand waves in generally quiet, but sporadically agitated, shallow-marine conditions. The very fine grained sandstone units characteristically pinch and swell over wave lengths of several metres; 'pinch and swell' beds locally terminate as discontinuous lenses enclosed by shale; the sandstone bodies have some large low-angle crossbedding sets; and they contain marine pelecypods (as at GSC loc. C-22199, Fig. 4) and small fragments of silicified wood, and have trace-fossil trails on bedding surfaces. The trails indicate temporary interruptions in deposition, but there are no root traces or other indicators of shoaling to or above water level. These properties suggest that the shallow submarine surface experienced long periods of tranquility, dominated by pelitic deposition but infrequently interspersed with short-lived, relatively high energy storms or currents, which produced sand waves and patches. Analogy of form and position prompts speculation that the discontinuous lenses may be lower shoreface facsimiles of the huge concretions that characterize the Ringnes Formation, and the abnormally large size and widespread distribution of the latter developed at least partly syngenetically during sedimentation through agitation and winnowing of sandy and silty patches distributed on the mud-dominated, shallow-offshore bottom surface. Upon burial, the ovate mounds or 'whalebacks' (term of King, 1918; also Allen, 1968) were cemented and their ellipsoidal forms enhanced diagenetically.

A possible depositional setting, somewhat similar to the foregoing interpretation, was suggested by Cotter (1975) for part of the Mancos Shale (Upper Cretaceous) of eastern Utah. There, the distal parts of thin deltaic sandstone tongues grade to siltstones and shales containing impressively large carbonate concretions. Cotter interpreted the sandstone tongues and associated concretionary rocks as products of shallow, lower shoreface tracts of low-energy coastal zone that was occasionally agitated when lashed by storms. Further, he suggested that the coast of Georgia offers a possible modern analogue to those environmental conditions.

Upper Jurassic and Lower Cretaceous

Deer Bay Formation (redefinition)

Nomenclature. Heywood (1955, p. 61; 1957, p. 9) named black shales in the general region of Deer Bay, north-central Ellef Ringnes Island, the Deer Bay Formation (Fig. 5). He did not specify a location for the Deer Bay type section, stating (1957, p. 9): "The Deer Bay Formation is named for its typical occurrence in the vicinity of Deer Bay where it extends over an area of approximately 130 square miles." Because he was unable to examine the lower part of the Deer Bay succession in the type region, the base of the formation was not defined formally. Stott (1969) mapped the base of the formation in the type region at the top of lower Callovian rocks, thus including as part of the Deer Bay Formation the Oxfordian-Kimmeridgian concretionary shale now called the Ringnes Formation (Fig. 14). The latter, as shown in previous sections of this report, is coeval with lower and middle parts of the Awingak Formation of Cornwall Island and southern Amund Ringnes Island. In the eastern part of Sverdrup Basin, the name Deer Bay Formation has been used for pelitic strata overlying the Awingak Formation sandstone, and underlying Isachsen sandstone (see Souther, 1963, p. 437; Thorsteinsson and Tozer, 1970, Fig. X-12). For regional consistency of nomenclature, and delineation of depositional assemblages within the Jurassic shale succession, it is now proposed that application of the name Deer Bay Formation should be restricted to the pelite-dominated succession lying above

Awingak Formation sandstone or Ringnes Formation concretionary shale, and below Isachsen Formation sandstone (Fig. 14). The effect of this redefinition, for the central and western parts of the Sverdrup Basin, is to raise the lower boundary of the Deer Bay Formation from the level of former usage---the top of the Wilkie Point (Jaeger) sandstones---to the base of pelitic strata lying on the Ringnes Formation or Awingak Formation.

The lower boundary of the redefined Deer Bay Formation is probably diachronous. From regional macrofossil evidence it ranges from possibly lower Lower Volgian to Upper Volgian, because of lateral transition of shale to sandstone at the basin margins (see Jeletzky, 1966, for Canadian Arctic Volgian macrofaunal zonations). The upper boundary (which remains as originally defined by Heywood) is as young as late Valanginian in the basin centre and, because of truncation, is somewhat older from place to place at the basin margins.

As restricted in the foregoing paragraph, the Deer Bay Formation of Amund Ringnes and Cornwall islands consists of five, locally mappable, informal members. From oldest to youngest, these are designated on the geological map and cross-sections as units JKdA (silty shale), JKdB (glauconitic sandstone), JKdC (silty shale), JKdD (locally glauconitic sandstone), and JKdE (silty shale, which grades upward as intercalated shale, siltstone and sandstone to the Isachsen Formation). On southern Amund Ringnes Island and western Cornwall Island, units JKdA and JKdB are included in the upper part of the Awingak Formation (informal unit Ja4 of Figure 8).

Distribution and thickness. The Deer Bay Formation underlies a widespread region of poor exposures in central Amund Ringnes Island, at Cape Ludwig, and in eastern and western Cornwall Island. The section exposed along Temperance River is as well exposed as any other in the region, but even there thick parts are concealed.

There are great ranges in the thickness of the Deer Bay Formation in the report area (Fig. 4), partly because of regional southward facies gradation of lower Deer Bay shale to upper Awingak sandstone and, locally, because of intraformational truncation of Deer Bay strata beneath upper Valanginian shales. The Deer Bay Formation is thickest (about 970 m) at Temperance River, the thickest reported section of the formation anywhere in the Sverdrup Basin. It is about 635 m thick north of Amund Ringnes Piercement Dome, about 755 m thick at Cape Ludwig, and about 230 m thick on southwestern Cornwall Island.

Lithology. The Deer Bay Formation consists mainly of shaly siltstone and silty shale; such pelitic rocks dominate the informal units JKdA, JKdC and JKdE. A widely mappable unit of buff sandstone and glauconitic sandstone (map unit JKdD) separates shales and siltstones of map units JKdC and JKdE and a thin interval of very fine grained, partly glauconitic sandstone (intraformational marker JKdB on the geological map) is present in the Deer Bay Formation in central Amund Ringnes Island. Faunal and facies considerations suggest the possibility that marker JKdB is a distal tongue equivalent to some of the upper part of Awingak informal member Ja4. Delineation of Deer Bay intraformational units and markers was not attempted in the pelitic terrain of northern Amund Ringnes Island, and there the entire formation is designated by the symbol JKdu.

Strata included in member JKdA consist of sparsely fossiliferous, dark green-grey to black, argillaceous, slightly sandy, parallel-laminated siltstone, and black, silty, papery shale. Very small amounts of sand are present as parallel, horizontal laminae and filled burrows. There are also some beds with medium to coarse, rounded, floating grains of milky quartz and grey chert. In central Amund Ringnes Island, member JKdA becomes coarser upward and grades to sandstone mapped as unit JKdB.

Map unit JKdB consists of very fine to fine-grained and silty, very thin bedded, flaggy, slightly glauconitic sandstone. The sandstone interval weathers to a slightly lighter tone than adjacent shale, allowing its delineation on aerial photographs. Some of the sandstone beds are characterized by hummocky cross-stratification (a term introduced by Harms et al., 1975, p. 87, 88).

Pelites composing map unit JKdC are dark green-grey clayey siltstones and silty shales, similar lithologically to strata of unit JKdA. Near Cape Ludwig and on western Cornwall Island, the unit coarsens in grain size and grades upward to sandy siltstone and silty sandstone of unit JKdD.

Map unit JKdD is best exposed along an unnamed river, directly north of Cape Ludwig. Strata in the lower part of the unit are tan-weathering, very fine grained, parallel-bedded platy siltstones, with abundant winding trails on bedding surfaces. The mean grain size coarsens upward, and the upper approximately 20 m consist of light buff, medium-grained (and partly coarse-grained), porous, quartz sandstone, with some low-angle crossbedding sets and some vertical, cylindrical burrows. Northwest of Cape Ludwig, there are a few thin (less than 1 m thick) lenses of red-brown-weathering, coarse-grained, pebbly sandstone. In central Amund Ringnes Island, unit JKdD consists of very fine to fine-grained, slightly glauconitic, very thin bedded sandstone, resembling unit JKdB.

Strata assigned to map unit JKdE consist of dark grey to black, shaly, finely laminated siltstone and silty, papery shale, with increasingly thick and abundant tan-weathering, fossiliferous, parallel-laminated and cross-laminated, platy, quartzose sandstone beds in the upper part. Carbonaceous detritus is abundant on bedding surfaces of the sandstone. At several localities in central Amund Ringnes Island, dark grey and black, well rounded chert pebbles as large as 1.5 cm lie randomly in shale of the lower part of unit JKdE. Buff-weathering, slightly calcareous mudstone concretions, about 1 to 2 m long, are relatively common at some levels of unit JKdE, and there are some small calcite rosettes, 'hedgehog concretions' (Norris, 1963b), and 'polar euhedrons' (Kemper and Schmitz, 1975), and some spherical iron-rich 'cannonball concretions'. Fossil bivalves and belemnites are common in the upper, sandier parts of the unit and large fragments and logs of silicified wood are present also.

All of the informal members comprising the Deer Bay Formation are increasingly finer grained northward. Silt components of the pelitic intervals diminish in thickness and abundance, and only very thin beds of very fine grained, partly glauconitic, medium grey and green-grey sandstone remain which cannot be mapped with any confidence. Buff-weathering mudstone concretions are more abundant in central and northern Amund Ringnes Island than in equivalent intervals near Cape Ludwig.

Deer Bay shale is altered in intriguing fashion in two widely separated places. About midway between Amund Ringnes Piercement Dome and the dome at Andersen Bay (loc. A on the geological map), shale in the upper part of the formation is altered to light grey and tan, very pyritic, pelitic hornfels, within two small circular mounds each of which is about 20 m across. There are neither igneous dykes nearby, nor obvious faults along which hot fluids might have penetrated to effect this alteration. Temperatures required for alteration of shale to pelitic hornfels are unlikely to be attained under surface conditions so it seems likely that the shale was altered in the subsurface conditions and exhumed to its present location; possibly, alteration was effected by plumes of hot fluids or gases emanating from deeper levels of mafic intrusion or from hot mobile parts of the huge piercement complex (see section on structural geology below).

Several kilometres south of Geologist Bay (loc. B on the geological map), a moundlike, bright yellow to yellow-brown sulphurous deposit rests on lower Deer Bay shale. Air in the environs of the deposit smells strongly sulphurous. Cobble- and pebble-erratics on the surface of the ground have yellow-green surface rinds, in contrast to the brown and red tones that characterize clasts in other places. Unlike conditions at locality A, the shale is not visibly metamorphosed. In short, evidence suggests that conditions at locality B were the reverse of those that prevailed at locality A, and that the sulphurous deposits at the former resulted relatively recently from surface and near-surface hydrothermal or gas emanations, rather than from hypabyssal alteration, which seems to have prevailed at locality A.

Contacts. Pelitic strata comprising the oldest unit of the Deer Bay Formation (JKdA) conformably overlie Ringnes Formation concretionary shale in central and northern Amund Ringnes Island. Sandstone comprising Awingak informal member Ja4 at Cape Ludwig grades northward to those Deer Bay pelites and, as a result, the Deer Bay - Awingak contact is locally a shale-sandstone facies boundary that is diachronous. Members JKdA and JKdC each grade upward to siltstone and sandstone of overlying members JKdB and JKdD in central Amund Ringnes Island, and each of the latter arenaceous members is overlain rather abruptly by the succeeding pelitic member.

Throughout Amund Ringnes Island and western Cornwall Island, the upper part of the Deer Bay Formation grades upward to Isachsen Formation sandstone through a transitional interval several tens of metres thick, consisting of intercalated shale, siltstone and sandstone, in which the sandstone units become thicker and more abundant upward. The top of the Deer Bay Formation was mapped at the base of the lowest, thick, buff- or grey-weathering sandstone bed.

At Jaeger River, and elsewhere in eastern Cornwall Island, Deer Bay unit JKdC is indicated on Map 1471A (and Figures 4 and 8) to be overlain abruptly and truncated southward to a zero edge by the Isachsen Formation. There is some paleontological evidence that the uppermost beds within the rocks mapped as unit JKdC are upper Valanginian, which if the case, means that there is an intraformational unconformity in the upper part of the Deer Bay Formation.

Age and correlation. Ammonites and the pelecypod genus *Buchia* have been used for most regional dating and correlation of the Deer Bay Formation and equivalent rocks (Jeletzky, 1973). Thorsteinsson and Tozer (1970, Fig. X-12) presented a diagrammatic representation of regional Deer Bay correlation, showing that the base of the formation in eastern Sverdrup Basin (where it rests on Awingak sandstone) is probably lower Upper Volgian (zone of *Buchia fischeriana*; see Jeletzky, 1966, p. 30, 43), and the top, immediately below Isachsen sandstone, is upper Valanginian. In the same diagram, the base of the Deer Bay Formation in the central and western parts of the basin was shown to extend downward to shale above lower Callovian sandstone, thus including within the Deer Bay Formation some Oxfordian-Kimmeridgian shale that now is assigned to the Ringnes Formation. By redefining the Deer Bay Formation, as proposed in foregoing paragraphs, the basal beds of the Deer Bay Formation lying on the Ringnes Formation are not older than Early Volgian. The top of the Deer Bay Formation, unchanged from its original definition, is upper Valanginian in places where it is gradational to overlying Isachsen sandstone, and older than that in the places where it probably is truncated by Isachsen sandstone.

Stratigraphic levels of Deer Bay macrofossil collections from Cornwall and Amund Ringnes islands, and the approximate ages of the faunas are summarized in Map 1471A and the Appendix. Particularly significant collections, for regional correlation purposes, were made from the thick succession of Deer Bay rocks in central Amund Ringnes Island, and the following paragraphs are concerned mainly with those collections and their interpretation. All of the macrofossil determinations and assignments of ages were made by J.A. Jeletzky.

Early Volgian faunas (some part of *Buchia mosquensis* Zone, Table of Formations) were collected from thin sandstone beds mapped as the top of the Ringnes Formation at GSC locality C-22222. This allows the possibility that basal shale of the immediately overlying Deer Bay Formation, which rests conformably on the Ringnes Formation, might also be as old as Early Volgian. Several collections of early Late Volgian faunas were made, and they were assigned by Jeletzky to the zone of *Buchia fischeriana* (d'Orbigny) sensu lato. The stratigraphically highest of these are at GSC localities C-26630 and C-22212, at the top of marker JKdB, about 330 m above the base of the Deer Bay Formation. Similar faunas were collected at GSC locality C-22248 and for those Jeletzky stated (pers. com., 1973): "The lot C-22248 is believed to ... represent the basal 30 to ?50 feet of the Deer Bay Formation as developed on Ellesmere Island"; at the latter, Awingak sandstone is well developed. Part of the thick Deer Bay succession of unit A, beneath the level of C-22248, is probably coeval, therefore, with the Lower Volgian part of the Awingak sandstone succession of Ellesmere Island (see Thorsteinsson and Tozer, 1970, Fig. X-12).

The next youngest faunal zone [probably the zone of *Buchia terebratuloides* sensu lato (late Late Volgian; see Jeletzky, 1971, Fig. 2)] is represented in the Deer Bay Formation by collection C-22201, about the middle of the pelitic interval designated as marker JKdC. Faunas assigned to the same zone were collected by K.J. Roy from uppermost Awingak sandstone beds at Jaeger River, and from Deer Bay pelites just above them, indicating partial equivalence of upper Awingak sandstone beds of the Cornwall Island basin-margin facies with Deer Bay shales as high as the level of collection C-22201 in Member C of the basin-central facies of Amund Ringnes Island.

GSC locality C-22207 is from shale beds not far below marker JKdD. Of this collection, Jeletzky (pers. com., 1973) stated: "Large *Buchia* fragments resemble those of giant forms of *Buchia okensis* f. typ. If so, the age would be early Berriasian. All fragments are, however, too poor to be certain of their specific affinities." This is the only collection from either Amund Ringnes or Cornwall islands that indicates the possible presence of Berriasian rocks [except for collections at C-22252 and C-26619, which contain *Buchia* sp. indet. of general Early Cretaceous (Berriasian or Valanginian) affinities]. The possibility that Berriasian rocks are absent or very thin on southern Amund Ringnes Island is enhanced by Kemper's (1975) demonstration of a widespread Berriasian hiatus near the eastern margin of Sverdrup Basin.

The Valanginian Stage is well represented faunally. Kemper (1975; 1977) collected Valanginian ammonites and *Buchia* specimens on northern Amund Ringnes Island, and correlated upper Deer Bay rocks there with sections in the eastern part of Sverdrup Basin; he concluded that the substage boundary between upper and lower Valanginian rocks is about 115 m below the top of the Deer Bay Formation at northern Amund Ringnes Island, and also that the Valanginian part of the formation is at least 400 m thick. In central Amund Ringnes Island, early Valanginian faunas (*Buchia keyserlingi*) were collected at GSC locality C-22224, in sandstone of marker JKdD. Kemper's work in the eastern part of the basin indicated that, over wide areas there, basal Valanginian beds overlie lower Berriasian or older strata, and a significant sub-Valanginian hiatus is present in the Deer Bay Formation. A lower Valanginian sandstone unit, 36 m thick, occupying a stratigraphic position homotaxial with unit JKdD, is present in the Deer Bay Formation of southern Axel Heiberg Island (Tozer, 1963b, p. 25, 26). Early Valanginian sand progradation was therefore widespread around the southeastern margin of Sverdrup Basin and, in many places, followed a phase when Berriasian and slightly older beds were truncated.

Middle and late Valanginian faunas were collected in several localities. Late Valanginian bivalves (*Buchia* n. sp. *inflata* Zone; see Jeletzky, 1964) are particularly abundant in uppermost Deer Bay beds, and in lowest strata of the Isachsen Formation. The Deer Bay - Isachsen contact on Amund Ringnes Island and western Cornwall Island is therefore upper Valanginian. In apparent contrast to the foregoing are formational relationships in eastern Cornwall Island. The youngest Deer Bay macrofaunas at Jaeger River and environs are dated by J.A. Jeletzky as latest Volgian (zone of *Buchia terebratuloides* sensu lato), however, marine microfloras from the same strata are considered Early Cretaceous, probably Valanginian (E. Davies, Univ. Toronto, pers. com., 1977). Pelite containing those faunas and floras is overlain directly, and truncated southward by sandstone mapped as basal beds of the Isachsen Formation. The ages yielded by the Deer Bay strata allow the possibility that the shales mapped as unit JKdC (Map 1471A) are both Volgian and Valanginian, separated by an intraformational unconformity along which sandstones of unit JKdD were eroded completely.

The Mould Bay Formation (Tozer, 1956, p. 23) of western parts of Sverdrup Basin includes faunas ranging in age from Oxfordian-Kimmeridgian (therefore equivalent to the Ringnes Formation, as shown previously) to as young as late Valanginian (Tozer and Thorsteinsson, 1964, p. 137). At the western margin of the basin, at Prince Patrick Island (Fig. 5), only Early Volgian and late Valanginian faunas are present in the Mould Bay Formation, and Late Volgian, Berriasian, and part of the Valanginian are not represented faunally (Kemper, 1975, p. 251). From Prince Patrick Island toward the axial part of the basin, at Mackenzie King Island, an interval comprising sandstone in the Mould Bay Formation contains Late Volgian faunas in its lower part, and early Berriasian faunas in its upper part (Tozer and Thorsteinsson, 1964, p. 145). The Jurassic-Cretaceous boundary in the western part of the basin is, therefore, at some level in the middle of the Mould Bay Formation. Previously cited evidence from Amund Ringnes and Axel Heiberg islands indicates that the prominent wedge of sandstone (unit JKdD) in the Deer Bay Formation is probably lower Valanginian and, therefore, not directly correlative with the sandstone of the Mould Bay Formation.

Jeletzky (pers. com., 1973) noted with interest that collections of faunas from GSC locality C-22245 (also C-26631) contain specimens of *Buchia pacifica*: "The unexpected discovery of *Buchia pacifica* faunas in lot C-22245 is of extreme interest, being the first instance of the presence of this North Pacific fauna in the purely boreal (North American boreal province) region of Sverdrup Basin. This discovery aids strongly the interregional correlation and dating of the Valanginian faunas of Sverdrup Basin...."

Interpretation. Part of the foregoing section presented paleontological evidence suggesting equivalence of lower Upper Volgian and older pelites of the Deer Bay Formation on central and northern Amund Ringnes Island with the upper part of the Awingak Formation at Cape Ludwig. Deer Bay shale at and below the level of marker JKdB presumably represents prodelta mud deposited in front of the short-lived, but highly constructive Volgian phase of Awingak delta progradation. No indicators of syndepositional slumping were noted in the Deer Bay strata. Also, microfaunas in the formation are indicative of widespread, shallow-marine conditions (J.H. Wall, pers. com., 1975). Therefore, it seems that the lower Deer Bay depositional surface was relatively shallow and smooth, lacking significant bathymetric relief, and that the rate of basin subsidence in Late Jurassic time was in approximate equilibrium with the rate of fine clastic influx.

Sandstone comprising unit JKdD marks a significant intra - Deer Bay event. Attention has been called by Jeletzky (1973) and Kemper (1975) to the widespread Berriasian hiatuses at Sverdrup Basin margins, and the possibility that, locally at least, basal Valanginian beds are sandy and rest directly on Volgian Deer Bay shale. For western Cornwall Island and southern Amund Ringnes Island, the early Valanginian progradational event seems to be represented by sandstone comprising interval JKdD and for central Amund Ringnes Island by a thin sandstone tongue of that wedge. Progressive submarine shallowing may be indicated by the change from sandstone with bedding-surface trails in the lower sandstone beds to sandstone with vertical burrows near the top of the interval.

Regional late Valanginian delta progradation is marked by delta-front intercalated sandstone and shale in the uppermost part of the Deer Bay Formation, thick- and massive-bedded delta-front Isachsen Formation sandstone, and succeeding delta-plain coaly strata.

Kemper (1975, p. 247) offered interesting speculations on Valanginian climatic conditions, based on observations of the upper part of the Deer Bay Formation. Widespread levels of crystal aggregates or rosettes (called "polar euhedrons" by Kemper), mass occurrence of driftwood with sparse pholad borings, and lack of diversity of invertebrate faunas (noticed first by Jeletzky, 1971, p. 14), as well as gigantism in some forms, suggested to Kemper that the Valanginian of the Sverdrup Basin was characterized by cold-water conditions, which subsequently warmed with the advent of Isachsen alluviation.

Revision. In foregoing discussion of the Awingak Formation it was noted that a thin interval of dark grey shale separates informal Awingak units Ja3 and Ja4. If the shales are Volgian, a possibility their contained palynomorphs allow, they may be equivalent to unit JKdA (Fig. 13).

A sample collected in 1979 from shales mapped at Jaeger River as unit JKdC, contained palynomorphs described as: "a rich terrestrial assemblage of typically Early Cretaceous aspect" [Robertson Research (Canada) report to Panarctic Oils Limited, 1979]. This supports the suggestion by E. Davies (pers. com., 1977) that some of the beds included in unit JKdC are Valanginian and are correlative with unit JKdE. Figure 13 depicts this possibility: units JKdC and JKdE are shown, separated by an intraformational unconformity.

Lower Cretaceous

Isachsen Formation

Nomenclature. Heywood (1955, p. 61; 1957, p. 11) introduced the term Isachsen Formation for a Lower Cretaceous sandstone succession at Isachsen Peninsula, northern Ellef Ringnes Island (Fig. 5). In the type region, the formation is about 900 m thick, and consists mainly of quartzose, nonmarine sandstone, conformably overlying the Deer Bay Formation and conformably underlying Christopher Formation pelite. The Isachsen Formation is distributed widely throughout the Sverdrup Basin. The name has been applied also to basal Lower Cretaceous sandstone lying unconformably on older Phanerozoic rocks beyond the eastern and southern margins of the basin, and as far beyond the southwestern margin as Banks Island (Fig. 1; Thorsteinsson and Tozer, 1962, p. 59 - 62; Miall, 1975).

Distribution and thickness. The Isachsen Formation is exposed over large areas of Amund Ringnes Island, and it also forms outcrops near the eastern and western coasts of Cornwall Island. Upper beds of the formation are at the crest of a low ridge on Haig-Thomas Island. There are well exposed Isachsen sections at Stratigrapher River, where the formation is about 980 m thick, and at Structural River, where it is about 1020 m thick. The formation is brightly coloured (light grey and buff), and presents a pleasant distinction in the generally drab grey landscape of the region. Where it is partly cemented, it commonly forms low cuestas and, in some places, has been eroded into impressive hoodoo forms. In low coastal areas, as at Temperance Bay, the rocks are very poorly cemented and underlie vast tracts of loose sand.

The top of the Isachsen Formation lies beyond the western shoreline of Cornwall Island; the minimum thickness of the formation there is about 525 m. Upper beds of the formation, including the contact with Christopher Formation pelites, are covered by recent marine mud and sand on eastern Cornwall Island. Thickness of Isachsen strata in that region may be on the order of 900 to 1000 m.

Lithology. Three vaguely defined lithological assemblages can be recognized in the succession of sandstone-dominated strata comprising the Isachsen Formation on Amund Ringnes Island.

(1) The lower assemblage is about 150 to 250 m thick, and is characterized particularly by fining-upward repetitions of thick to massive beds of light grey, light buff, and white, coarse- to medium-grained (and partly pebbly) quartz sandstone. (The pebbles are well rounded, up to 2 cm in diameter, and are almost entirely milky quartz.) The sandstone beds have carbonaceous hash on bedding surfaces, and abundant root traces above the lower 100 m. Some beds in the lower several metres of the assemblage contain specimens of *Buchia*, which are too poorly preserved for identification, but indicate a marine site of accumulation for those strata. Many of the sandstones have medium to large sets (as thick as 1 m) of tabular cross-strata. Dark tan and rust-brown, fine-grained, very thin bedded sandstone, with ripple laminations, and commonly with impressions of wood and leaves, and dark grey, shaly, fissile, partly carbonaceous and partly ferruginous siltstone compose the upper part of some of the repeated, fining-upward sequences. Some carbonaceous siltstone units are 10 to 15 m thick. They resemble thick coal seams from a distance but, in fact, contain very little clean coal. A bed of light buff-grey, partly laminated, very fine grained, non-welded felsitic tuff, about 1 m thick, was observed about 100 m above the base of the Isachsen Formation northwest of Stratigrapher River, and a similar bed was noted in an outcrop near the western flank of Amund Ringnes Piercement Dome. Because of poor exposures, the lateral extent of the tuff beds could not be determined, so it is not clear whether there are two exposures of the same bed, or whether there are two tuff beds at slightly different stratigraphic levels.

(2) The intermediate, vaguely defined Isachsen assemblage comprises about 300 to 450 m of sandstone and pelitic strata characterized particularly by well developed, fining-upward cycles, from less than 1 m to about 15 m thick. The lower part of each cycle is commonly pale brown-grey, coarse to medium grained (and locally with tabular shale clasts), thin to thick bedded, partly cross-stratified sandstone. The lower parts of most cycles are succeeded by tan to red-brown, platy and flaggy, fine-grained sandstone with some ripple cross-strata. The tops of complete cycles consist of black, sandy, clayey, carbonaceous, thinly laminated siltstone and silty shale and, in some places, very thin (less than 0.5 m) beds of blocky, dull black coal.

The intermediate assemblage has root traces and plant fragment impressions; it contains no marine macrofossils or traces of marine organisms. The succession is moderately ferruginous, the iron occurring as hematitic grain coatings and cement, siderite cement and small red-brown ferruginous nodules.

(3) The upper, vaguely defined assemblage of Isachsen strata is dominated by light grey, light buff and brown-buff quartz sandstone (Fig. 19). These rocks are coarse to fine grained, and partly pebbly (as well rounded, milky quartz pebbles to about 2 cm long), and have abundant medium to thick sets of high-angle, tabular cross-strata with truncated tops, and a few sets of trough cross-strata. The light-coloured strata of each sequence are overlain in some places by thinner and less abundant beds of flaggy, tan- and rust-brown - weathering, ferruginous, fine-grained sandstone units containing some small ironstone nodules, as well as some thin, carbonaceous, dark grey shaly siltstones and silty shales, and a few thin beds of silty coal. The uppermost 40 to 60 m, approximately, contain very little siltstone and shale (Fig. 19), but do contain thin coal seams and, locally, abundant root traces. These beds are characterized particularly by tabular cross-strata. Beds at the top of the formation have vertical, U-shaped burrows resembling *Diplocraterion* (Häntzschel, 1975, p. 195). The thick, light-coloured sandstone beds in this assemblage are moderately well cemented at some outcrops, and form low ridges and hoodoos. The upper assemblage of Isachsen rocks is about 300 to 350 m thick.

The boundaries between the foregoing, threefold informal divisions of Isachsen strata are so vague that they cannot be mapped with confidence. Nevertheless, there may be some value in recognizing that general distinctions exist within the Isachsen Formation when interpreting regional depositional processes. From Lougheed Island (Fig. 1) westward, the Isachsen Formation consists of three parts: an upper and lower succession of mainly nonmarine, partly coaly sandstone, separated by about 30 to 40 m of silty, marine, tentatively Aptian shale (Balkwill et al., 1982). The marine shale is traceable in wells as far east as Ellef Ringnes Island. Whether or not there is a stratigraphic relationship between those divisions of the Isachsen Formation and the succession at Amund Ringnes Island is not presently known.

In summary, on Amund Ringnes Island, the lower and upper parts of the Isachsen Formation are sandstone-dominant and tend to be more topographically prominent than the thick, middle part which is considerably more pelitic, thinner bedded and recessive. Also, it is characterized when weathered by dark grey, drab yellow and tan colours, in contrast to the lighter tones imparted by quartzarenites lying above and below (Fig. 19).

Sand grains composing the Isachsen strata are almost entirely clear and slightly milky, angular to subrounded quartz, with less than 5 per cent accessory grains of white to dark grey chert, white mica (possibly sericite), and angular black coal grains. Conglomeratic beds have pebbles and granules of clear and milky quartz and light to dark grey chert. The pebbles and granules are well rounded, as are grains in the very coarse sandstone beds. The degree of rounding decreases with finer grained fractions, such that fine-grained sandstone has abundant angular grains. Small euhedral quartz crystals were noted in some well samples, but were not observed in outcrop samples. Chert pebbles and grains have relict bioclastic textures (crinoid and pelecypod fragments are visible) and some have oolitic textures. Many of the chert pebbles have white, powdery, tripolitic rinds that surround dark grey cores, but the degree of this exterior alteration is not consistent within any given bed and, thus, it seems more likely to be the result of predepositional processes than of postdepositional diagenetic alteration.

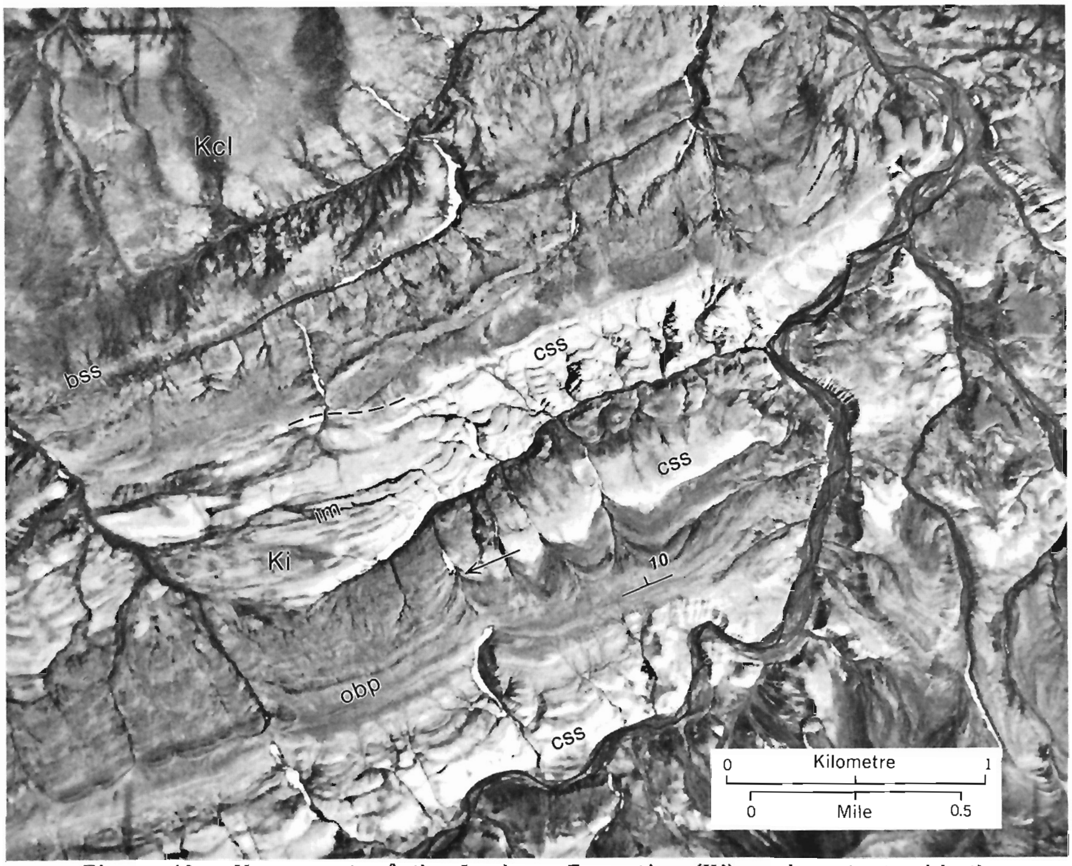


Figure 19. Upper part of the Isachsen Formation (Ki); and contact with the lower part of the Christopher Formation (Kcl) at Stratigrapher River (which flows from bottom to top at right-centre of photograph), northeastern Amund Ringnes Island. Contact marked by dashed line. Light-toned beds in Isachsen Formation are interpreted as channel sandstone (css); note northward, lateral truncation of channel sandstone at arrow. Medium-toned beds are very fine grained sandstones and pelitic strata, interpreted to be overbank deposits (obp), and dark-toned beds are carbonaceous shale and coal, which may be deposits of interdistributary marshes (im). Ridge-forming marker in lower part of Christopher Formation pelites is interpreted as a barrier island sandstone (bss). Part of NAPL photo A16193-27 (enlarged).

In most outcrops, Isachsen sandstone is poorly cemented, very porous, and friable. Locally, some thick and massive beds are moderately well cemented by microcrystalline quartz or calcite. Some fine-grained sandstone in the middle part of the formation is well cemented with siderite and limonitic clay, and some beds near the top are cemented with pyrite.

Contacts. The Isachsen Formation rests conformably and gradationally on Deer Bay pelite throughout Amund Ringnes Island and on western Cornwall Island. The contact between the formations was mapped at the surface and chosen in drillholes (Fig. 8) at the base of thick-bedded to massive buff-weathering sandstone, lying above the intercalated tan sandstone and black siltstone and shale of Deer Bay unit JKdE. In eastern Cornwall Island, rocks mapped as basal Isachsen overlie abruptly Deer Bay pelitic strata of unit JKdC (and possibly also some Valanginian beds correlative with unit JKdE) and southward, across Cornwall Island hinge, progressively truncate those strata.

The upper limit of the Isachsen Formation was mapped at the top of thick-bedded to massive, buff-weathering sandstone, above which are conformable, intercalated siltstone, shale and sandstone assigned to the lower part of the Christopher Formation. The Isachsen-Christopher contact is well exposed in sections at Structural and Stratigrapher rivers (Fig. 19). It is not exposed on Cornwall Island.

Age and correlation. The Isachsen Formation is one of the thickest and most widely distributed lithologic units in the Sverdrup Basin. Within the approximate modern limits of the basin (Fig. 1), Isachsen sandstone strata lie conformably and gradationally on pelitic rocks of the Deer Bay Formation, and the youngest macrofossils collected from uppermost Deer Bay strata (and in a few places from basal Isachsen beds) are late Valanginian (Jeletzky, 1973; Kemper, 1975). Beyond the margins of Sverdrup Basin, such as at Banks Island (Miall, 1975), central Melville Island (Tozer and Thorsteinsson, 1964), and eastern Ellesmere Island (Thorsteinsson and Tozer, 1970, Fig. X-12; Thorsteinsson, 1972), basal Cretaceous sandstone beds assigned to the Isachsen Formation overstep Mesozoic and Paleozoic rocks along a regional, angular unconformity. In those places, the basal Isachsen beds are Aptian, or possibly Barremian (Plauchut and Jutard, 1976). Some sections on southeastern Ellesmere Island demonstrate clearly a progressive facies gradation of basinal lower Christopher Formation pelites to sandy shales at the basin margin, and from those rocks to basal Cretaceous (Isachsen) sandstones beyond the southeastern margin of the basin (Balkwill and Bustin, 1975).

Thus, both the upper and lower contacts of the Isachsen Formation are diachronous from the middle part of Sverdrup Basin to the basin margin and beyond it (Fig. 20). Lower Isachsen (Valanginian, and perhaps Hauterivian and Barremian) sandstone strata in midbasin have no coeval facies beyond the eastern and southern margins where that interval of time is represented by a sub-Isachsen hiatus. Isachsen sandstone of Aptian age beyond the basin margin is represented within the basin by coeval pelite of the lower part of the Christopher Formation.

The Isachsen Formation of Cornwall and Amund Ringnes islands represents a long-lived, basin-wide phase of deltaic and alluvial progradation. Within the formation there may be several late Valanginian to Aptian hiatuses, which are presently undetected because of insufficient detailed stratigraphic data.

Interpretation. The foregoing contrasts in the age and correlation of Isachsen sandstone strata within the Sverdrup Basin with respect to Isachsen sandstone strata beyond the margins of the basin exemplify a tectonic-stratigraphic event of first-order, circum-Arctic importance. The upper Valanginian, ?Hauterivian, and ?Barremian Isachsen sandstone beds within Sverdrup Basin (which includes Isachsen rocks on Amund Ringnes Island and western Cornwall Island) represent the youngest strata whose distribution is confined strictly within the eastern and southern limit of Sverdrup Basin (Fig. 1). Isachsen sandstone beds of Aptian age overstep the boundaries of the basin, and they and succeeding Cretaceous and Tertiary formations lie unconformably on older Phanerozoic strata as part of a formerly widespread continental shelf assemblage. Erosional remnants of this assemblage now lie beyond the eastern and southern margins of the basin, and extend particularly southwest of the basin to Banks Island (Miall, 1975) and to the northern Interior Plains of mainland Canada (Thorsteinsson and Tozer, 1970, Fig. X-13; Lerand, 1973; Yorath et al., 1975). Rocks mapped as basal Isachsen sandstone on eastern Cornwall Island lie unconformably on Deer Bay shale, and they may belong to the Aptian phase of truncation and depositional overstepping at and beyond the Sverdrup Basin southern margin (although, as noted previously, there are other plausible explanations for relationships on eastern Cornwall Island).

K.J. Roy (1973) conducted sedimentological studies of Isachsen strata on Amund Ringnes Island. The results of his paleocurrent measurements indicate a predominant northward direction of sediment transport (Fig. 18). Further, Roy concluded that the Isachsen Formation in this area represents a delta-complex assemblage of deposits formed during a major regressive-transgressive cycle. His conclusions are expanded as follows:

(1) The lowermost massive and thick, clean Isachsen sandstone units may have been delta-mouth sands and peripheral upper shoreface sands that accumulated from vigorous, constructive delta progradation over upper Deer Bay delta-front sand and pelite. The presence of marine pelecypods in some basal Isachsen beds indicates local marine deposition. Partly pebbly sandstones and coaly pelites in the upper part of the lower assemblage may be deposits of active delta distributary channels (sandstones) and interdistributary flood-basin marshes (coal and carbonaceous pelites).

(2) The thick middle Isachsen assemblage contains complete and truncated, upward-fining cycles of channels, point bars, overbank flood-plains, and interfluvial marshes of a large, meandering fluvial system. Complete cycles in this assemblage are as thick as 20 m, which may approximate the depth of the largest river(s). Sandstone strata comprising the middle assemblage generally are finer grained than assemblages above and below, suggesting lowering of stream gradients during mid-Isachsen deposition and, possibly, subdued rates of uplift in source terrains. The abundance of fossil leaves and wood fragments in these rocks indicates a widespread vegetated cover on or adjacent to the Early Cretaceous alluvial plain and, by inference, sufficient rainfall to support well developed plant growth. This possibility is in contrast to climatic conditions implied for Late Triassic and Early Jurassic by the relative paucity of fossil plant material in Upper Heiberg Member strata.

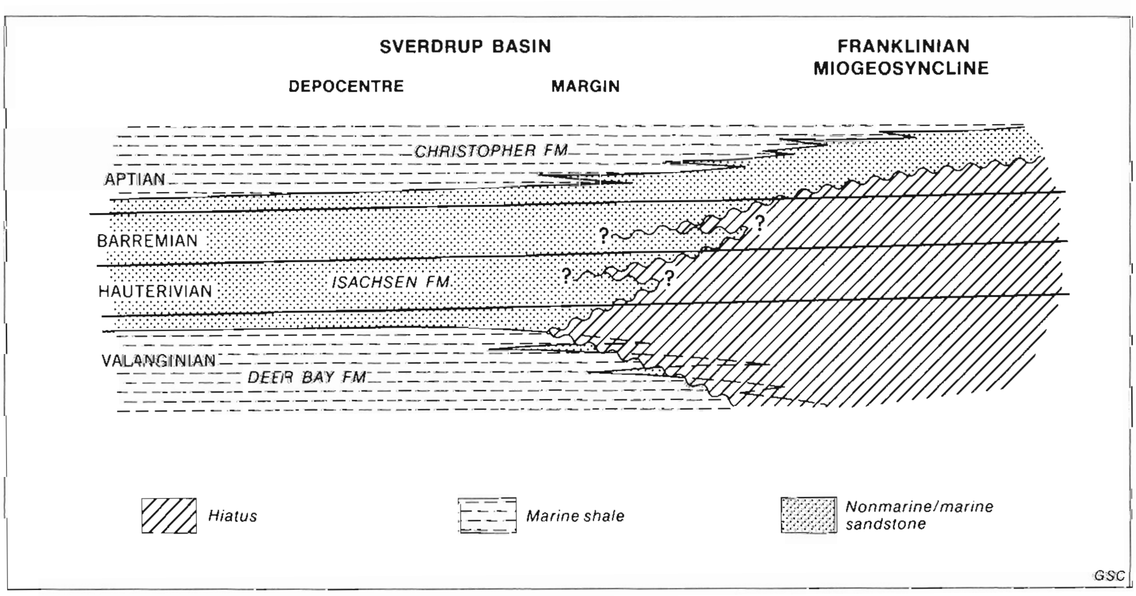


Figure 20. Suggested facies/time relationships, Isachsen and Christopher formations from central part of Sverdrup Basin to basin margins and to Franklinian miogeosyncline (see also Fig. 1).

(3) The upper assemblage of Isachsen rocks contains partly pebbly sandstone strata, and subordinate beds of pelite and coal. This sandstone-dominated assemblage may mark renewed vigour within the alluvial system. The prevalence of truncated tabular cross-strata suggests that the alluvial plain was characterized by braided streams (Smith, 1970). Some massive, fine-grained, well sorted sandstones may have been deposited by wind on the vast Aptian alluvial plain. Uppermost, burrowed and pyritic Isachsen sandstones represent beach and coastal barrier sands reworked by coastal processes from the alluvial plain sands as the Christopher sea advanced southward. *Diplocraterion*, which is present in uppermost Isachsen beds, has been suggested (Sellwood, 1970) as an indicator of shallow, agitated marine conditions.

The Isachsen Formation is impressively thick, considering that it consists almost entirely of alluvial deposits. Preservation of such a thick, nonmarine assemblage required active subsidence of the Sverdrup Basin during late Valanginian to Aptian time, concomitant with vigorous erosion of source terrains southeast of the basin. Thus arises an intriguing comparison with the stratigraphic-tectonic conditions implied for the Deer Bay Formation. Deer Bay shallow-marine pelites are about 970 m thick as a maximum, and accumulated in about 20 Ma (early Early Volgian to late Valanginian, Fig. 16): their rate of accumulation and therefore the approximate rate of basin subsidence, was about 44 m per Ma. Isachsen alluvial sandstone strata are about 1000 m thick, and accumulated in about 15 Ma (late Valanginian - early Aptian); basin subsidence rate for Isachsen accumulation was therefore about 66 m per Ma. Maintenance of alluvial systems throughout the Sverdrup Basin during Isachsen deposition thus required vigorous uplift and stripping of source terrains beyond the basin margins so that the sand supply was not appreciably diminished. The more pelitic, middle part of the Isachsen Formation may indicate a phase of diminished coarse sand supply, regional lateral shifting of major fluvial systems, or, if the beds are coeval with the mid-Isachsen Aptian (?) marine shales of western Sverdrup Basin, a shift from alluvial plain to lower delta plain environments that accompanied a relative rise of sea level. Rejuvenation, providing a more vigorous, braided-stream regime, seems to be indicated by the sandstones composing the upper assemblage of the three-part Isachsen succession.

The accumulation of very thick, intrabasin sandstone assemblages, such as the Isachsen Formation, is therefore a response to uplift beyond the basin margins, rather than being the effect of decreased intrabasin subsidence rates and basin 'filling'. Aptian depositional stepping over stripped older terrains is widespread throughout the northern hemisphere (Casey and Rawson, 1973), signalling a significant change in Arctic stratigraphic-tectonic style, from one of well defined (but probably connected) basins to broad continental shelf regimes. The relationship of the thick assemblage of Sverdrup Basin Isachsen rocks with the basal Cretaceous rocks beyond the basin margins illustrates the response to this hemispheric event in the Canadian Arctic.

Christopher Formation

Nomenclature. The name Christopher Formation was given by Heywood (1955, p. 61; 1957, p. 12) to dark grey shale lying above the Isachsen Formation and below the Hassel Formation in the region of Christopher Peninsula, northern Ellef Ringnes Island (Fig. 5). The formation is exposed over wide areas of the Sverdrup Basin, and the name has been applied also to Lower Cretaceous shales on Banks Island (Fig. 1) (Thorsteinsson and Tozer, 1962, p. 62 - 65; Miall, 1975).

Glauconitic sandstone beds near the middle of the formation are mappable in most of the central part of Sverdrup Basin (Balkwill and Roy, 1977). This allows local separation of the formation into informal lower and upper members.

Distribution and thickness. Christopher Formation pelitic rocks crop out in widely separated parts of Amund Ringnes Island. There are small, poor exposures on eastern Cornwall Island, and beneath the lowland plain of western Haig-Thomas Island. The formation is best exposed in the northern part of Amund Ringnes Island, between Stratigrapher River and Cape Sverre, where a section was measured with a transit and rod. The Christopher succession there is about 975 m thick (Fig. 8). Of this total, about 500 m compose the lower informal member (map unit Kcl), and about 475 m the upper informal member (map unit Kcu).

Total thickness of the Christopher Formation at Slime Peninsula, where informal members could not be recognized in the poor exposures, is estimated from graphic calculations to be about 540 m.

Lithology. The lower 60 m, approximately, of unit Kcl consist of coarsening-upward, parallel-bedded, very thin and thin beds of medium- to fine-grained, grey-green, flaggy to platy sandstone, which is intercalated with thin beds of dark brown, platy siltstone, and dark grey and dark green-grey, silty, papery shale. The sandstone strata are moderately well cemented with siderite, and locally with pyrite. Some beds are extensively bioturbated. A locally prominent, 5 to 6 m thick, tan-weathering sandstone bed marks the top of the intercalated sandstone-pelite succession, above which lies a very thick assemblage of silty shale (Fig. 8).

Most of unit Kcl consists mainly of dark greenish grey, moderately silty, papery shale and clayey, papery to platy siltstone, with abundant buff-brown, elliptical, calcareous mudstone nodules ranging to about 2 m long. (The nodules resemble those in the upper part of the Deer Bay Formation; they are less abundant, less brightly coloured, and considerably smaller than the distinctive nodules in the Ringnes Formation.) Some of the nodules have well developed cone-in-cone structure. Other diagenetic structures in unit Kcl include abundant carbonate rosettes ("polar euhedrons" or "hedgehog concretions") comparable in size and abundance to those in the upper part of the Deer Bay Formation, and spherical ironstone ("cannonball") concretions about the size of baseballs. The succession seems to be barren of invertebrate macrofossils, but contains abundant silicified wood fragments.

The upper 60 m, approximately, of unit Kcl become coarser upward by intercalation of beds of very fine grained, medium green-grey, platy to flaggy, slightly glauconitic sandstone, typically with well developed hummocky cross-stratification. Beds at the top of the glauconitic sandstone succession are fine to medium grained, weakly cemented, porous, very glauconitic, and contain poorly preserved pelecypods, fish bones, teeth and scales.

Shale composing the lower and middle parts of the upper member contrasts with that forming most of unit Kcl, in that the former are considerably less silty, dark grey to black (rather than green-grey), contain a few red-brown mudstone nodules (rather than abundant buff-brown nodules), and at least some beds contain abundant well preserved marine macrofossils. The upper 75 m of unit Kcu are increasingly coarse grained upward, as intercalations within shale of very thin beds of parallel-bedded, green-grey siltstone, and tan to brown, very fine grained sandstone. Some of the sandstone beds contain abundant, well preserved pelecypods, and are partly well cemented by calcite. Thin sandstone beds in the lower part of the intercalated succession contain well developed, spiral, trace-fossil forms resembling *Zoophycos*.

X-ray mineralogical determinations of some samples of the Christopher Formation are presented in Table 2.

Contacts. The base of the Christopher Formation was mapped at the top of the uppermost, massive, light buff weathering, Isachsen sandstone bed (Figs. 8, 19). The contact is conformable and well exposed in most parts of eastern Amund Ringnes Island, but it is concealed by recent marine deposits in eastern Cornwall Island, and in the water-strewn lowland at Slime Peninsula.

The top of informal unit Kcl was mapped at the approximate top of glauconitic sandstone beds forming the upper part of that succession; because the sandstone beds generally are poorly cemented and do not form a prominent topographical air-photo marker, the boundary between units Kcl and Kcu is an approximation. This contact could not be delineated with any certainty in the poorly exposed terrain at Slime Peninsula.

Sandstone and shale at the top of unit Kcu are overlain conformably by fine-grained, glauconitic sandstone beds included in basal beds of the Hassel Formation. The contact is best exposed about 16 km southeast of Cape Ludwig, along the line of measured section BAA72-4.

Age and correlation. The Christopher Formation on Amund Ringnes Island ranges in age probably from Aptian to late Middle Albian.

As is commonly the case throughout the Sverdrup Basin, the lower part of the formation on Amund Ringnes Island lacks identifiable macrofossils. *Tropaeum* of Aptian age has been identified tentatively from lower Christopher strata at Mackenzie King Island (Tozer and Thorsteinsson, 1964, p. 1610). No Barremian faunas have been collected (Jeletzky, 1971, p. 39). Age delineation of lower Christopher strata is hindered further because, in Canadian Arctic areas, there are difficulties in delineating Aptian microfossil assemblages from those of the Barremian and Early Albian (Chamney, 1973).

Middle Albian faunas are abundant in nodular shales in the lower part of map unit Kcu. In reporting on a collection from GSC locality C-22253, a few metres above the base of the unit, Jeletzky stated: "The presence of *Cleoniceras (Grycia)* n. sp. in the log C-22253 gives weighty support to the proposed early Middle Albian dating of this lot." Middle Albian faunas were collected at several other localities in the lower part of unit Kcu. Jeletzky reported that pelecypods collected within 5 m of the top of the unit, at GSC locality C-22217, are possibly Albian, but cannot be dated definitely. The youngest Christopher beds on nearby Ellef Ringnes Island are latest Middle Albian (Stott, 1969, p. 26).

Indeterminate marine pelecypods were collected from Christopher Formation shale at GSC locality C-36868, eastern Cornwall Island. Samples of shale from the same location contained a diversified foraminiferal fauna, indicative of an Early to Middle Albian age (J.H. Wall, pers. com., 1974). The exposures are so small and poor that it is not clear whether the rocks are equivalent to map unit Kcl or Kcu.

Early Cretaceous pollens were identified by W.S. Hopkins, Jr., from Christopher shale samples at GSC locality C-29928, southwestern Amund Ringnes Island.

Greenish grey sandstone is present in the middle of the Christopher Formation on Ellesmere and Axel Heiberg islands (Thorsteinsson and Tozer, 1970, p. 583). Those sandstone beds once may have been laterally continuous with glauconitic sandstone forming the top of unit Kcl on Amund Ringnes Island. Late Early Albian faunas [*Cleoniceras (Amadesmoceras?)* aff. *subbaylei* and *Arcthoplites belli*] have been collected from beds just below the sandstone (Thorsteinsson, 1971a; Jeletzky, 1964, p. 17).

If the pelite-dominated succession comprising informal unit Kcl is Aptian and Lower Albian, as it seems to be, then it represents a marine basinal assemblage that is coeval approximately with Aptian and Lower Albian nonmarine sandstone remnants, assigned to the Isachsen Formation beyond the southern and southwestern margins of Sverdrup Basin (Fig. 20) including Banks Island (Plauchut, 1971; Miall, 1975, p. 574).

Jeletzky (1971, p. 45) commented on the regional significance of nonmarine wedges of sandstone, of late Early Albian and Middle Albian age, in widespread parts of the Canadian Western Interior Basin, as responses to regional Cordilleran tectonism. Coeval, but considerably more subdued, epeirogeny may have prompted marine arenaceous deposition in parts of the Sverdrup Basin. From studies of foraminifers, W.V. Sliter (pers. com., 1977) suggested that the sandstone was deposited in relatively deep marine conditions. There are no present data to suggest where the source terrains were to provide detritus for the mid-Christopher sandstone strata.

Resumption of regional Middle Albian pelitic deposition is marked by basal beds of Christopher map unit Kcu. Middle Albian (particularly latest Middle Albian) seas penetrated wide areas of the interior part of North America (Jeletzky, 1971, p. 44). Thus, rocks comprising the upper informal Christopher member have coeval, similar pelitic facies equivalents over wide parts of the Western Interior Basin of Canada as, for example, the Horton River Formation of Anderson Plain (Yorath et al., 1975, p. 17).

Interpretation. Sandstone strata in the intercalated sandstone-pelite succession at the base of unit Kcl were formed probably by reworking of underlying Isachsen Formation deposits by shallow-marine currents during early phases of the Christopher transgression. Despite the lack of preserved macrofossils, the sandstone beds are sufficiently glauconitic and bioturbated to indicate their probable marine origin. The coarsening-upward, prominent sandstone bed at the top of the intercalated succession (Fig. 8) may be a widespread, relict sand-shoal, created by shallow-marine processes during early phases of Christopher marine transgression. Possible root traces were observed at Stratigrapher River, which may indicate local, temporary emergence of this depositional tract. Succeeding pelitic rocks of unit Kcl have abundant "polar euhedrons", and Kemper's (1975) thesis of cold-water environments for such diagenetic forms might be applied to these rocks in the same manner as to the Valanginian part of the Deer Bay Formation. Also, the paucity of macrofaunas in the interval may be indicative of relatively cold water.

Hummocky cross-stratification, of the type common in thin, glauconitic sandstone beds in part of unit Kcl, has been interpreted (Harms et al., 1975, p. 87, 88) as a product of strong wave action (possibly from storm-wave surges) in moderately shallow offshore environments. However, Sliter's (pers. com., 1976) conclusion that foraminifers from the level of the sandstones are diagnostic of relatively deep marine conditions contradicts the suggestion that the sandstones represent a phase of regional shallowing.

Pelitic rocks composing most of unit Kcu are much finer grained than pelites of unit Kcl, reflecting their relative position far from basin margins during the Middle Albian regional marine transgression. Microfaunas from this succession, however, are characteristic of inner to middle shelf environments (J.H. Wall, pers. com., 1974). Also, there are no indicators of turbidite deposition, nor of soft-sediment plastic flow. The succession, therefore, seems to have accumulated in a moderately shallow, smooth-floored basin, lacking significant bathymetric relief. As proposed for parts of the Jurassic succession, this relatively stable condition required the rate of basin subsidence to be in approximate equilibrium with amounts of pelitic influx.

Nassichuk and Roy (1975) reported two occurrences of moundlike carbonate rocks, consisting of pelecypods and ammonoids in a bioclastic limestone matrix, and with serpulid worm tubes, in about the middle of the Christopher Formation, adjacent to Hoodoo Dome, southern Ellef Ringnes Island. Comparable mounds have not been found in other outcrops of the Christopher Formation. Modern serpulid mounds commonly form in shallow, agitated, marine environments (although their distribution also ranges to the outer continental shelf). The position of the fossil mounds adjacent to Hoodoo Dome suggested to Nassichuk and Roy the important structural possibility of extremely local shallowing of the Albian sea floor above actively rising diapiric masses.

Cretaceous and older (radiometric ages)

Mafic intrusive rocks

Distribution. Coarsely to finely crystalline gabbro and other mafic intrusive masses have penetrated progressively younger rocks in the sedimentary succession from southern Cornwall Island to northern Amund Ringnes Island. They are confined to the Savik Formation and underlying rocks at southern Cornwall Island, and reach the upper part of the Hassel Formation near Cape Sverre (Fig. 8). Nearly vertical mafic dykes are particularly abundant in Triassic rocks on central Cornwall Island. The longest dyke observed is about 20 km long. None of the dykes is wider than a few metres. Sills, a few metres thick and extending over areas of at least several square kilometres, are particularly abundant in the Blaa Mountain and Deer Bay formations. Lenticular mafic intrusive sheets, inclined at low to moderate angles to bedding, are prominent in the Heiberg Formation at Mount Nicolay, in the Deer Bay and Ringnes formations near Geologist Bay, and in the Deer Bay Formation several kilometres north of Amund Ringnes Piercement Dome. The descriptive part of the structural geology section of this report includes additional comments on the geometry of the intrusive rocks.

Mafic intrusive rocks were penetrated below a depth of 790 feet (241 m) K.B. in Central Dome H-40, and below depths of 1226 feet (374 m) K.B. in East Amund I-44 (Fig. 8).

Lithology. Blackadar (1964) studied the petrography and chemistry of mafic intrusive rocks in the Queen Elizabeth Islands. In order of decreasing abundance, he classified the rocks as gabbro, olivine-bearing gabbro, quartz gabbro, olivine-bearing diorite, diorite, and quartz diorite. The intrusive rocks are dark grey-green, and coarsely to finely crystalline; they commonly have diabasic textures. Blackadar concluded that the suite of intrusive rocks in the Queen Elizabeth Islands has compositions approximating those of ideal tholeiites.

Contacts. At the surface, mafic intrusive rocks tend to form frost-shattered piles of felsenmeer, thus concealing the contacts with the sedimentary rocks. Chip samples from Central Dome H-40 and East Amund I-44 indicate that the country rocks adjacent to the intrusions are altered over widths of a few to several metres (Fig. 8). Thicknesses of the zones of alteration are in most cases proportional to the approximate thickness of the intrusive masses; also, there is a tendency for intrusions containing observable quartz (quartz gabbro and quartz diorite) to have widths of alteration greater than the intrusions lacking quartz. Pelitic country rocks are bleached and hardened to light grey pelitic hornfels, commonly with minute dark grey spots, and the arenitic rocks are cemented by quartz.

The mafic sills on Amund Ringnes and Cornwall islands are folded concordantly with enclosing sedimentary rocks. Thick, widespread intrusive sheets are folded more or less concordantly with the sedimentary rocks, although in detail the sheets are partly concordant with bedding and, in some places, cut the strata at low to moderate angles. At Structural River, some dykes appear to transect northwest-striking fold axes; almost certainly, however, the dykes are much older than the folds and have no dynamic relationship with them (see section on structural geology, interpretation).

Some gabbro masses in Amund Ringnes Piercement Dome are long and straight, parallel to the edges of the domes, and have aphanitic margins. They appear to have intruded the evaporitic rocks in the domes at a late stage of dome evolution.

Age and correlation. Dykes and sills cut rocks as young as the upper part of the Hassel Formation at Cape Sverre and, therefore, are at least as young as Late Albian or Cenomanian. Radiometric ages were obtained by whole-rock K-Ar determinations from mafic intrusive rocks at three surface localities: (1) a sill in the Blaa Mountain Formation in central Cornwall Island has yielded a radiometric age of about 118 Ma; (2) a sill in the Ringnes Formation, several kilometres south of Amund Ringnes Piercement Dome, was dated at about 144 Ma; and (3) a sample from the thick intrusive sheet in the Deer Bay Formation north of the piercement dome yielded an age of about 118 Ma. All of the determinations were made at the Department of Geology, The University of Alberta (R.St.J. Lambert, pers. com., 1975, 1977).

Mafic samples from Ellef Ringnes Island provided radiometric ages ranging from 110 to 102 Ma (Larochelle et al., 1965). Samples from dykes cutting Permian rocks on northern Grinnell Peninsula, Devon Island (Fig. 5), gave radiometric ages of about 114 and 112 Ma (J.W. Kerr, pers. com., 1976).

There are mafic intrusive and volcanic rocks on western Axel Heiberg Island up to the stratigraphic level of the lower part of the Kanguk Formation (lower Upper Cretaceous). There is no direct evidence to indicate that there are any younger mafic intrusive or volcanic rocks in the Sverdrup Basin.

Panarctic Oils Limited (D. Henao and F.G. Fox, pers. com., 1976) provided radiometric ages determined from samples of mafic rocks at the following three levels in Panarctic Amund Central Dome H-40 (Fig. 8): about 114 Ma at 6450 feet (1967 m); about 132 Ma at 6520 feet (1987 m); and about 224 Ma at 8080 feet (2464 m). (The radiometric age indicated for the latter is about the age of the Triassic-Permian time-stratigraphic boundary, which would require that the country rocks are earliest Triassic or older. However, F.G. Fox advised that, because of the very low potassium content in that sample, the age determination should not be considered especially meaningful---and in particular, not good evidence that the country rocks are older than Mesozoic.)

Interpretation. Further discussion of the mafic intrusive rocks is deferred to the structural geology part of this report, because of the importance of the mafic rocks in interpreting the style and timing of tectonism in the central part of the Sverdrup Basin.

Lower and (?)Upper Cretaceous

Hassel Formation

Nomenclature. The Hassel Formation, named by Heywood (1955, p. 61; 1957, p. 13), consists of a succession comprising brightly coloured sandstone overlying the Christopher Formation, and underlying Kanguk Formation shale, in central and eastern Ellef Ringnes Island (Fig. 5). The name was taken from nearby Hassel Sound. Rocks occupying a homotaxial position beyond the southwestern margin of Sverdrup Basin, on Banks and Eglinton islands, also have been referred to the Hassel Formation (Plauchut, 1971), but Miall (1975) suggested that those rocks should be reassigned to a new stratigraphic unit, as yet unnamed.

Distribution and thickness. Poorly cemented Hassel sandstone underlies low, hilly terrain at Slime Peninsula, and incomplete but better exposed parts of the formation are present southeast of Cape Sverre. From graphic calculations, the formation is estimated to be about 450 m thick at the former locality, but neither the base nor the top is well exposed. The section near Cape Sverre was measured using a transit and rod, and is also about 450 m thick.

Lithology. The Hassel Formation is composed almost entirely of sandstone. In the northern part of Amund Ringnes Island, a distinction can be made between a lower interval of glauconitic sandstone, probably of marine accumulation, and a much thicker succession, which is probably nonmarine. This twofold distinction is present also on Ellef Ringnes Island (Hopkins and Balkwill, 1973) and King Christian Island (Balkwill and Roy, 1977). The distinction is less obvious from the air, and almost impossible to detect on aerial photographs; it is difficult to map with confidence, and therefore no delineation between lower and upper sandstone divisions was attempted on the geological map.

The lower sandstone succession is about 50 m thick, and consists of light green-grey - weathering, very fine to medium-grained (but predominantly fine-grained), very poorly cemented, slightly feldspathic quartzose sandstone. The lower part of the succession has some very thin beds of dark grey, silty shale. The greenish coloration is imparted by finely dispersed grains of glauconite. Some beds are intricately bioturbated, but no macrofossils were observed. The rocks are very thin bedded, and partly cross-stratified as small to medium, low-angle, lenticular sets.

The remainder of the formation, which is by far the greatest part (about 400 m thick near Cape Sverre), consists of fining-upward cycles of granule lenses, coarse- to fine-grained sandstone, siltstone, and very minor amounts of carbonaceous shale and very thin beds of dull black coal. The sandstone is dominantly light grey and buff-grey, but some is orange and red-brown. The latter is characteristically well cemented by hematitic grain coatings and limonitic clay. Some sandstone beds have well developed, medium to large, high-angle, tabular cross-strata. Siltstone beds are mainly red-brown or dark grey; the reddish beds typically have lenses of coarse quartz grains and granules suspended in the silt matrix. The shale is very silty and partly carbonaceous.

Two dark brown weathering mafic volcanic flow breccias are intercalated in the middle and upper parts of the formation near Cape Sverre (Figs. 8, 21). At Cape Sverre, the flows consist of nonsorted and nonstratified, angular, polygonal blocks of aphanitic to finely crystalline, partly vesicular basalt, ranging from a few centimetres to about 1 m in diameter, enclosed in a silty, partly sandy, mudstone matrix. The matrix and adjacent Hassel wallrocks lack visible alteration effects at contacts with the blocks or with the flows as a whole, leading to the conclusion that relatively low temperatures prevailed there at the time of emplacement. Southeastward from Cape Sverre, toward the mouth of Stratigrapher River, the flows grade from this brecciated character to aphanitic, partly vesicular basalt, lacking brecciation and an intraflow pelitic matrix. As far as can be determined from the partly covered succession, the two flows maintain constant stratigraphic levels throughout the region. In a following section, the brecciated parts of the flows are interpreted as the results of phreatomagmatic extrusion.

Hassel strata at Slime Peninsula are composed dominantly of light buff and white, fine- to coarse-grained, partly carbonaceous, quartzose sandstone, which is so friable and porous that it weathers to low rolling hills of loose sand.

Figure 21. Brecciated, partly vesicular basalt flow breccia, middle part of Hassel Formation, near Cape Sverre, northern Amund Ringnes Island. GSC 199240.

There are also thin beds of chert-granule conglomerate, with rounded, grey and brown chert granules in dark red-brown, ferruginous mudstone matrix, and a few very thin beds of dark grey, carbonaceous shale. The buff and white sandstone beds are prominently cross-stratified in some places, with medium to large, high-angle, tabular sets. No fine-grained, glauconite sandstone beds comparable with the lower part of the formation at Cape Sverre were observed at Slime Peninsula, but the lower beds are poorly exposed, and it is possible that a thin interval of glauconitic sandstone may be present at the base of the formation.

Contacts. Light green-grey, fine-grained glauconitic sandstones, mapped as basal beds of the Hassel Formation, lie conformably on intercalated sandstones and dark grey, pelitic strata assigned to the uppermost beds of the Christopher Formation. The contact is fairly well exposed southeast of Cape Sverre near GSC locality C-22217. Comparable basal sandstone beds were not observed in the poor exposures at Slime Peninsula. If the succession is present there, it must be very thin; if it is absent, then light grey, probably nonmarine Hassel sandstone beds rest directly on (and perhaps truncate) upper Christopher strata, although no structural discordance was observed across the boundary. Uppermost Hassel sandstone is abruptly, but conformably overlain by dark green-grey to black, soft, Kanguk Formation shale. This contact is exposed at several localities southeast of Cape Sverre, particularly near the site of GSC locality C-22698.

Age and correlation. Macrofossils were not observed in Hassel strata on Amund Ringnes Island. Glauconitized foraminifers (*Trochamina* sp. and *Haplophragmoides* sp.) were identified by W.V. Sliter from the beds in the lower part of the formation, but they are not diagnostic of a particular Cretaceous stage.

From palynological evidence (Hopkins and Balkwill, 1973), the age of the Hassel Formation on Ellef Ringnes Island was concluded to be probably Late Albian, and possibly as young as Cenomanian. Microplankton, tentatively identified as Cenomanian, have been described from Hassel strata at Graham Island (Thorsteinsson and Tozer, 1970, p. 583).

The thin succession referred to the Hassel Formation at Banks and Eglinton islands is entirely glauconitic, and is considered to be an Upper Albian marine shoreface deposit (Miall, 1975). The lithology, stratigraphic position, and age suggest that those rocks may be lateral equivalents of the glauconitic sandstone strata forming the lower part of the Hassel Formation near Cape Sverre, and at Ellef Ringnes and King Christian islands. Miall (ibid.) suggested that the interval at Banks and Eglinton islands should be reassigned to a new, as yet unnamed stratigraphic unit, in order to emphasize its distinction from the thick, overlying, nonmarine Hassel succession in the Sverdrup Basin.

Interpretation. The lower part of the Hassel Formation at Cape Sverre is uniformly fine grained, partly bioturbated, glauconitic (partly as glauconitized foraminifers), partly cross-stratified (as low-angle sets), and lies between probable delta-front sandstones and pelites of the uppermost Christopher Formation and partly coaly, nonmarine sandstones of the upper part of the Hassel Formation. The glauconitic succession, therefore, is probably a shallow-marine shoreface deposit, which was sorted by littoral processes.

The upper, thick part of the Hassel Formation at Cape Sverre, and all or most of the strata at Slime Peninsula, contain a few thin coal beds and relatively little pelitic material. The succession at Slime Peninsula is coarser grained, with thicker granule beds, suggesting probable derivation of the succession from source terrains lying south of the region although, at present, there are insufficient paleocurrent data to support this possibility. Flat-topped, tabular cross-strata are well developed locally in the upper Hassel succession, and such characteristics in fluvial deposits, lacking significant overbank pelitic beds, are suggested to be products of braided-stream complexes (Smith, 1970). The absence or substantial thinning of the lower, glauconitic facies at Slime Peninsula probably indicates that glauconitic beds were deposited there, and later eroded by fluvial action associated with the nonmarine parts of the formation. Alternatively, it may be that the lower part of the Hassel Formation at Slime Peninsula represents relatively coarse deposits of braided distributaries, at the edge of a northward-prograding deltaic lobe, from which active marine currents moved sand to wide peripheral areas of coeval marine shoreface accumulation, such as Cape Sverre.

Palynological determinations by Hopkins (Hopkins and Balkwill, 1973) indicated that Hassel sediments were deposited during warm-temperate or possibly subtropical climatic conditions, which implies a mean annual temperature of about 16 degrees Celsius.

The mafic sheets in the Hassel Formation on northern Amund Ringnes Island are brecciated locally, partly vesicular, and concordant with bedding throughout their extent, but neither the wallrocks nor the sandy mudstone matrix of the brecciated parts of the sheets shows evidence of thermal alteration. These characteristics are in contrast to sills and dykes of the general region, and may imply that the sheets in the Hassel Formation are flows, rather than sills, and that the brecciated parts of the flows were extruded at relatively low temperatures, possibly in response to phreatomagmatic processes.

Phreatomagmatic processes, discussed by Lorenz et al. (1970), result when mafic intrusions rise to shallow stratigraphic levels and encounter water-saturated beds, thus heating pore-fluids and gradually raising the temperature of water to the vaporization point. Under these conditions, fracturing and secondary intrusion at shallow levels (or local extrusion) by water-vapour - mobilized mixtures of cooled igneous rocks and fluidized wallrocks can be achieved until the regime cools and stabilizes at the shallow source level of abnormal temperature and pressure. At Cape Sverre, conditions for such processes may have existed: pelites composing the upper part of the Christopher Formation accumulated rapidly (Fig. 16), and relatively high pore-fluid pressures probably were maintained during early stages of burial. Feeder dykes for basalt flows reaching upper parts of the Christopher Formation may have raised fluid temperatures to critical levels; where overburden pressures were relatively low, fluidized mixtures of cooled basalt, Christopher pelites, and Hassel sands might have penetrated to the surface of Hassel sand accretion and there spread laterally as local flows. Two brecciated mafic sheets, similar to those at Cape Sverre, are present in the Hassel Formation at Haakon Fiord, eastern Ellef Ringnes Island, and there is a single sheet in the Isachsen Formation, several kilometres east of the head of Strand Fiord, Axel Heiberg Island (Fig. 5).

Upper Cretaceous

Kanguk Formation

Nomenclature. This formation was named by Souther (1963, p. 442), who designated the type locality as Kanguk Peninsula, western Axel Heiberg Island (Fig. 5). In ascending order, the succession of Upper Cretaceous rocks in that region is as follows (Fig. 22): quartzose sandstone of the Hassel Formation; black shale; basaltic lavas of the Strand Fiord Volcanic Formation; dark grey and black shale; olive-grey siltstone and shale; and the uppermost beds, light-coloured sandstone of the Eureka Sound Formation. Souther assigned the black shale between Hassel sandstone and Strand Fiord Volcanics to the upper part of the Hassel Formation, and defined the Kanguk Formation as shale resting between Strand Fiord Volcanics and Eureka Sound sandstone. Fricker (1963) proposed the term Bastion Ridge Formation for the interval of shale between the Hassel sandstone and Strand Fiord Volcanics, and also recognized an informal lower shale member and upper siltstone member within the Kanguk Formation. Thorsteinsson (1971b) applied the term Kanguk Group to the Upper Cretaceous pelitic and volcanic succession, composed of the Bastion Ridge, Strand Fiord and Kanguk formations. However, Strand Fiord Volcanics are restricted to western Axel Heiberg Island, as also, by Fricker's definition, is the Bastion Ridge Formation. Internal Kanguk divisions, similar to those recognized by Fricker, are present also on Ellef Ringnes Island (Balkwill and Hopkins, 1976). There are reasons, presented in a following section on age and correlation, for suggesting that lower parts of the Kanguk Formation on Amund Ringnes (and Ellef Ringnes) Island are correlative with the Bastion Ridge Formation.

No mappable boundaries could be delineated within the Kanguk Formation on Amund Ringnes Island; the succession mapped as the Kanguk Formation includes all strata between the Hassel and Eureka Sound formations.

Distribution and thickness. There are good exposures of the lower 210 m of the Kanguk Formation near Cape Sverre; upper beds of the formation at this locality are concealed by Quaternary marine mud. The succession at Slime Peninsula probably represents the complete formation, but the rocks are very poorly exposed because of a widespread veneer of Quaternary alluvium and marine mud. From graphical calculations, the formation is estimated to be about 300 m thick in that region.

LITHOLOGY	SOUTHER (1963)	FRICKER (1963)	THORSTEINSSON AND TOZER (1970)	THORSTEINSSON (1971b)
Sandstone, siltstone, shale	*EUREKA SOUND FORMATION*	*EUREKA SOUND FORMATION*	*EUREKA SOUND FORMATION*	*EUREKA SOUND FORMATION*
Siltstone and shale	*KANGUK FORMATION*	*KANGUK FM* "upper member"	*KANGUK FORMATION*	*KANGUK GROUP*: *KANGUK FORMATION*
Shale		*KANGUK FM* "lower member"		
Basalt	*STRAND FIORD FORMATION*	*STRAND FIORD FORMATION*	*STRAND FIORD FORMATION*	*KANGUK GROUP*: *STRAND FIORD FORMATION*
Shale	*HASSEL FM* "upper member"	*BASTION RIDGE FORMATION*	*BASTION RIDGE FORMATION*	*KANGUK GROUP*: *BASTION RIDGE FORMATION*
Sandstone	*HASSEL FM* "lower member"	*HASSEL FM*	*HASSEL FM*	*HASSEL FM*

GSC

Figure 22. History of Upper Cretaceous stratigraphic nomenclature, Strand Fiord, Axel Heiberg Island.

Lithology. Kanguk strata on northeastern Amund Ringnes Island are mainly dark green-grey to black, slightly silty, poorly indurated, papery shale, with abundant parallel, very thin beds of yellowish grey, soft, plastic, jarositic clay. The light-coloured, jarositic clay beds, intercalated with dark grey shale, lend a distinctively banded aspect to many outcrops. An interval about 15 m thick, consisting of abundantly fossiliferous, medium green-grey, glauconitic siltstone and very fine grained sandstone, lies about 45 to 60 m above the base of the formation. Macrofossils in the sandstone include well preserved pelecypods, gastropods, ammonites, and fragments of silicified wood with cylindrical pholadlike borings, as well as thin, partly phosphatic beds containing bone fragments, teeth and scales of fish (GSC locs. C-22215, C-22698). The general northeastward dip of the strata is interrupted by intricate flexure-flow folds with varying amplitudes, all of which are too small to depict on the geological map; the folds are consistently asymmetric to the northeast, with axial planes that dip moderately southwestward.

Kanguk shale is extremely acidic. The pH values (in aqueous suspension) of 15 surface samples from Amund Ringnes and Ellef Ringnes islands, determined by A.E. Foscolos, ranged from 2.65 to 5.10 with a mean average of 3.40. (It is not surprising, therefore, that the Kanguk Formation supports almost no plant life, whereas the less acidic Christopher Formation and older shales support some plant growth.)

Kanguk shales at Slime Peninsula are poorly indurated, dark grey, slightly silty and papery, and the lower strata, especially, have the characteristic colour bands imparted by some very thin parallel beds of yellowish grey jarositic clay. The beds dip westward toward Fog Bay and lack the intricate flexurel-flow folds that are present in the rocks at Cape Sverre.

X-ray mineralogical analyses of some Kanguk Formation samples are presented in Table 2.

Contacts. Basal Kanguk pelites lie abruptly and conformably on Hassel Formation sandstone near Cape Sverre and at Slime Peninsula.

Kanguk shale at Cape Sverre is overlapped by recent marine mud. At Slime Peninsula, the formation appears to be overlain comformably by sandstone assigned to the Eureka Sound Formation, although the contact is so poorly exposed that the relationships could not be observed clearly.

Age and correlation. Macrofossil collections from GSC localities C-22215 and C-22698, which are at and slightly below the level of glauconitic sandstone, are particularly interesting. Jeletzky's report stated: "The well preserved and diagnostic fossils in lot C-22700 permit its unreserved early Turonian dating (i. e. , ***Watinoceras*** and ***Inoceramus labiatus*** Zone; see Jeletzky, 1968, p. 27, 28; 1971, p. 51, 52)." He stated further: "The lot C-22698 can be placed further in the upper part (subzone) of the interregional *Watinoceras* and *Inoceramus labiatus* Zone characterized by ***Watinoceras reesidei*** and ***Scaphites delicatulus***.... In Arctic Canada this zone was reported: 1) From the middle part of the Slater River Formation (about 1100 ft above the base according to Dr. C.R. Stelck, pers. com.) of the Mackenzie River Valley....2) From unnamed Cretaceous rocks (Favel Formation facies) of Lac des Bois, District of Mackenzie, N.W.T. .... and 3) From the rust-weathering member of the Upper Cretaceous shale division in northeastern Richardson Mountains (see Jeletzky, 1959, p. 22)." And in summation, Jeletzky reported: "This is the first record of marine lower Turonian rocks from the Canadian Arctic Achipelago in general and the Sverdrup Basin in particular. It permits emendation of Jeletzky's (1971, p. 52, Fig. 12) latest paleogeographical interpretation of the early Turonian history of this area which reflected the hitherto complete lack of any positive data." It is clear from the foregoing that the lower part of the Kanguk Formation at Cape Sverre is coeval with widely distributed strata in the northern part of the Canadian mainland.

Comparison of Kanguk stratigraphy on Ellef Ringnes Island (Balkwill and Hopkins, 1976) with rock units on western Axel Heiberg Island provides further information for regional correlation of the Kanguk Formation (Fig. 22). On Ellef Ringnes Island, the Kanguk pelite succession can be divided into two mappable assemblages: a lower succession of black, slightly silty shale, with abundant very thin jarositic clay beds (which locally have oxidized and imparted brick-red colours to some shales in the lower part of the succession); and an upper pelite succession, which is very silty, contains abundant small ironstone nodules, has significantly fewer jarositic clay beds, and the basal beds of which carry late early or early late Santonian macrofossils (Balkwill and Hopkins, ibid.). Santonian or early, early Campanian macrofossils, collected by the writer and identified by J.A. Jeletzky, were collected from beds slightly higher in the Kanguk succession on Ellef Ringnes Island; and well exposed shale at the top of the formation there contains palynomorphs that are likely Campanian or possibly Maastrichtian (W.S. Hopkins, pers. com., 1976). Fricker (1963, p. 119) recognized two informal Kanguk members on western Axel Heiberg Island: a lower member, composed mainly of dark grey shale, and containing no diagnostic macrofossils; and an upper member, dominated by light olive-grey siltstone, containing Santonian and Campanian *Inoceramus* species. Comparison of the descriptions of Fricker's intraformational Kanguk divisions, and their stratigraphic positions, suggests that the Bastion Ridge Formation and Fricker's "lower Kanguk member" are correlative with the black shale forming lower Kanguk strata at Ellef Ringnes Island, and that Fricker's "upper siltstone member" is equivalent approximately to the silty shale forming the upper part of the Kanguk Formation on Ellef Ringnes Island.

Cenomanian Kanguk strata have been reported from Graham Island (Fig. 5; Thorsteinsson and Tozer, 1970, p. 583). Considering that the early Turonian macrofaunas at Cape Sverre were collected about 45 m above the base of the formation, some part of the beds below the Turonian faunas might be Cenomanian. The incompletely exposed succession at Cape Sverre lacks any of the attributes of the upper part of the Kanguk Formation on Ellef Ringnes Island. If it is entirely "lower Kanguk", then it may range from Cenomanian to lower Santonian. The presence of glauconitic, partly phosphatic rocks in the lower part of the succession may represent subdued rates of accumulation and possibly an intraformational hiatus. The Kanguk succession at Slime Peninsula may range from Cenomanian to Maastrichtian.

Microfaunal studies of the Kanguk Formation do not improve the foregoing age estimates. Kanguk surface samples generally are barren of calcareous foraminifers, probably because they were dissolved in the very acidic Kanguk strata, and the remaining siliceous agglutinated foraminifers and simple radiolarians are not diagnostic of particular stages (J.H. Wall, pers. com., 1976).

Interpretation. The foregoing paragraphs cite evidence indicating that the Kanguk Formation can be divided over wide areas into a lower, possibly Cenomanian to lower Santonian shale assemblage, and an upper, Santonian to possibly Maastrichtian siltstone assemblage. Regional volcanism, perhaps partly related to events at Strand Fiord, had a profound influence on the lithology of lower Kanguk shale, by contributing the distinctive ash-derived clays of the succession and by imparting its extreme acidity and high iron content. Preservation of the very thin tuffaceous clay beds implies that low-energy conditions of accumulation prevailed until late early or early late Santonian.

If the siliceous microfaunal assemblages recovered from surface samples are truly representative of the biocoenose, a possible deep, cool marine environment is indicated for the lower Kanguk strata; but there is a strong possibility that calcareous foraminifers were leached in the acidic Kanguk strata and that the siliceous faunas are not representative of the original microfaunal content (J.H. Wall, pers. com., 1975). Furthermore, glauconitic, fossiliferous thin sandstone strata in the lower Kanguk at Cape Sverre have lithologies and fabrics suggesting that they, like the mid-Christopher sandstone, are products of sand accumulation on storm-wave - agitated offshore tracts during a phase of basin shallowing.

Silt-dominated Santonian rocks at the base of the upper part of the Kanguk Formation are local representatives of a phase of widespread marine transgression toward the craton in Arctic and western Canada (see Jeletzky, 1971, p. 54 - 60). Jeletzky (op. cit., p. 60, Fig. 15) emphasized that the Upper Cretaceous marine rocks in the Arctic Archipelago probably accumulated in an arcuate, northward-facing seaway that connected the Canadian Western Interior Basin with ancestral Baffin Bay and western Greenland. This transgression was not accompanied by noticeable marine deepening of central Sverdrup Basin, because upper parts of the Kanguk Formation contain microfaunas suggestive of accumulation in shallow-marine environments (J.H. Wall, pers. com., 1975).

Eureka Sound Formation

Nomenclature. Troelsen (1950, p. 78) introduced the name Eureka Sound Formation for coaly sandstone in the general region of Eureka Sound, Ellesmere Island (Fig. 5), but did not designate a type section. From fossil evidence (obtained by himself and others), he concluded that the Eureka Sound rocks there could be either Cretaceous or Tertiary. Some rocks that he considered part of the Eureka Sound Group are in fact Cretaceous, but are remnants of the Hassel and Isachsen formations, and not of the Eureka Sound Group. Furthermore, he concluded that Eureka Sound sediments were deposited after Mesozoic and older rocks of the region underwent regional tectonism (now referred to as the Eurekan Orogeny; Thorsteinsson and Tozer, 1970, p. 585). This conclusion was prompted because he included within the Eureka Sound Formation some rocks that are known now to be younger than any part of the succession folded during the compressional phase of the Eurekan Orogeny (Balkwill and Bustin, 1975).

Tozer (1963b, p. 29) renamed the unit the Eureka Sound Formation because Troelsen's Eureka Sound Group had not been divided into formations, and regarded outcrops on Fosheim Peninsula, Ellesmere Island, as typical. [Earlier, Thorsteinsson and Tozer (1957) had corrected Troelsen's observations on the structural relationships of the Eureka Sound Formation, ascertaining that all strata properly assigned to the formation in the region of Eureka Sound were folded more or less concordantly with older rocks.] In the same publication, Souther (1963, p. 444, 445) designated a type section of the Eureka Sound Formation at Strand Fiord, Axel Heiberg Island. E.T. Tozer (pers. com., 1976) advised the writer: "Designation of a type section for the Eureka Sound Formation at Strand Fiord, Axel Heiberg Island, by Souther, was not intentional. In his original manuscript, Souther assigned the rocks at this locality to a new formation, with a designated type section. Later it was decided to assign the beds in question to the Eureka Sound Formation but inadvertently the text was not wholly modified to accommodate the change and the reference to the type section remained."

As mapping in the Arctic Archipelago progressed, the name Eureka Sound Formation came to be applied to rocks that range lithologically from coaly, nonmarine sandstone to marine shale that range in age from late Campanian to Eocene. They occur in such widely distributed and tectonically diverse settings as the Eurekan Fold Belt of eastern Sverdrup Basin (Thorsteinsson and Tozer, 1970), in small grabens superimposed on Paleozoic folds of the Franklinian miogeosyncline (Fig. 1) (Kerr, 1974), and as part of the Cenozoic continental terrace wedge beneath the Arctic Coastal Plain (Miall, 1975).

Neglecting the Arctic Coastal Plain, which is not of direct concern for this paper, two principal categories of strata have been assigned to the Eureka Sound Formation within and adjacent to Sverdrup Basin: nonmarine and marine sandstone lying mainly in the central part of Sverdrup Basin [including the type regions of Tozer (1963b) and Souther (1963)] where basal Eureka Sound beds conformably overlie Kanguk pelite and contain late Campanian to Maastrichtian palynomorphs; and mainly nonmarine sandstone, with some pelite, containing Paleocene and Eocene microfloras in the basal beds, and which almost everywhere lie with obvious disconformity on Mesozoic and older rocks within and beyond the margins of Sverdrup Basin.

Clearly, the uppermost Cretaceous and Tertiary nomenclature should be revised, in order to distinguish these categories of rocks and to emphasize their relationships in the late Mesozoic and Cenozoic development of the Archipelago; formal revision, however, should be based on more complete regional data than are now available. In this paper, the term Eureka Sound Formation is applied to sandstone at Slime Peninsula that lies conformably (and apparently gradationally) above Kanguk Formation shale. Arenites in south-central Amund Ringnes Island, and on Cornwall Island, lying unconformably on Lower Cretaceous and Triassic rocks, are referred to informally as "unnamed Tertiary sandstones".

Distribution and thickness. Seaward-dipping, poorly exposed, Upper Cretaceous Eureka Sound arenites (map unit Ke) are the youngest strata along the southwestern coast of Amund Ringnes Island at Slime Peninsula. The approximate thickness of this incomplete section, based on regional dip and outcrop width, is about 300 m.

Lithology. Eureka Sound strata at Slime Peninsula consist mainly of buff-grey and yellow-grey, fine- to medium-grained, parallel-bedded (very thin and thin beds), partly shaly, quartzose sandstone. Shaly siltstone beds constitute about one third of the lower part of the succession, where they form intervals as thick as a few metres. The pelite beds are thinner and less abundant upward. The upper parts of the succession contain some lignitic carbonaceous partings and poorly preserved, carbonized root traces, but no coal beds were observed.

Contacts. Basal Eureka Sound beds (map unit Ke) dip westward at low angles (about 5°) and seem to be concordant with upper Kanguk shale strata, although exposures are poor throughout much of low-lying Slime Peninsula, and the contact between the two formations is not observable directly.

Age and correlation. Samples of carbonaceous shale, collected from GSC locality C-21794, about 210 m above the base of the Eureka Sound Formation (map unit Ke) at Slime Peninsula, yielded palynomorphs, which W.S. Hopkins (pers. com., 1976) considers early Maastrichtian or possibly late Campanian.

Samples were collected by Hopkins, K.J. Roy, and the writer in other places within the Sverdrup Basin where the Eureka Sound Formation lies conformably on upper Kanguk shale as, for example, in central and southern Ellef Ringnes Island (see Stott, 1969) and at Strand Fiord, Axel Heiberg Island (see Souther, 1963, p. 444). From palynological studies, Hopkins (pers. com., 1974, 1975, 1976) concluded that basal Eureka Sound beds at those sections (and in some places at most or all other sections) are Upper Cretaceous. [For example, the top of the 700 m thick Eureka Sound section at Malloch Dome, Ellef Ringnes Island (Fig. 5), is believed by Hopkins to be not younger than middle Maastrichtian.] If the foregoing relationships indicate the general condition, then it might be predicted that Eureka Sound beds lying conformably on Kanguk shales in such places as Lougheed Island and Sabine Peninsula, Melville Island (see Tozer and Thorsteinsson, 1964) are probably Upper Cretaceous, and not Tertiary as has been generally supposed (Thorsteinsson and Tozer, 1970, p. 584; Plauchut, 1971).

Nonmarine sandstone and pelite, containing Maastrichtian palynomorphs, lie on deeply eroded Mesozoic strata along the uplifted northern rim of Sverdrup Basin in the subsurface beneath the Arctic Coastal Plain (Fig. 1) (Meneley et al., 1975, p. 539). The unconformity beneath the Maastrichtian beds, which are slightly younger than the Eureka Sound strata at Slime Peninsula (W.S. Hopkins, pers. com., 1976), represents uplift and erosion of at least 2400 m of middle and upper Mesozoic strata before Maastrichtian deposition.

Thin intercalations of marine and nonmarine Maastrichtian strata are present as isolated remnants on the Arctic Platform at Somerset Island (Hopkins, 1971), Bathurst Island (Kerr, 1974, p. 62 - 64); and Devon Island (Fortier, 1963b, p. 219). The age of those beds is about the same, or slightly younger than the basal Eureka Sound strata at Slime Peninsula and other places in central Sverdrup Basin where the formation lies conformably on Kanguk shale (Hopkins, pers. com., 1976).

Interpretation. The facies and structural disposition of uppermost Cretaceous and lower Tertiary rocks (i. e. rocks included in broad usage of the name Eureka Sound Formation) provide a valuable basis for dating and interpreting tectonic events in the Canadian Arctic Archipelago.

Upper Campanian or lower Maastrichtian strata at Slime Peninsula (here assigned to the Eureka Sound Formation: map unit Ke) conformably overlie Campanian Kanguk Formation marine shale, and with coeval Eureka Sound beds on nearby islands mark initiation of latest Cretaceous marine regression. The strata are so poorly exposed that meaningful interpretations of their depositional environment are nearly impossible, although the intercalated sandstone and pelite in the lower part of the succession may be proximal delta-front deposits (as they seem to be at Hoodoo Dome, southeastern Ellef Ringnes Island; Balkwill and Hopkins, 1976), and the partly root-bearing sandstone in the upper part of the succession may be delta-plain facies. The lack of conspicuous fining-upward cycles and apparent absence of coal beds suggest that the delta plain consisted of braided distributaries with small flood-basin marshes.

The unconformity along the northern rim of Sverdrup Basin requires that there must have been great uplift and stripping along a northeastward-trending linear belt of Mesozoic sandstone and shale, before deposition of the Maastrichtian beds there. Campanian Kanguk Formation shale on Ellef Ringnes Island is not very sandy, indicating that it is unlikely that Late Cretaceous uplift of the northern rim of the basin began before Campanian time. Most of the detritus generated from erosion along the uplift was probably shed northward across the site of the modern continental shelf. But since uplifts cannot be one-sided, it is likely, therefore, that some clastic detritus was shed southward toward the site of the Mesozoic depocentre of the Sverdrup Basin. The upper Campanian and lower Maastrichtian strata at Slime Peninsula, and in other structurally low parts of the central Sverdrup Basin, therefore, may be remnants of detritus shed during late Campanian - early Maastrichtian uplift along the northern rim of the basin, and transported southward toward the narrow Boreal seaway that then connected the West Greenland and Arctic basins (see Jeletzky, 1971, p. 73 - 75). The northern rim of the basin sagged or subsided soon after, and received upper Maastrichtian and lower Tertiary clasts.

Whether or not the foregoing suggestion is partly or entirely tenable, it is clear that sediments forming the thick wedge of uppermost Cretaceous and Tertiary strata that now lie on the subsided site of the Late Cretaceous uplifted rim of the basin were directed northward to the continental shelf. Relationships on Amund Ringnes and Cornwall islands indicate that this area was one of the probable major uplifted source regions for uppermost Cretaceous - lower Tertiary detritus: small remnants of upper Paleocene or lower Eocene sands (map unit Tpe) lie along the crest of Cornwall Arch, on folded and deeply eroded Mesozoic rocks (see following section entitled Unnamed Paleocene-Eocene Sandstones); their deposition postdates uplift of the arch and erosion of its crest, at some time after deposition of the structurally conformable Eureka Sound beds at Slime Peninsula, and before late Paleocene. Broadly contemporaneous uplift of a comparably styled region of Axel Heiberg Island also can be demonstrated (Balkwill et al., 1975). The thick wedge of uppermost Cretaceous and lower Tertiary rocks beneath the Arctic Coastal Plain, therefore, is probably a depositional product of latest Maastrichtian - early Tertiary internal uplift of broad structural arches within Sverdrup Basin.

Tertiary

Unnamed Paleocene-Eocene sandstones

Nomenclature. Small erosional remnants of carbonaceous sandstone lie unconformably on Lower Cretaceous and Triassic strata in south-central Amund Ringnes Island and in central Cornwall Island. The outliers contain palynomorphs considered by W.S. Hopkins (pers. com., 1972, 1973) to be late Paleocene to possibly middle Eocene in age. The sandstone is the product of a depositional event that had no obvious continuity with deposition of the strata at Slime Peninsula, assigned in the foregoing section to the Eureka Sound Formation. To avoid further confusion in the application and meaning of the name Eureka Sound Formation, the outliers are informally referred to here as unnamed Paleocene-Eocene sandstone, and are indicated on the geological maps by the symbol Tpe.

Distribution and thickness. Paleocene-Eocene weakly cemented to uncemented sandstone forms small erosional remnants in at least four places: as a sinuous, partly dissected band of poor exposures, no more than 10 m thick, in south-central Amund Ringnes Island; and three weakly indurated, partly slumped outliers of sandstone in central Cornwall Island, which are conspicuously yellow-buff weathering in contrast to the dark grey Triassic strata on which they rest disconformably. At the largest of these outliers (site of GSC loc. C-19605), the Tertiary sands may be as much as 20 m thick.

Lithology. Sandstone strata comprising erosional outliers mapped as unit Tpe are distinctively yellow-buff, fine to medium grained, abundantly carbonaceous (as carbonaceous hash on parting surfaces), and have small to medium trough cross-strata. Beds adjacent to stream cutbanks are partly disrupted by recent slumping, so it is difficult to obtain an impression of vertical changes in the lithology of the succession. Foresets of cross-strata in central Cornwall Island face mainly westward and northwestward.

Contacts. There are abrupt unconformities and great hiatuses between sandstones of map unit Tpe and underlying strata in the central part of Cornwall Island and south-central Amund Ringnes Island. At the former, the brightly coloured lower Tertiary beds rest on gently dipping, dark grey Triassic pelitic strata, assigned here to the Blaa Mountain Formation; and, at the former, the sinuous patch of Tertiary beds straddles the southward-dipping contact between the Deer Bay and Isachsen formations.

Those structural relationships contrast with the contacts at Slime Peninsula, where Eureka Sound (Ke) beds lie conformably on underlying Kanguk strata, providing clear evidence for Late Cretaceous - early Tertiary uplift and erosion of the northward-plunging regional arch that extends through Cornwall and Amund Ringnes islands. This topic is expanded in a following section on structural geology.

Age and correlation. Samples from central Cornwall Island and south-central Amund Ringnes Island (GSC locs. C-19605, C-19606, C-19608) contain palynomorphs assigned a late Paleocene to middle Eocene age by Hopkins (pers. com., 1972, 1973). Paleocene-Eocene strata are distributed widely in the eastern part of Sverdrup Basin and beyond the basin boundaries. The succession of Eureka Sound strata, about 3000 m thick, at Tozer's type area (Fig. 1) is mainly lower Tertiary (although the basal beds are Maastrichtian), as are successions on eastern Axel Heiberg Island (Balkwill et al., 1975), southern Ellesmere Island (West et al., 1975), and a large part of the continental terrace wedge beneath the Arctic Coastal Plain (Miall, 1975).

Interpretation. Outcrops of Paleocene-Eocene beds (map unit Tpe) are small and poorly exposed. Some high-angle tabular cross-strata are preserved at the locality near the head of Jaeger River; they face westward and northwestward, possibly indicating local transport in those directions. The sinuous pattern of partly dissected Tertiary deposits in south-central Amund Ringnes Island resembles a relict stream channel incised in underlying Mesozoic strata, but the contacts cannot be observed clearly enough to provide supporting evidence for this speculation. According to Miall (1975), marine conditions prevailed on the continental shelf at Banks Island well into Eocene time. If similar conditions held for the continental shelf adjoining the northern rim of Sverdrup Basin, then fluvial channels crossing Cornwall and Amund Ringnes islands may have been part of the tributary network that supplied Paleocene and Eocene clastic detritus to the continental terrace wedge.

The most significant contribution of the contrasting structural relationships of map units Ke and Tpe is in bracketing the time of uplift and erosion of the northward-plunging Cornwall Arch. Upper Campanian or lower Maastrichtian fine-grained arenaceous and pelitic strata (Ke) lie conformably on Campanian Kanguk shale, and their deposition thus predates uplift of the Arch; but the Paleocene-Eocene sands (Tpe) lie along the crest of the Arch on folded Lower Cretaceous and Triassic rocks, and they thus postdate the uplift. The hiatus below Tertiary rocks represents latest Cretaceous and early Paleocene uplift and erosion of at least 3600 m at south-central Amund Ringnes Island and central Cornwall Island (Fig. 4, Secs. A-B, E-F).

Quaternary

Glacial-fluvial gravel

Distribution and thickness. Low rounded hills and ridges of nonstratified to crudely stratified gravel, interpreted as glacial-fluvial deposits (Balkwill et al., 1974), are present in several widely separated localities on Amund Ringnes and Cornwall islands (Fig. 2). There are sinuous low ridges, several metres high, near Geologist Bay, and a few kilometres west of Structural River, and a partly dissected ridge, about 15 km long, near the western flank of Amund Ringnes Piercement Dome. A cluster of small, rounded to conical hills, a few metres high and a few tens of metres wide, lies about 25 km southeast of Cape Sverre, and a rounded hill crests the 131 m high peak near Cape Ludwig.

Lithology. The gravels in the sinuous ridges and rounded hills are nonstratified to crudely stratified and consist of boulders and cobbles of varied size and lithology (mainly buff, grey, and pink quartzite, but also relatively abundant limestone and gabbro, and a few clasts of gneissic rocks and pink granite) embedded in a noncemented silty sand matrix. The largest observed boulders are about 0.5 m long. Some of the clasts are angular. Sand and finer grained parts of the matrix have been winnowed from the surface of the deposits so that there is a lag veneer of large clasts, which protects the noncemented deposits from significant erosion. The relative abundance of mafic igneous clasts in this lag veneer imparts a dark tone on aerial photographs which, combined with the linearity of the ridges, causes them to resemble gabbro dykes.

Correlation and interpretation. Sand and gravel deposits, similar in lithology to those on Amund Ringnes and Cornwall islands, are scattered widely on nearby Ellef Ringnes Island, where St-Onge (1961) identified some of the ridges as eskers. However, St-Onge (1965) also suggested that some of the gravel hills on Ellef Ringnes Island are erosional remnants of the Beaufort Formation, a partly conglomeratic Neogene formation that blankets the Arctic Coastal Plain (Fig. 1; Tozer, 1956, 1970; Hills and Fyles, 1973). Stott (1969, p. 29, 30) pointed out that the bouldery gravels on Ellef Ringnes Island look unlike the more regularly stratified, finer grained Beaufort strata on northern Ellef Ringnes Island and, further, that in at least one place the bouldery gravels rest on Beaufort sands. He concluded from these observations that the boulder gravels are probably Pleistocene glacial-fluvial deposits.

The presence of striated cobbles in the gravels on Amund Ringnes Island, as well as grooves and striations in bedrock, and widely scattered isolated erratics supports Stott's interpretation of a glacial-fluvial origin for the polymict gravels. Similar small gravel hills are present also on King Christian Island (Balkwill and Roy, 1977).

Blake (1970) concluded that the Queen Elizabeth Islands were covered by a late Pleistocene ice sheet, which he named the Innuitian Ice Sheet. He inferred that the ice sheet was centred across a broad belt through Bathurst Island, northwestern Devon Island, and south-central Ellesmere Island, and from there the ice flowed northwestward across Cornwall Island and the Ringnes islands. All of the crystalline terrains, from which granite and gneissic clasts in the gravels might have been derived, lie in regions south of Blake's inferred spreading axis for the Innuitian Ice Sheet. Therefore, the clasts may have been relocated during Innuitian ice movement, but their original northward transport to the region must have occurred during an earlier phase of glaciation, when the ice-spreading axis was centred on the Precambrian Shield.

The gravel ridges and hills are the only vestiges of glacially constructed morphology. The absence of tills seems surprising, in view of the probable susceptibility of the poorly indurated Mesozoic bedrocks to erosion by ice.

Marine deposits

Distribution and thickness. Nonindurated sand and mud form a veneer on bedrock over wide parts of the lowland plains of Amund Ringnes and Cornwall islands. The largest areas covered by these deposits are east from Fog Bay along the southern coast of Amund Ringnes Island, and along the eastern coast of Cornwall Island. Marine deposits on the lowland plains are less than 30 m above sea level and in most places are at general elevations of about 10 m or less above sea level. Thickness of the deposits is difficult to observe at most places but probably is less than a few metres. For example, marine mud covering Christopher shale near Gordon Head (eastern Cornwall Island) is about 2 m thick. Systems of subparallel beach ridges, about 0.5 m high, are abundant at Fog Bay and west of McLeod Head.

Marine mud along the northeastern coast of Amund Ringnes Island is at least several metres thick, and lies at elevations as high as 90 m above sea level.

Lithology. Materials composing marine deposits on the lowland plains are directly related to the lithology of underlying bedrock. Areas blanketed by sand, and having well developed beach ridges, are mainly underlain by sandstone bedrock, such as the Heiberg, Isachsen, Hassel or Eureka Sound formations. Sand-dominated deposits are buff-grey, fine to coarse grained, and parallel bedded. The mud is dark grey, reflecting its derivation from the dark grey Mesozoic pelite; it is partly sandy and contains marine pelecypod shells.

Marine deposits at Cape Sverre and vicinity are nonindurated, poorly stratified, and consist of dark grey, sandy mud, with some cobble-size clasts and a few pelecypod shells. The deposits form a northward- and eastward-dipping veneer, several metres thick, plastered on bedrock; in contrast to the deposits on the lowland plain, the materials at Cape Sverre seem to have little direct relationship to the underlying bedrock.

Interpretation. The rather close relationship of lithology to underlying bedrock type indicates that the marine deposits on the lowland plains were eroded from the poorly cemented bedrock and deposited nearby. Islands and other irregularities in the modern coastline are emerged topographic undulations from the former shallow submarine surface and are not constructional features of modern coastal processes; the only recent constructional forms are the low beach ridges.

The setting and lithology of deposits at Cape Sverre demand that they have a more complicated origin than materials on the low coastal plains. The former are at elevations of about 90 m, appear not to be directly related to immediately underlying bedrock, and contain random coarse clasts in a mud matrix. Marine shells were collected at an elevation of about 95 m near Mount Nicolay, proving that the region was formerly submerged at least to that level. The deposits at Cape Sverre are possibly relicts of that level of regional submergence.

Cores from modern offshore regions, such as Massey Sound, are predominantly clay and silt, whereas modern coastal sediments near the Ringnes islands are mainly sand and silt (Horn, 1963). By analogy, the marine sediments at Cape Sverre might be deposits of former offshore submarine tracts. Cobbles in the muddy sediments could have been ice-rafted and dropped in the offshore muds.

Alluvium

Distribution and thickness. Recent alluvium, consisting of uncompacted mixtures of sand, silt and clay, is delineated on the geological map in those places where it completely obscures bedrock. The alluvial deposits are mostly small lobate fan deltas, along the coastal edges, from where they extend inland as narrow floodplains. Streams have been superimposed by recent erosion to adjustment with present sea level; thus the alluvial deposits form only a thin veneer, probably less than a few metres thick, on the laterally planed bedrock valley floors.

Lithology. Sediments composing floodplain deposits and associated fans are related directly to the bedrock through which the short consequent streams are cut. Streams cutting across sandstone-dominated terrains have mainly sandy floodplains and associated deltas; and those cutting across pelitic rocks have muddy floodplains and deltas. (Because the deposits are poorly compacted and are commonly thixotropic during runoff, the latter are particularly treacherous areas to traverse.)

Stratigraphic summary

The foregoing descriptions and interpretations of the lithologic column on Amund Ringnes and Cornwall islands prompt the following generalizations regarding the stratigraphic style of Mesozoic rocks in the south-central part of Sverdrup Basin.

Approximate mean rates of accumulation for rock-stratigraphic units in central Amund Ringnes Island are depicted in Figure 16. (Very thin marker intervals, such as unit JKdD are omitted.) The rates indicated for nonmarine formations are considerably more tenuous than for the marine units, because of the lack of biostratigraphic control in the former. (For example, if there are substantial hiatuses in the Isachsen Formation, the rate of accumulation for the real time represented by the strata would be considerably greater than is shown.) The fastest rate of accumulation in the column is indicated for Albian silty shale comprising the upper part of the Christopher Formation. The upper beds of that succession are interpreted as prodelta and delta-front facies that were deposited in advance of prograding Hassel Formation fluvial systems. In a similar fashion, the delta-front sandstone and pelite composing the Lower Heiberg Member accumulated at a much faster than normal rate, in advance of Upper Heiberg alluvial progradation. Extremely subdued rates of accumulation are indicated for Pliensbachian to Lower Volgian strata, and for the lower Upper Cretaceous part of the Kanguk Formation. Rapid acceleration of rates of accumulation is indicated for the Norian and Aptian-Albian stages, and also for the Valanginian Stage---provided there is a Berriasian hiatus, as is suggested by regional stratigraphic evidence. The Volgian and Aptian-Albian accelerations are broadly contemporaneous with groupings of radiometric ages obtained from mafic intrusive rocks. Possible associations of phases of mafic intrusion and accelerated basin subsidence and sediment accumulation are proposed in the section on structural geology.

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Some formations are thinned because of erosional truncation from western Cornwall Island to eastern Cornwall Island. The name Cornwall Island hinge is applied here to the recurrently active, stratigraphic-?tectonic element that produced this thinning.

Some relatively thin sandstone units on Cornwall Island grade northward to appreciably thicker marine pelite on Amund Ringnes Island.

Strata interpreted as alluvial plain and subaerial delta deposits lack significantly thick pelitic intercalations (except for the middle part of the Isachsen Formation). The sedimentary fabric of those strata indicates that deposition may have been shaped dominantly by large braided river systems.

Arenites in the succession are mineralogically mature, and contain only chert as significant lithic clasts. Source rocks for the sands (possibly excluding the Eureka Sound Formation) were likely mature terrains such as the Paleozoic and Proterozoic strata of the Arctic Platform (Fig. 1), where erosional remnants of formerly widespread formations remain. Additional mineralogical maturation of the detritus probably took place with successive phases of weathering and erosional cannibalization accompanying northward transport. Structural-stratigraphic relationships along the northwestern rim of Sverdrup Basin suggest that upper Campanian or lower Maastrichtian Eureka Sound arenites at Slime Peninsula were derived from uplift of the northwestern rim, southward transport, and deposition adjacent to a shrinking narrow seaway situated mainly south of the southern margin of Sverdrup Basin.

Pelitic strata in the succession consist mainly of clayey, quartzose siltstone. Parts of the Savik Formation and lower Kanguk strata represent the only thickly developed intervals of clay shale.

Mafic igneous rocks, with significant variations in radiometric ages, are systematically distributed with respect to the sedimentary succession. These and other characteristics suggest that the mafic intrusions represent integral events in the tectonics of basin evolution and resultant stratigraphic style.

STRUCTURAL GEOLOGY

Cornwall Arch (Balkwill, 1974), which plunges northward through Cornwall and Amund Ringnes islands, is the dominant tectonic element in the south-central part of Sverdrup Basin. The arch, originally named Cornwall Anticline by Fortier (1963a, p. 519), is at least 200 km long and 70 km wide; it has structural relief of about 4000 m across the crest at Cornwall Island (Fig. 4, Sec. A-B), and of about 5000 m along the plunge from southern Cornwall Island to Cape Sverre (Fig. 4, Sec. I-J). The arch is asymmetric in cross-profile: strata on the western flank on both Cornwall and Amund Ringnes islands form a homoclinal succession that dips westward at angles ranging from 4° to 7°; strata on the eastern flank of Cornwall Island dip eastward at 10° to 16°; and beds on the eastern flank on Amund Ringnes Island are disrupted by folds and faults (Fig. 4, Secs. A-B, C-D, E-F, G-H).

Elements comprising surface structures of Cornwall Arch are folds, normal faults, gabbro dykes and sills, a huge evaporite-cored piercement complex, and gypsum sills and dykes. The almost total absence of plant and alluvial cover allows most of the surface structure to be seen clearly on aerial photographs.

The first part of this section describes the structural elements and includes some comparisons with the style of structural elements on neighbouring islands. The second part attempts to explain the genesis and style of structures on Amund Ringnes and Cornwall islands, and advances the premise that structures in the central part of Sverdrup Basin represent sucessive responses to changing stress regimes during basin evolution, and are not the products of a single episodic tectonic event.

Description of structural elements

Folds

Cornwall Arch is a northwestward-plunging fold of regional proportions. At the surface and near-surface of Amund Ringnes and Cornwall islands, there are mappable subsidiary folds that assume three general styles.

(1) Broad, ovate, periclinal culminations and complementary depressions, with limbs that dip gently (less than 8°), are exemplified by structures in central and western

Amund Ringnes Island (Map 1471A). Central Dome H-40 and West Amund I-44 wells were spudded near the crests of the two large periclinal culminations. Central Dome H-40 is particularly informative regarding subsurface structural style, in that it was drilled to a depth of about 3364 m, thus reaching a stratigraphic level low in the Blaa Mountain Formation or in Blind Fiord Formation, and to that level encountered no indication of piercement by mobilized evaporitic rocks.

(2) Large northwestward-striking anticlines and synclines with box-shaped cross-profiles (Fig. 4, Secs. C-D, E-F) characterize eastern Amund Ringnes Island. These folds have relatively straight, gently plunging axes, and limbs that dip gently to moderately (at Structural River as great as 40°). Beds on the limbs of some of these straight folds are thinned and others are broken by normal strike faults, as exemplified by the structural style developed in Christopher, Isachsen and Deer Bay strata near aptly named Structural River. Folds in Jurassic rocks several kilometres south of Jaeger River are included with this group because they have relatively straight northwestward-trending axes. Folds with similar orientation and style are present in western Axel Heiberg Island, but are absent on Ellef Ringnes Island and other parts of western Sverdrup Basin.

(3) Disharmonic flexure-flow folds, with non-systematically spaced small amplitudes (at most several metres), are developed at two localities, widely separated by distance and stratigraphic level: folds with northwest-striking axes and northeastward-directed asymmetry are present in shales of the lower part of the Kanguk Formation near Cape Sverre; and folds with eastward-striking axes and northward-directed asymmetry are present in Blaa Mountain pelitic strata in south-central Cornwall Island.

Faults

Little topographic relief and poor exposure prevent observation of dip separation on most of the faults in the area. All of those on which dip separation could be observed are normal faults; with the exception of some faults on Cornwall Island, the other faults are probably normal faults also.

The faults may be classed in the following three general categories, based on orientation and association with folds.

(1) Normal faults associated with ovate culminations, such as in central Amund Ringnes Island, assume a general radial pattern and have dip separations on the order of a few metres to perhaps a few tens of metres.

(2) Northwestward-striking faults on eastern Amund Ringnes Island break the limbs of some folds. Along strike, some of the faults near Structural River extend to zones of thinned beds on moderately to steeply dipping fold limbs. Deer Bay and Awingak strata are in fault contact along a strike fault on the western limb of an anticline at Cape Ludwig, and the separation must be on the order of a hundred metres or more.

(3) Systems of northeastward-striking faults are present in eastern Amund Ringnes and Cornwall islands. A set of faults on eastern Amund Ringnes Island strikes about N28°E, and has dip separations of a few metres to a few tens of metres. The faults are very straight and arranged as a subparallel set, which transects northwest-striking fold axes at high angles (Map 1471A). Some members of this group are occupied by co-extensive gabbro dykes.

A northeast-striking fault with a partly curved surface trace and almost negligible stratigraphic separation cuts Awingak sandstone at Cape Ludwig. Sandstone wallrocks are well cemented with quartz for a distance of about 2 m contiguous to the fault, whereas sandstone beds of the Awingak Formation away from the fault are poorly cemented.

At Jaeger River, a pair of subparallel faults (a and b of Fig. 23), striking about N15°E, cuts the Upper Member of the Heiberg Formation and overlying strata to about the middle of the Awingak Formation. Stratigraphic separation on the shorter, more westerly of these faults indicates west-side-down motion. However, stratigraphic separation on the larger fault, here named the Jaeger River Fault (Map 1471A), changes along the strike of the fault. Near its southern end, red-weathering Jaeger sandstone on the eastern side of the fault lies against Upper Heiberg sandstone forming the wallrocks on the western side, thus indicating some relative east-side-down slip. In the valley of Jaeger River, the Jaeger Formation forms the western wallrocks and Upper Heiberg coaly sandstone forms the eastern wallrocks, implying some relative west-side-down motion; and, northward from Jaeger River valley, stratigraphic relationships across the fault suggest that the eastern block is relatively downthrown. The trace of the fault at Jaeger River cannot be observed clearly because of poor exposures, but there are slickensided surfaces over a width of several metres, indicating that the break is more in the nature of a fault zone than a sharply defined fault surface. Too few in-place observations of slickensided surfaces are available for interpretation of slip direction.

About 5 km west of the Jaeger River Fault, a straight lineament occupied by a gabbro dyke strikes about N15°E, and cuts a set of curved dykes that strike northwestward. The curved dykes appear to be offset a few hundred metres right laterally (Fig. 23).

At Mount Nicolay, there are two subparallel, north-northwest - striking lineaments, about 1 km apart. The more easterly of the lineaments seems to be a normal fault with the western hanging wall downthrown. The western lineament is a dyke which abuts the large steeply dipping gabbro intrusive sheet at Mount Nicolay.

The interpretive part of this section proposes that the systematically oriented, northeastward-striking faults and dykes are products of late Neocomian northwestward downwarping of the Sverdrup Basin floor at Cornwall Island, accompanied by some northward sliding of the sedimentary succession.

Structural geometry of mafic intrusive rocks

Coarsely to finely crystalline gabbro (and locally quartz diorite) dykes, sills and intrusive sheets penetrate progressively higher rocks in the stratigraphic succession from south to north, that is, toward the marine-dominated depocentral region. Intrusions are confined to the Savik Formation and underlying rocks on Cornwall Island, to the Deer Bay Formation and underlying rocks in southern Amund Ringnes Island, and to the Hassel Formation at Cape Sverre (Fig. 4). This is a local example of the basin-wide mafic intrusion fabric: sills, dykes, intrusive sheets and volcanic flows are highest in the stratigraphic column in the basin depocentral region (western Axel Heiberg Island), and are at progressively lower stratigraphic levels toward the basin margins (Balkwill et al., 1975).

Dykes in central Cornwall Island and eastern Amund Ringnes Island are nearly vertical, as much as several kilometres long (a dyke cutting Triassic rocks in western Cornwall Island is about 20 km long) and are at most not wider than a few metres. Many of the dykes are coextensive with faults, or with lineaments that are interpreted as faults, notably the lineament several kilometres west of the Jaeger River Fault (lineament c of Fig. 23). Some of the dykes are folded, others are truncated and offset by faults. Dykes in Blaa Mountain and Lower Heiberg strata in central Cornwall Island tend to have curvilinear surface traces.

Sills are more abundant, thicker, and more widespread in shale-dominated intervals than in the sandstone

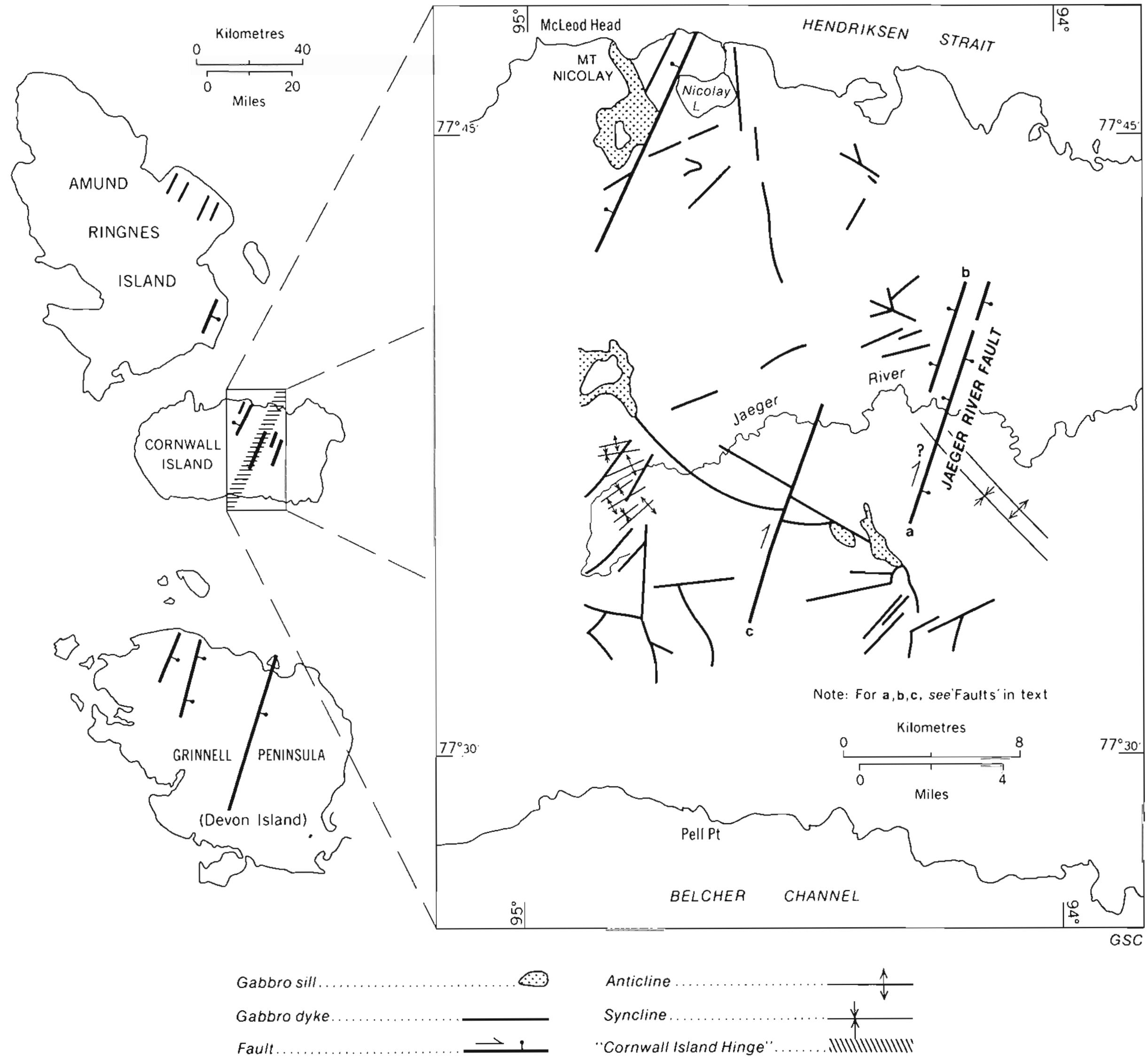

Figure 23. Principal structural elements, central Cornwall Island.

formations. Gabbro sills a few metres thick and several square kilometres in area are folded concordantly with Blaa Mountain pelites in central Cornwall Island and with Deer Bay strata near Structural River.

Lenticular intrusive sheets have intruded the Heiberg Formation at Mount Nicolay, Ringnes and Deer Bay pelites near Geologist Bay, and the Deer Bay Formation north of Amund Ringnes Piercement Dome. The intrusive sheets are as thick as 50 m and are on the order of several kilometres long. They differ significantly from intrusions classed as dykes or sills in that the sheets truncate the Mesozoic strata at slight angles, rather than being in the plane of stratification or at some obviously high angle to it. A large mafic body north of Amund Ringnes Piercement Dome illustrates the complexity of intrusive sheet geometry: the main part of the mass dips northward, almost concordantly with enclosing Deer Bay shales; from the western end of the main mass, part of a narrow dyke rises obliquely upward in the stratigraphic section to a tonguelike sill in the upper part of the Deer Bay Formation; from the eastern end of the main mass, a thin sheet rises stratigraphically at a low angle to bedding to a level of termination near the contact of the Deer Bay and Isachsen formations. (These observations have important applications to seismic interpretation, because it cannot be safely assumed that all sheetlike intrusions in the region, which are more or less concordant with bedding, are necessarily sills and therefore in the plane of bedding.)

Two dark brown weathering, mafic igneous sheets are intercalated concordantly with sandstone in the middle and upper parts of the Hassel Formation near the northern coast of Amund Ringnes Island. The base of the lower sheet is about 150 m above the base of the Hassel Formation, and the upper sheet is about 360 m above the base of the formation. Each of the sheets is about 15 m thick. At Cape Sverre, each of the sheets has characteristics of volcanic flow breccias (Fig. 21): they are composed of relatively smooth surfaced, angular polyhedral blocks, ranging up to about 30 cm long, of aphanitic, slightly vesicular basalt; the blocks are randomly embedded in dark grey, poorly indurated mudstone in which there are randomly dispersed, fine to coarse, quartz sand grains. The mudstone matrix shows no obvious indication of thermal alteration by the adjacent basalt blocks. Southeastward from Cape Sverre, near GSC locality C-22217, the sheets appear to be composed entirely of angular, polyhedral basalt blocks, lacking a mudstone matrix of the type associated with the equivalent intervals at Cape Sverre; and at the southeastern limit of exposure of the sills, they are composed of nonbrecciated, aphanitic to finely crystalline gabbro, with some small vesicles. Because of poor exposures, the contacts with adjoining Hassel sandstone cannot be observed directly. Two mafic igneous sheets, with similarly developed lateral changes in internal fabrics, are present in the Hassel Formation near Haakon Fiord, eastern Ellef Ringnes Island (Stott, 1969). The sheets are suggested to be partly the products of phreatomagmatic extrusion.

Amund Ringnes Piercement Complex

There are no evaporitic piercement structures in the surface rocks of Cornwall Island.

Amund Ringnes Piercement Dome (Norris, 1963b; North Cornwall Dome of Gould and de Mille, 1964) is a northwestward-elongated diapiric mass of gypsum, with included blocks and large masses of gabbro, limestone, dolomite and anhydrite, which lies athwart the crest of Cornwall Arch. Surface area of the dome is about 35 km^2 and the evaporitic mass may extend to a depth of about 7 km (Fig. 4, Secs. G-H, I-J). The northern part of the dome is elongated westward so that the nose of the dome points toward the flanks of the piercement dome at nearby Andersen Bay. Because of this, it seems likely that the surface parts of the domes are culminations above a huge subsurface diapiric mass, for which the term Amund Ringnes Piercement Complex may be applied. The mass may be comparable in size and structural style to Dumbbells and Contour domes, a set of piercements on eastern Ellef Ringnes Island (Gould and de Mille, 1964; Stott, 1969). For interpretation, it is notable that the dome at Andersen Bay is on the western flank of Cornwall Arch and not along its crest. Lithology of the diapiric matrix and enclosed xenoliths is described in the section on stratigraphy.

The diapiric rocks are in vertical or nearly vertical, approximately conformable fault contact with adjacent country rocks (Fig. 4, Secs. G-H, I-J). Dips of the country rocks decrease abruptly away from the piercement contacts; for example, Deer Bay pelite is vertical along the western contact of Amund Ringnes Piercement Dome, but dips only about 8° at the contact with the Isachsen Formation, about three-fourths of a kilometre away from the edge of the dome.

Foliation in gypsum is vertical or nearly vertical at the margins of the dome. Toward the interiors of the domes, the foliation assumes a fabric of randomly spaced, apparently nonsystematically oriented flow-folds. In some places, the flow-folds have nearly horizontal axial surfaces and, also, the long axes of xenoliths tend to be aligned parallel to the dome margins, so that near the edges the material comprising the domes has a 'streamed' structural fabric. This style is similar to that observed in piercement domes on Ellef Ringnes Island (Gould and de Mille, 1964, p. 728).

Gypsum dykes

The locations of four gypsum dykes near Amund Ringnes Piercement Dome are depicted on the geological map. Two dykes are subparallel to bedding in the Ringnes Formation on the north flank of the dome. Although locally discontinuous, the gypsum is distributed along a zone about a kilometre in length, but only about 2 m wide, as a maximum. A thin gypsum dyke cuts obliquely across lower beds of the Deer Bay Formation near the northwest rim of the dome. All of the foregoing are composed of finely crystalline, partly foliated light grey gypsum, locally with thin elongate inclusions of pelitic wallrocks.

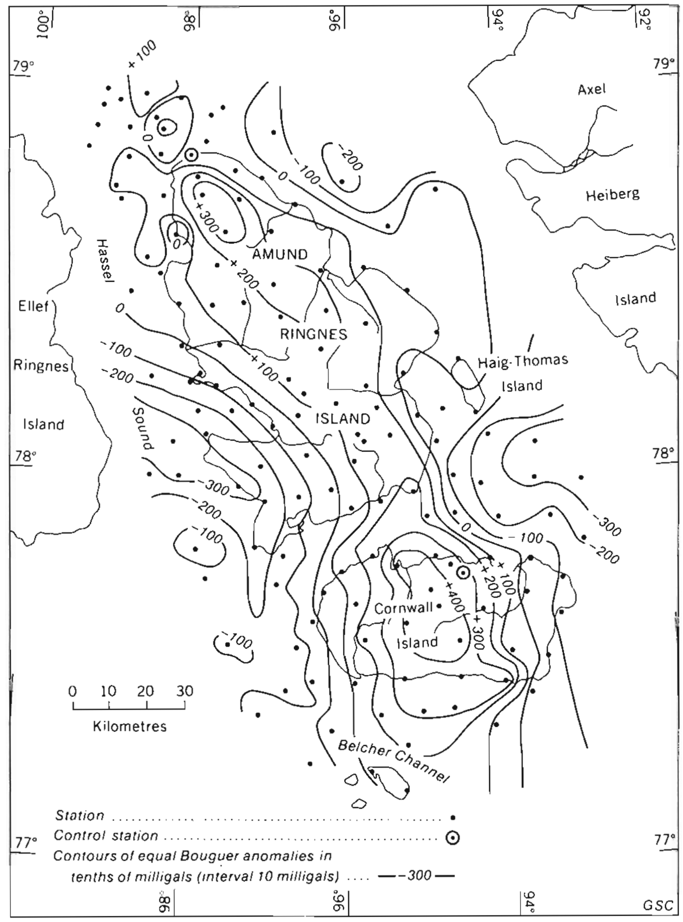

Figure 24. Bouger anomaly map, Amund Ringnes, Cornwall and Haig-Thomas islands, Arctic Archipelago (from Sobczak and Weber, 1970).

The most noteworthy gypsum dyke cuts bedding in the Savik, Ringnes and Deer Bay formations at a high angle near the southern end of Amund Ringnes Piercement Dome (Fig. 6a). Pelitic wallrocks adjacent to the dykes are bleached and hardened to pelitic hornfels containing small pyrite porphyroblasts. The dyke appears to be truncated by a folded gabbro intrusive sheet from which a radiometric age of about 143 Ma was obtained from whole-rock analysis, leading to the possibility that the gypsum dyke is older than mid-Late Jurassic. This conclusion is not entirely certain, because there is no proof that the dyke was not originally emplaced in a discontinuous fashion along strike, in the manner of dykes along the northern flank of the dome.

Regional gravity

A large positive Bouguer anomaly coincides with the axis of Cornwall Arch (Sobczak and Weber, 1970; Fig. 24, this paper). Details of the anomaly closely mimic surface structure as follows: the gradient on the eastern flank of the anomoly is steeper than that on the western flank; a re-entrant low coincides with the position of the box-shaped syncline at Structural River, southeastern Amund Ringnes Island; a small circular low occupies Andersen Bay, site of a buried piercement dome; and there is an elliptical high southwest of Slime Peninsula on which the Sun Gulf Global Linckens Island P-46 well was located.

Interpretation

Previous concepts

Previous regional interpretation of the structural geology of the south-central part of Sverdrup Basin concerned two principal aspects: the age and kinematics of piercement structures; and the crustal nature of Cornwall Arch.

Thorsteinsson (1974) reviewed the history of concepts regarding the piercement structures. Beginning with the first systematic geological investigations in the Sverdrup Basin, summarized by Fortier (in Fortier et al., 1963), some workers have held the opinion that the piercement structures, along with the folds and faults in the central part of Sverdrup Basin, are byproducts of tangential compression during a mid-Tertiary tectonic event named the Eurekan Orogeny by Thorsteinsson and Tozer (1970, p. 585). The opinion was reached from the inference that the nonmarine sandstone succession, which lies on the Kanguk Formation and which is folded adjacent to the piercement dome, is coeval with the folded and faulted Eureka Sound Formation of Ellesmere Island and eastern Axel Heiberg Island. The opinion was that the piercement domes and adjacent folded rocks, in their entirety, must be younger than the youngest rocks involved, which were believed to be Tertiary. Alternative views have been held that the subcircular diapirs in the basin rose halokinetically over a long time, as the upper Paleozoic evaporitic rocks were loaded gradually with Mesozoic sediments (Kranck, 1961; Hoen, 1964; Gould and de Mille, 1964; Schwerdtner and Clark, 1967; Stott, 1969).

Sobczak (1963, p. 17, Fig. 7), from consideration of gravity measurements, concluded that Cornwall Arch marked the response in supracrustal rocks of northward-trending uplift of a basement block, with the large positive gravity anomaly on the arch amplified by the presence of a mafic intrusive body at some intermediate depth (about 3000 m). Later, Sobczak (pers. com., 1974) suggested that uplift (and the gravity anomaly) could be more satisfactorily explained by the presence at some deep level of a large mafic intrusive mass.

Structural-lithic assemblages

Supracrustal rocks in the region of Cornwall Arch can be distinguished as three structural-lithic assemblages with contrasting mechanical properties, which are discussed most conveniently in the following order: (1) upper Paleozoic evaporites; (2) rocks above upper Paleozoic evaporites; and (3) rocks below upper Paleozoic evaporites.

Upper Paleozoic evaporites

Gypsum and anhydrite of the Otto Fiord Formation are well exposed along the eastern margin of Sverdrup Basin (Thorsteinsson, 1974). Piercement domes in the axial region of the basin have evaporitic cores and, although the evaporites lack macrofossils, there are included blocks of carbonate rocks containing Carboniferous faunas, which are coeval with faunas from rocks associated with evaporites at the basin margins (Gould and de Mille, 1964, p. 724; Stott, 1969; Thorsteinsson, 1974).

Halite is not known to occur at the surface of any of the diapirs in the Sverdrup Basin, but gravity surveys by Weber and Sobczak (1962) indicated negative anomalies over some domes, prompting Gould and de Mille (1964, p. 745) to suggest that the circular domes in the axial part of the basin are cored with halite. Their prediction was confirmed by Hoodoo Dome L-41, drilled in 1972, adjacent to a piercement dome on southeastern Ellef Ringnes Island. It entered halite at a depth of 2032 feet (620 m), and remained in halite-dominant lithologies to a total depth of 14 045 feet (4284 m) (Davies, 1975), thus proving the existence of a halite lithofacies of the Otto Fiord Formation.

The very existence of the piercement domes and complexes in the axial part of the basin demonstrates that the assemblage of upper Paleozoic evaporites was sufficiently thick and mobile under the load impressed by overlying rocks to form the most important level of structural disharmony in the supracrustal package. Because of the distribution of piercement structures, Meneley et al. (1975) postulated that an upper Paleozoic carbonate shelf extended across the west-central part of Sverdrup Basin, dividing it into two evaporitic basins which they named the Axel Heiberg basin in the east, and the Barrow Basin in the west (Fig. 7). Amund Ringnes Piercement Complex is near the central part of their postulated Axel Heiberg evaporitic basin.

Rocks above upper Paleozoic evaporites

The assemblage of rocks above the evaporites consists of upper Paleozoic carbonates (which are present as inclusions in some domes), probable upper Paleozoic pelites, and Mesozoic terrigenous clastic rocks in which the structures now at the surface were formed. With few exceptions, the surface Mesozoic rocks in the region of Amund Ringnes and Cornwall islands are poorly indurated, and it is empirically apparent that they have low compressive and tensile strengths. Their rheological response to stress might approximate that of a thick, relatively homogeneous ductile mass, lacking significant strength anisotropies. Such rocks tend to respond to differential geological stresses by deforming along zones of pervasive flow, rather than by breaking on sharply defined faults. Older Mesozoic rocks, and the upper Paleozoic carbonate rocks, may be better indurated and stronger as a result of their once-great depths of burial; they might be expected to respond to differential geological stresses in a more brittle fashion than the upper parts of the assemblage, resulting in a structural style characterized by discrete faults.

From interpretation of seismic data, Meneley et al. (1975) estimated that the present thickness of strata above the evaporites in the central part of Sverdrup Basin is about 7200 m, a figure that provides an approximate minimum thickness for the stratigraphic cover that once existed over evaporites at Amund Ringnes Island.

Rocks below upper Paleozoic evaporites

Trettin et al. (1972) summarized the geophysical evidence for the nature and extent of crustal structure of the Sverdrup Basin. They inferred that the crust, consisting of Precambrian basement and deformed rocks of the Ellesmerian Orogenic Belt, is thinned beneath the axial part of the basin, in compensation for the thick succession of relatively light clastic rocks lying on the basement.

No rocks older than the upper Paleozoic evaporites are known to occur in any of the piercement domes. From this it may be assumed that rocks below the evaporites (i.e. the Precambrian crystalline basement, deformed strata of the Ellesmerian Orogenic Belt, and possibly some pre-evaporitic lower Sverdrup Basin strata) form a more or less rigid, brittle structural basement below the evaporites. Gould and de Mille (1964) and Stott (1969) suggested that lower Paleozoic evaporites might be involved in some of the Sverdrup Basin diapirs, but Thorsteinsson (1974, p. 7) argued against this possibility on the basis of the known facies distribution of lower Paleozoic strata.

Evaporite diapirs

Theoretical considerations

Much geological literature is devoted to the theory of halite diapirism, and to explanations for the initiation and development of real piercement structures (Braunstein and O'Brien, 1968; Mattox, 1968; Kupfer, 1970a; Coogan, 1974). The United States Gulf Coast region of domes is one of the first places where differences in specific gravities between halite and overlying rocks were invoked as the principal causes of diapirism; but there are many parts of the world where tectonic forces are considered to have been the driving forces.

For buoyant rise of halite, Trusheim (1960, p. 1523) concluded that a minimum thickness of about 300 m of halite is required before flowage can start. The required thickness of overlying sediments depends on their lithology and pore-fluid properties; estimates range from about 900 to 1500 m (Kupfer, 1970b, p. 53, 54) to the range of 1800 to 2300 m (Heard, 1972, p. 209). With these approximate conditions, halite should be expected to rise diapirically through the overlying sediments. Odé (1968, p. 58) explained the process in straightforward terms: "The process by which domes form therefore is comparable with that in a beaker containing two fluids of different densities, with the denser fluid above the lighter one. When the interface between the two fluids is disturbed, instability results, the driving force of which is the density reversal. As the materials in the beaker become redistributed, the denser one descends and the lighter one ascends. If the two materials are viscous, the rate of this process of reversals is determined by the viscosities." Three conditions are thus required: a thick layer of halite; at least moderate burial depth; and disturbance of the halite or overlying rocks. Reasons for initiating the disturbance, suggested in the volume edited by Braunstein and O'Brien (1968), include: regional tension, regional compression, mobilization of salt by high temperatures, variations in thickness of mother salt, and basement rock movements.

The thickness of upper Paleozoic evaporites in the central part of Sverdrup Basin at the time of initial diapirism cannot be determined easily. The existence of the large piercement structures is ample evidence that the mother salt layer was sufficiently thick to allow halite migration. Regional stratigraphic evidence (Thorsteinsson and Tozer, 1970; Meneley et al., 1975) indicates that by late Middle Triassic time the evaporite rocks were overlain by at least 3000 m of upper Paleozoic and Triassic strata, a thickness greater than the previously cited theoretical estimates required to initiate diapirism.

Hanna (1959) pointed out that diapirism in the Gulf Coast geosyncline migrated in time away from the craton, more or less contemporaneously with basinward migration of the depocentre. This concept may have important implications in terms of the relative ages of Sverdrup Basin diapirs.

Regional and local considerations

Gould and de Mille (1964) and Stott (1969) cited local thinning of the Hassel Formation adjacent to some of the domes on Ellef Ringnes Island as evidence of syndepositional dome growth. Other Mesozoic units vary considerably in thickness from place to place in the Ringnes islands, but there is insufficient detailed surface stratigraphic control at present for conclusions about the chronology of dome growth on the basis of thickness variations of Mesozoic rocks. Unconformities between Cretaceous rocks and upper Paleozoic limestone conglomerates have been reported from Isachsen Dome (Gould and de Mille, 1964, p. 728), eastern Ellef Ringnes Island.

A progessive northeastward change in structural style is observable from western King Christian Island, which is near the western margin of the postulated Axel Heiberg evaporite basin (Fig. 7), to northern Amund Ringnes Island, near the middle of that basin. Large ovate, northwestward-striking anticlines are separated by broad, flat-troughed synclines at King Christian Island and western Ellef Ringnes Island; deep drillholes in the anticlinal culminations encountered no evidence of piercement by evaporites (Balkwill and Roy, 1977); northwestward-elongated anticlines on central and southern Ellef Ringnes Island are pierced by evaporite domes with nearly circular surface plans (Stott, 1969, Map 4-1968); and the culminations of long, sinuous anticlines with nonsystematically oriented, curvilinear axial traces, are pierced by huge, elongate diapir complexes on eastern Ellef Ringnes Island and northern Amund Ringnes Island (Stott, ibid.; Map 1471A, this report). Moreover, the anticlinal crests of this suite of structures, from the simple folds near the basin margin to complex fold-piercements in the basin axis, are spaced at nearly regular wavelengths of about 18 to 25 km. This regional structural fabric, considered together with the depositional history of the basin and the mechanics of piercement from geophysical theory, suggest the following possible chronological evolution (Fig. 25).

The strength value of halite and associated evaporites was exceeded to initiate creep at some time in Early or Middle Triassic time, when the thickness of beds above the evaporites was on the order of Heard's (1972) theoretically required sediment load of about 1.8 to 2.3 km. At that time, evaporite mobilization was directed to areas of least potential, in the manner of fluid kinetics. In the absence of clear evidence from the column of rocks in the Ringnes islands for specific causes of mobilization gradients and sites of initial disturbance, two general conditions are likely to have determined the directions of evaporite migration and the sites of accumulation: (a) local lithologic facies and thickness variations within the evaporite succession, which gave rise to inherent variations in viscosity; and (b) variations from place to place in the overburden pressure of rocks lying on the evaporites, as a function of the thickness, facies, and relative states of compaction of those rocks. With evolution of a regional field of unequal mobilization potential, migration was initiated to small evaporite-cored swells, located in places where the mobilization potential of the evaporites was relatively high, and the overburden pressure relatively low. Thorsteinsson and Tozer (1970, p. 586) speculated that the sites of circular and elliptical piercement domes in central Sverdrup Basin were localized because the evaporites were overlain directly by structurally weak upper Paleozoic pelitic rocks. (However, they concluded also that piercement did not take place until Tertiary, and then as a response to regional compression.) Their former speculation may be valid: regions of relative undercompaction in pelitic strata directly above the evaporites would result in inequalities in fluid-pressure gradients within the pelites, and local variations in the effective overburden pressure on the evaporites; initial migration, therefore, should proceed to sites of relatively low effective overburden pressure in undercompacted pelite. Moreover, foregoing discussions of stratigraphy cite evidence that the very thick succession of Triassic pelites accumulated rapidly in the axial part of Sverdrup Basin, thus prolonging the initiating dynamics into early Mesozoic. Initiation of evaporite migration, and development of initial disturbances and small evaporite-cored swells seems likely, therefore, to have begun at latest by early Mesozoic time, with the phase of vigorous Triassic deposition in the basin, and consequent creation of unequal distribution of effective load on the upper Paleozoic evaporites (Fig. 25b).

If the concept proposed by Hanna (1959) for the Gulf Coast geosyncline has application for the Sverdrup Basin, then migration of evaporites and the initiation of swells might be expected to progess with time from proximal margins of the basin toward the basin axis. Regional sedimentological evidence indicates that Triassic clasts prograded to the basin mainly from two directions: (a) from the eastern (and southeastern) margin; and (b) from a re-entrant at the southwestern margin of the basin. The thick clastic wedge developed from the latter probably prograded northeastward toward the basin axis, with the result that attendant evaporite-related structures in the region of the Ringnes islands acquired northwestward trends. Fluid-dynamic theory predicts that the buoyant evaporite layer should develop sinusoidal waves, the wavelengths of which depend on the ratios between the viscosities and thicknesses of the evaporitic layer and adjacent layers (Ramberg, 1972), and the theory has been illustrated by model experiments (Parker and McDowell, 1955). The crests of the waves in south-central Sverdrup Basin are spaced at intervals of about 18 to 25 km; the spacing was fixed in early stages of evaporite mobilization and, once fixed, served as the sites of future evaporite walls, domes and swells.

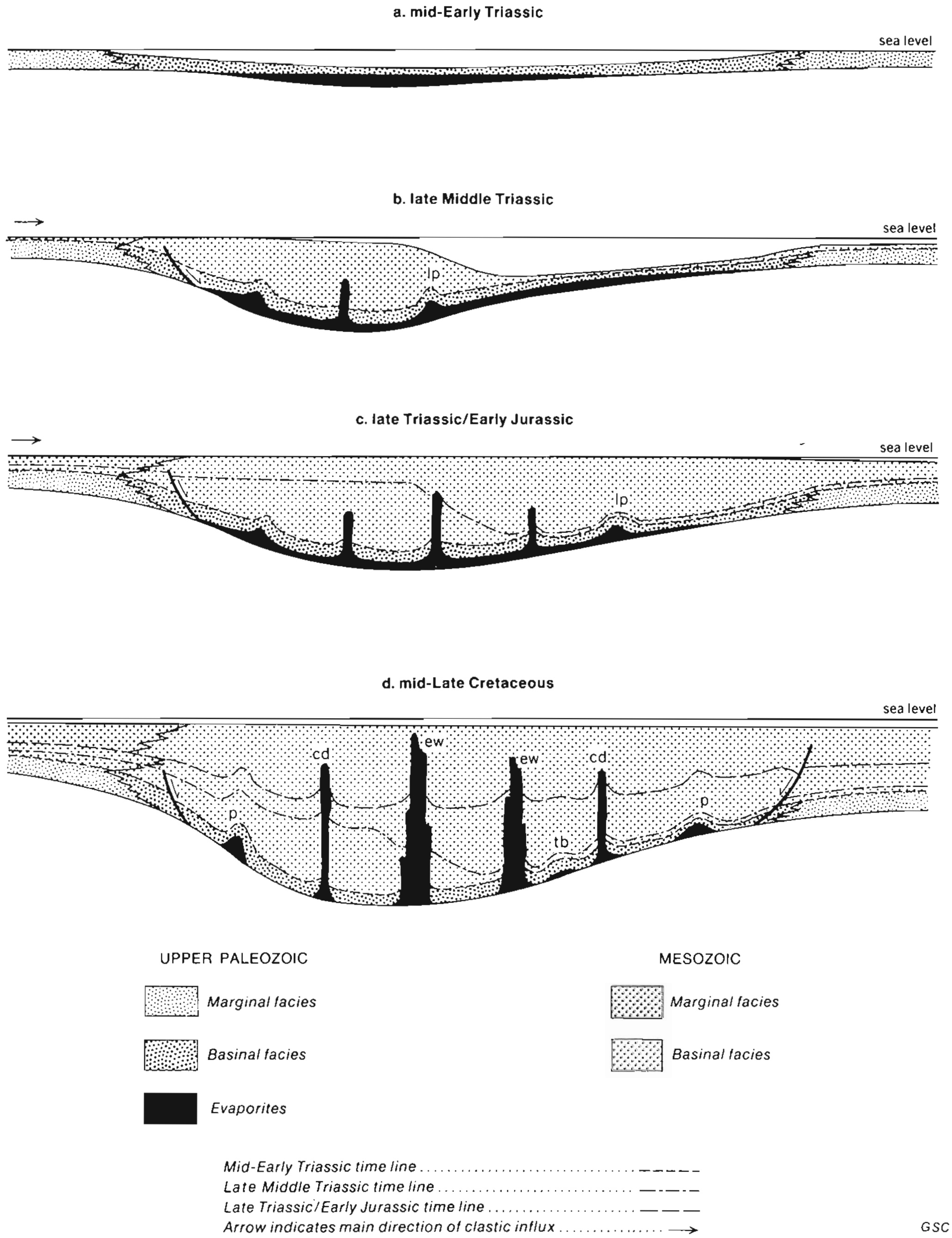

Figure 25. Conceptual evolution of evaporite diapirs, northeast-southwest section across central part of Sverdrup Basin: lp - low effective overburden pressure; p - pillows; cd - circular (in plan) domes; ew - evaporite walls; tb - 'turtle-backs'. Arrow indicates main direction of clastic influx. Not to scale.

Trusheim (1960) suggested that the systematic ordering of evaporite structures in the North German Basin evolved in a manner similar to the foregoing. Salt walls of that basin have elongate sinuous forms and have risen from the deepest parts of the basin; the region of salt walls is adjoined by salt stocks, which are circular or oval in plan; and the salt stocks are surrounded by a girdle of salt pillows, where the thickness of salt and depth of subsidence was insufficient to cause piercement. The latter are undernourished or incipient structures, arrested in an embryonic stage of development.

In contrast to the Hanna model, Gussow (1968, p. 44) proposed a progressive migration from deeper parts of a subsiding basin toward the margins, as a result of lateral migration during regional subsidence of the critical isotherm level required to mobilize halite.

Dome evolution progressed with continued loading by Mesozoic sediments over the layer of evaporites. Huge piercement walls with local culminations were able to develop in the axial part of the basin, where the supply of evaporites may have been greatest, and where, certainly, the thickness of Mesozoic strata and consequent load was greatest (Fig. 25d). Simpler structures developed at the basin margin, as the variables of evaporite viscosity and thickness and overlying load served to arrest widespread piercement. (The heights of individual domes in the region of piercements also were determined by those variables, so there is little likelihood that piercements were maintained at the same general stratigraphic level contemporaneously.) According to the proposed model, the nonpierced anticlinal swells of King Christian Island are the simplest and possibly oldest structures of the genetic-chronological array.

Stratigraphic-structural evidence cited in a following section shows that widespread deposition in the central part of Sverdrup Basin ended in Maastrichtian time, and was followed (or accompanied) by great uplift of large-scale basin segments during early Tertiary (ending at the latest by middle Eocene) time. During uplift, erosion exhumed the domes to their modern structural levels. Regional uplift might be expected to have the following consequence for the piercements. If dome growth resulted from instability of the deeply buried, greatly loaded, mother evaporite layer, and the rates and amounts of growth were in a state of quasi-equilibrium with this load, then regional uplift and erosion should have relieved the forces and conditions driving the process. The result of this may have been that the piercements became 'frozen' in positions of relative dynamic stability, such that upward mobilization ceased at some time during regional uplift (that is, during early Tertiary). In the same context, areas of piercement domes in the eastern part of Sverdrup Basin were reloaded in early Tertiary by lower Tertiary rocks as thick as 3000 m (Thorsteinsson and Tozer, 1970, p. 584), with the result that the diapirs there remobilized and syndepositionally pierced the overlying Tertiary strata. (Many of the piercements in that area were remobilized once again during the middle Eocene-Oligocene phase of tangential compression that produced reverse faults and tight folds in the region.)

Lag domes

There is no reason to suppose that laterally constant viscosities prevailed within the mother evaporite layer or in the overlying strata. Lateral variabilities in the halite/anhydrite proportions of the evaporite facies, for example, could cause parts of the evaporite layer to lag during mobilization, with the creation of isolated, relict masses. Because of relatively greater withdrawal of neighbouring materials to feed the growing domes, these masses should stand with some structural relief as lag domes (called 'turtlebacks' by Trusheim, 1960). The broad periclinal culminations with gently dipping limbs, on which Central Dome H-40 and West Amund I-44 were drilled, may be products of this process.

Uplift of Cornwall Arch

Uplift of Cornwall Arch is dated by palynological determinations by W.S. Hopkins (pers. com., 1973, 1974) of samples from the Eureka Sound Formation at Slime Peninsula, and from the outliers of Tertiary rocks in south-central Amund Ringnes Island and central Cornwall Island. The former lie gradationally on the Kanguk Formation and are dated by Hopkins as Maastrichtian. The latter overlie unconformably the Mesozoic rocks along the crest of the arch, and are dated by Hopkins as late Paleocene to middle Eocene. Therefore, uplift of the arch and erosion to relatively deep levels (at least 4500 m of Mesozoic strata were removed from central Cornwall Island and 2700 m from south-central Amund Ringnes Island) took place between deposition of the Maastrichtian beds and the Paleocene-Eocene beds. These figures represent the approximate thicknesses of strata between the top of the Kanguk Formation (a convenient datum because it is near the uppermost level of marine rocks in the stratigraphic column) and the levels of Mesozoic strata on which the Tertiary rocks lie. This event is broadly contemporaneous with broad uplift of the Princess Margaret Arch on Axel Heiberg Island (Trettin et al., 1972, p. 134, 135), which preceded late Eocene-Oligocene compressive tectonism on Ellesmere Island and eastern Axel Heiberg Island (Balkwill et al., 1975). It is significant for interpretation of some structures impressed on the arch that the estimated amount of uplift is a measure of true uplift of the arch above sea level, and not relative uplift from adjacent downwarping. Uplift of this magnitude requires structural adjustment in order to satisfy the requirements of balance of regional geometry. Uplift of the arch and development of its associated structures may have developed from fundamentally different mechanisms, considered in the following paragraphs.

(1) Sobczak (pers. com., 1974) has suggested that uplift resulted from intrusion by huge, thick mafic igneous masses at depth. This seems improbable, because the uplift occurred during the interval from late Maastrichtian to late Paleocene - middle Eocene, and regional geology and radiometric age determinations indicate that intrusive rocks in central Sverdrup Basin are no younger than early Late Cretaceous in age. (The abundant mafic intrusions along the crest of Cornwall Arch are exhumed from the deeper, more abundantly intruded levels of rocks exposed there, and are not concentrated because the arch served as a locus for intrusion.)

(2) Thorsteinsson and Tozer (1970, p. 585) implied that mid-Tertiary tangential shortening of rocks above upper Paleozoic evaporites along a relatively flat décollement in the evaporites and the filling of structural culminations by the mobile evaporites were responsible for central Sverdrup Basin structures. But this mechanism seems an unlikely cause for a regional element of the size of Cornwall Arch for several reasons: (a) a pronounced regional positive gravity anomaly (Fig. 24) is not consistent with the required thick mass of low-density, ductile rocks; (b) Amund Ringnes Piercement Complex lies mainly on the western flank of the arch, and not directly along its crestal line, as might be expected if the arch was filled with evaporites; (c) the volume of evaporites required to fill the arch would be enormous; and, perhaps most significantly, (d) the arch is older than the phase of compressive tectonism in the eastern part of the basin.

(3) The geometry of observable structures could result from tangential shortening of the entire assemblage of rocks, by slip on reverse faults in structural basement, pervasive flow in evaporites, and development of folds and faults in upper levels. The principal objection, as for the preceding suggestions, is that uplift of the arch is demonstrably older than the phase of regional tangential compression in the eastern part of Sverdrup Basin. Furthermore, in most

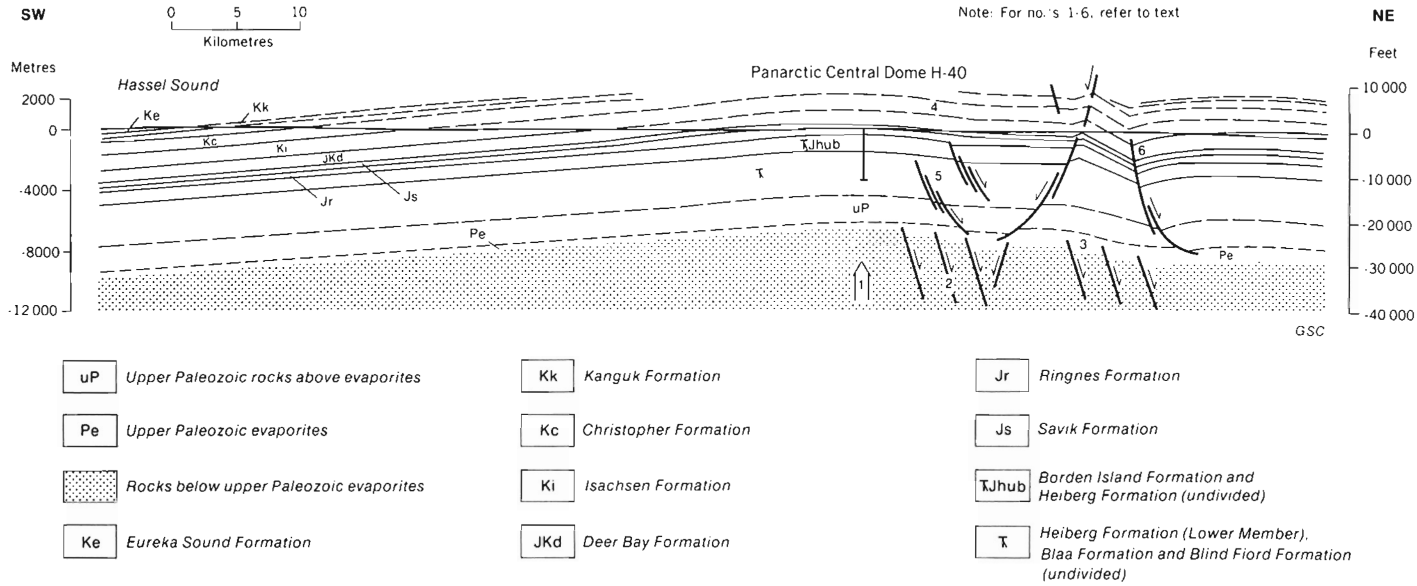

Figure 26. Suggested evolution of Cornwall Arch and related structures, Amund Ringnes and Cornwall islands (see text). Line of section as for section E-F, Figure 4.

orogens resulting from regional compression, it is recognized that tectonism progressed chronologically from internal regions of complex structure to external regions of simpler structure (Douglas and Price, 1972), yet Cornwall Arch, with its simple structure, is considerably older than the intricate structure of the eastern part of the basin.

(4) The kinematic model favoured by the writer (Balkwill, 1974) partly follows Sobczak's (1963) early suggestion that the arch developed from uplift of a basement block, in the manner indicated in Figure 26. It supposes that crustal fracturing of structural basement (Fig. 26, no. 1) was accomplished along systems of extension faults having relative uplift to the west (no. 2) and that the mobile upper Paleozoic evaporites (no. 3) provided a zone of strain discontinuity, so that lateral extension from slip on faults in the structural basement was transferred easily to lateral pervasive flow at the level of evaporites. From this, faults and folds in rocks above the evaporites were allowed to develop in a style that is more or less independent of faults in the structural basement, although the sets of faults below and above the evaporites likely have coincident orientations. Folds with northwest-striking axes in the poorly indurated, low-strength, near-surface rocks are considered to be drape folds (no. 4), developed through pervasive cataclastic flow---demonstrated at the surface by the greatly thinned limbs of some folds. Passing into deeper levels of more brittle rocks, the folds may be transitional to normal strike faults (no. 5). Field observations (Hamblin, 1965) and the results of experimental models (Cloos, 1968) indicate that the dip angles of normal faults over uplifted blocks may decrease with depth. It seems likely that the surface normal faults pass at low angles into zones of pervasive strain, or décollement in ductile evaporites. Narrow folds in the surface rocks are interpreted as zones of dip reversal (no. 6) above the normal faults, analogous in style to the reverse drag folds interpreted for the Colorado Plateau (Hamblin, 1965). Thus, the amount of horizontal extension required to maintain material balance across Cornwall Arch is accomplished on normal faults at deep levels below the evaporites, by lateral plastic flow at the level of the evaporites, and by normal faults and pervasive cataclastic flow in relatively weak rocks above the evaporites. For the latter, bed lengths are slightly greater after deformation than before, but this is balanced by orthogonal thinning on fold limbs.

Small disharmonic flexure-flow folds in Kanguk strata at Cape Sverre have northeastward-directed asymmetry, suggesting that they developed from sliding of the ductile claystones away from the crest of Cornwall Arch during its uplift.

Tectonic influences on stratigraphic style

Basin subsidence

The south-central part of Sverdrup Basin subsided about 10 800 m from Carboniferous to latest Cretaceous time. Geophysical evidence (Sobczak and Weber, 1973, p. 524) indicates that the basin is floored by continental crust, thinned by about 5 km beneath the axis. The basin is a stuffed secondary basin, in the terminology of Fischer (1975). Klemme (1975, p. 33) classified the basin as intracontinental-composite (i.e. with intracontinental basins containing multicycle deposits, characterized by second-cycle Mesozoic orogenic clastic strata). Inclusion of the Sverdrup Basin with this group requires some qualification, because there is no direct evidence to indicate that the Mesozoic clastic rocks in the basin resulted from an orogenic event. The Tertiary clastic beds of the basin, however, are largely syntectonic.

Causes of crustal thinning at the site of Sverdrup Basin are not known. Sweeney (1977) suggested that initial subsidence of about 500 to 600 m may have been prompted by lithospheric cooling after the mid-Paleozoic Ellesmerian Orogeny. Thick upper Paleozoic evaporites of Sverdrup Basin have abrupt facies transitions to coeval rocks, suggesting the possibility that early basin margins were partly rift-induced, and that initial subsidence was prompted by crustal stretching. The distribution of facies and thicknesses of strata in the basin closely mimic the prebasin Paleozoic tectonic and facies elements, and the latter, in turn, were at least partly superimposed on and influenced by the structural grain of Precambrian crystalline basement. Whatever the initiating causes, subsidence and deposition continued as cogenerating processes until latest Cretaceous time. If values of about 2.3 and 3.3 are taken for mean densities of basin fill and the upper mantle, respectively, then about one third of the total subsidence (or about 3600 m) resulted from primary generating mechanism in the upper mantle and lower crust, and about two thirds (7200 m) of subsidence and accumulation resulted from isostatic adjustment to loading (see Fischer, 1975).

Rates of subsidence and sediment type

Sweeney (1977), using data available to him in 1974, published curves depicting rates of subsidence for parts of the Sverdrup Basin and from the curves he generalized that the basin developed in three depositional phases: late Paleozoic (330 - 230 Ma B.P.), early Mesozoic (225 - 124 Ma B.P.), and late Mesozoic (124 - 74 Ma B.P.). Furthermore, he suggested that each phase began with rapid basin subsidence, which decreased exponentially with time. Rates of subsidence, depicted in Figure 16, disagree partly with Sweeney's curves, because they include recently acquired data not available to him. Sweeney's method demonstrates remarkably active subsidence rates that characterize parts of the column, particularly the Triassic succession, but neglects the lithology of the sediments.

Preservation of very thick nonmarine arenite successions---Upper Heiberg Member, and Isachsen, Hassel and Eureka Sound formations---required active subsidence during basinwide phases of alluviation, at times exceeding the rates of subsidence that prevailed during marine pelite deposition. Causes for episodic, basinwide phases of alluviation, therefore, must lie beyond the margins of the basin, rather than within it. If the primary sources for the clastic detritus were to the south, on Paleozoic and Proterozoic mature clastic terrains, as they seem to have been, then phases of accelerated uplift and stripping of those terrains (relative to sea level) was a major factor in changing a marine depositional regime in the basin to an alluvial-deltaic regime. Each of the four basinwide phases of alluviation (late Norian - Sinemurian, Valanginian - early Aptian, late Albian - Cenomanian, and late Campanian - Maastrichtian), therefore, must mark a significant, first-order epeirogenic event on the northeastern part of the North American craton. Records of those events on the craton have been erased by erosion of almost all Mesozoic strata.

Relatively thin Jurassic arenites on Cornwall Island (the Borden Island and Jaeger formations and part of the Awingak Formation) display repetition of similar lithofacies, characterized by glauconitic or ferruginous, partly phosphatic, partly pebbly sandstone beds, containing relatively abundant marine shells. These strata are interpreted as deposits of relatively high energy tracts. The repetitive stacking of this facies on Cornwall Island suggests that stabilization of the rate of subsidence and rate of clastic influx prevailed at the basin margin during a large part of Jurassic time. Thin intercalations of marine pelitic strata with the pebbly arenites, therefore, are more likely to be responses to disruption of the regime by regional eustatic changes of sea level, than to first-order events within the basin or cratonward, beyond its margin.

Cornwall Island hinge and related unconformities

A vaguely defined, northeastward-trending stratigraphic hinge may be drawn through east-central Cornwall Island (Fig. 23). Some formations thicken considerably northward and westward of this hinge; and alluvial plain, and some deltaic, and littoral sandstone facies grade northward and westward to marine pelitic rocks. The hinge is oblique to the approximate east-west local margin of the Sverdrup Basin, and is oblique also to the trend of Cornwall Arch. Some marine units (Savik and Deer Bay formations) are truncated on the eastern side of the hinge beneath alluvial plain sandstone (of the Awingak and Isachsen formations, respectively).

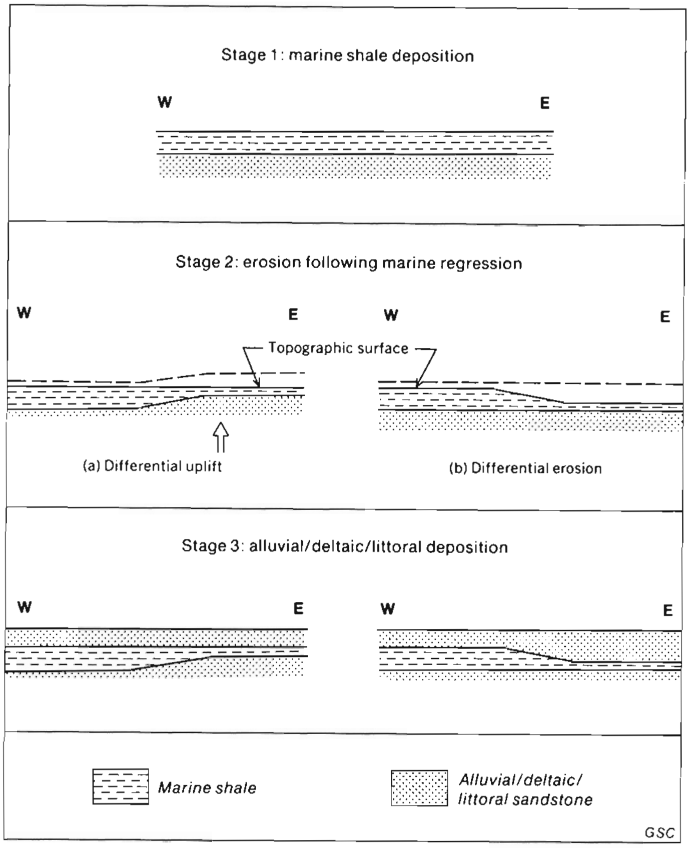

Figure 27. Schematic east-west sections through Cornwall Island, illustrating possible explanations for differential truncation of marine units and thickening of nonmarine units across Cornwall Island hinge.

Two fundamentally different sets of conditions could accomplish such thinning (Fig. 27): (a) truncation of strata on the eastern flank of the hinge may have been a direct consequence of episodic differential uplift followed by regional erosion; or (b) differential erosion of strata may have resulted from episodic fluvial occupation of topographic lowlands, located recurrently on the eastern flank of the hinge. For the latter, fluvially deposited successions resting on truncated marine beds should be thicker on the eastern flank of the hinge than elsewhere; this relationship can be demonstrated for the Awingak Formation but, because of lack of outcrop, not for the Isachsen Formation. However, paleocurrent data and regional facies distribution indicate that eastern Cornwall Island was part of a broad avenue through which large rivers prograded during phases of Mesozoic time. Major fluvial systems usually do not occupy structurally uplifted regions. Therefore, available evidence indicates that it is as likely that at several times eastern Cornwall Island was eroded differentially by large vigorous streams, as it is that the region was tectonically uplifted and stripped.

Mafic intrusions and basin evolution

Attention was directed in the descriptive part of this section to the local and basinwide fabric of gabbro and associated mafic intrusive rocks, stressing the condition that those rocks are highest in the stratigraphic column at the site of the Mesozoic depocentre (west-central Axel Heiberg Island), and reach progressively lower stratigraphic levels toward the basin margins. Moreover, as a generalization, the radiometric ages of mafic intrusions (and the stratigraphic ages of volcanic flows) are systematically distributed, being oldest in the older strata of the depocentre, and progressively younger upward through the stratigraphic column there, and outward from there toward the basin margins. These relationships suggest that the mafic intrusions and volcanic flows represent responses to events of importance in the evolution of the basin, and lead to proposal of the model defined in Figure 28.

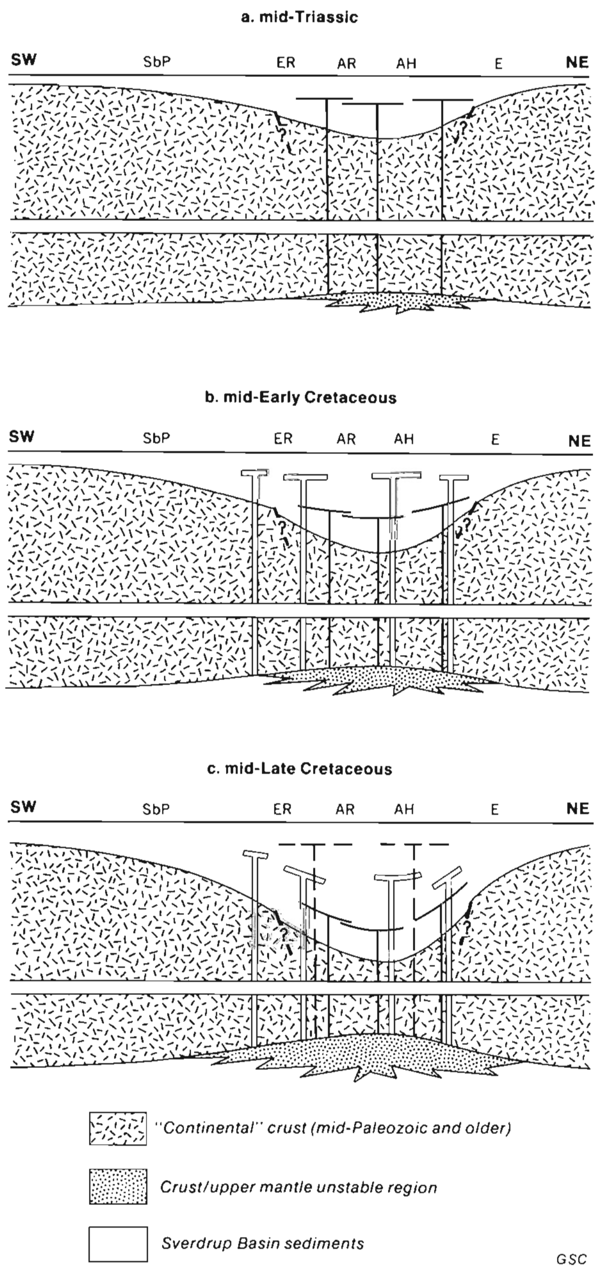

Figure 28. Conceptual evolution of basin subsidence and mafic intrusion, in a southwest-northeast section across Sverdrup Basin: SbP - Sabine Peninsula (Melville Island); ER - Ellef Ringnes Island; AR - Amund Ringnes Island; AH - Axel Heiberg Island; E - Ellesmere Island. Not to scale.

Whatever the cause of initial crustal thinning and basin subsidence, the exposed record on Cornwall and Amund Ringnes islands shows that the basin was well established by Middle Triassic, when there was relatively rapid, thick accumulation of pelitic sediments. Sills and other mafic intrusions at deep subsurface levels of Triassic rocks below Amund Ringnes Island are not dated radiometrically. The deeply buried intrusions in the subsurface of Amund Ringnes Island (Fig. 8) reasonably may be about the same age. (From considerations of the mechanics of sill intrusion (Mudge, 1968; Gretener, 1969) they cannot be much younger, because of the general inability of rising fluids to intrude as subhorizontal layers at very deep levels.)

The mafic rocks were derived from the upper mantle, and presumably mafic fluids pierced the crust as vertical conduits or dykes to levels in Mesozoic strata at which the overburden pressure was sufficiently low to allow lateral migration as sills and slightly discordant intrusive sheets. Abnormal fluid pressures, which likely prevailed in the rapidly deposited, undercompacted Triassic pelites, probably facilitated lateral migration through creation of a decrease in the effective overburden pressure. Local and regional evidence indicates that the intrusive process was repeated on at least three subsequent occasions or phases (Fig. 16): in Late Jurassic (Volgian) during intrusion of gabbros yielding radiometric ages of about 144 Ma; in early Valanginian during intrusion of mafic rocks aged at 132 Ma; in late Neocomian to Albian during intrusion of sills with ages of 102 to 118 Ma; and by the presence of undated sills (at least as young as Late Albian) in the Christopher and Hassel formations in the Ringnes islands, and the volcanic flows in lower Upper Cretaceous strata at Strand Fiord, Axel Heiberg Island. The radiometric ages of each phase of mafic intrusion are approximately contemporaneous with stratigraphic ages of widespread marine transgression (as exemplified by rocks composing the lower part of the Kanguk Formation) or of particularly vigorous basin subsidence and sediment accumulation (exemplified by the upper part of the Christopher Formation) (Fig. 16). It is tempting, therefore, to speculate that the process of crustal fracturing that allowed mantle-derived mafic intrusion was accompanied by active foundering or sagging of the basin floor. A previous section dealt with phases of accelerated loading on upper Paleozoic evaporites and the likelihood that these were accompanied by surges of diapirism into the Mesozoic succession. If there is validity to the suggested association of times of mafic intrusion, with regard to active basin subsidence and accelerated deposition, then the surges of mafic intrusion and the surges of diapirism may be approximately contemporaneous.

Syndepositional structures

The foregoing section proposed that mafic intrusions are an integral part of basin evolution and sedimentation. Northeast-striking faults and mafic dykes on Cornwall Island may illustrate a local effect of the process.

Several kilometres west of the Jaeger River Fault, a bifurcated, northwest-striking pair of dykes is truncated and offset right-laterally by a northeast-striking dyke, which is one of the prominent array of subparallel lineaments on Cornwall Island (Fig. 23). Neither of the dykes has been dated radiometrically, although the offset dykes are joined with a sill that yielded a radiometric age of about 117 Ma (Map 1471A). Northeast-striking dykes on Grinnell Peninsula, Devon Island (Fig. 23), partly coextensive with normal faults, have yielded radiometric ages of about 112 to 114 Ma (J.Wm. Kerr, pers. com., 1976). If the dyke along which offset is observable near Jaeger River (and other northeast-striking lineaments of the same array on Cornwall Island) is about the same age as the dykes on Grinnell Peninsula, then their stratigraphic age is about late Neocomian or early Aptian.

There are reversals of stratigraphic throw along northeastward-striking Jaeger River Fault; such reversals may be the result of lateral slip on the fault. (A northwestward-striking fold pair cuts across Jaeger River Fault without observable offset and, therefore, is younger than the fault. The folds are parallel to sets of northwest-striking folds on eastern Amund Ringnes Island and, like them, are believed to be adjustments to latest Cretaceous - early Tertiary uplift of the eastern flank of Cornwall Arch.) Some amount of down-to-the-north stratigraphic separation is present at Mount Nicolay, on another member of the northeastward-striking fault array.

The geometry and probable ages of the array of northeast-striking faults and dykes, described above, indicate the possibility of some northward, down-to-the-basin motion of the Mesozoic sedimentary mass in late Neocomian or early Aptian. Regional stratigraphic evidence indicates that a widespread phase of marine transgression and possibly accelerated basin subsidence began about that time, of which the stratigraphic products in the basin are pelites of the lower part of the Christopher Formation. The northeastward-striking array of faults and dykes parallels the vague trend suggested for Cornwall Island Hinge, for which there is abundant stratigraphic evidence, cited previously, for repetitive influence during the Mesozoic. The axes of disharmonic flow folds and associated flow rolls in Blaa Mountain pelites near the head of Jaeger River strike northeastward to about east-west, implying shortening across those axes. Such folds could have developed during a phase of sediment-sliding toward the basin axis and, because the structures formed before the rocks were well lithified, it seems likely that they are older than the proposed late Neocomian - early Aptian phase.

ECONOMIC GEOLOGY

Coal

Coal beds in the Upper Member of the Heiberg Formation, and Awingak, Isachsen, Hassel and Eureka Sound formations are mainly thin or very thin and cannot be considered of any economic value. The thickest coal beds observed are on the order of about 0.5 m thick, and are in the Isachsen Formation on eastern Cornwall Island. (Some black beds in the Isachsen Formation resemble thick coal seams from a distance, but on close examination were found to consist of carbonaceous black siltstone and shale.)

Uranium

The possibility of significant uranium deposits occurring in surface rocks of Cornwall and Amund Ringnes islands is not good. Although there are thick arenites containing carbonaceous detritus, the strata lack significant amounts of felsic volcanic detritus, an attribute considered to be most favourable for deposition of epigenetic uranium deposits in sandstone (Gabelman, 1971). Parts of the sandstone formations were traversed using a small scintillometer, but no anomalies were found.

Gas and oil

No active oil or natural gas seeps were noted during reconnaissance mapping of Amund Ringnes, Cornwall, and Haig-Thomas islands, although there are sulphurous deposits in the Deer Bay Formation (loc. B on Map 1471A) that may be partly the result of natural gas emanations.

At the time of writing, four dry boreholes had been drilled on or adjacent to Amund Ringnes Island (Table 1), and one well on Cornwall Island. The deepest borehole (Amund Central Dome H-40) bottomed at a level of 3364 m in the thick succession of Triassic pelitic rocks.

Reservoir beds

Strata comprising the Borden Island Formation and uppermost part of the Heiberg Formation constitute the gas reservoir at King Christian Island and at discoveries on the western coast of Ellef Ringnes Island (*Oilweek*, April 19, 1976). This succession is exposed over wide areas on Cornwall Island, along the crest of Cornwall Arch and also along the northern and southern rims of Amund Ringnes Piercement Dome. There is a significant difference in the degree of surface cementation of the strata at those separated localities: on Cornwall Island the strata are generally very poorly cemented and have excellent surface porosity (except locally at Mount Nicolay, where the sandstones are enclosed on three sides by gabbro intrusive sheets and are moderately well cemented by quartz); adjacent to the piercement dome, where there are both abundant large mafic intrusions and a large evaporite mass, sandstone is quartz-cemented and has poor intergranular porosity. Direct association of mafic intrusive rocks with the degree of sandstone cementation is probably an oversimplification. Width of cementation of sandstone strata crossed by dykes and sills is most commonly only a fraction of the width of the intrusion. Jaeger (1959) showed that the effects of the heat front adjacent to mafic dykes and sills dissipated abruptly away from the intrusions, so there is little likelihood that quartz is remobilized at shallow levels and precipitated in the pores of country rocks. It may be, however, that fissures (some of which were subsequently filled by mafic fluids that cooled as dykes and sills) were created during early stages of an intrusive event, allowing conduction of silica-bearing hydrothermal fluids from deep levels to permeate porous parts of the column, with resultant precipitation of quartz. Cemented sandstone wallrocks of the Awingak Formation, along a fault near Cape Ludwig (see Stratigraphy) thus may be a local demonstration of a phenomenon that is more widespread at deeper levels.

Other prospective Mesozoic reservoir intervals, from youngest to oldest, include porous sandstone comprising the Hassel, Isachsen, and Jaeger formations, sandstone intercalations in the Lower Member of the Heiberg Formation, distal sandstone tongues of the Schei Point Formation (a basin-marginal equivalent of Blaa Mountain pelites, which probably is present between Cornwall and Table islands, Figs. 4, 5), and the Bjorne Formation (Fig. 4). Cretaceous and Jurassic successions in this group outcrop widely on Cornwall and Amund Ringnes islands; their potential as reservoirs lies only in the offshore, interisland waterways where in some places they are buried to moderate depths and have not been exhumed since their deposition.

Upper Paleozoic rocks exposed along the southern margin of Sverdup Basin, as at Grinnell Peninsula (Fig. 5), are largely carbonates and sandstones. These rocks are believed to grade northward to pelitic strata in the axial part of the basin (Thorsteinsson and Tozer, 1970, p. 571), but there is no evidence (except for the confidential Mobil Cornwall 0-30 well) at present to indicate the variety of upper Paleozoic facies that exists there.

Source beds and organic metamorphism

Snowden and Roy (1975) discussed aspects of regional organic metamorphism for the Sverdrup Basin, based on gas analyses of well cuttings. From data mainly extrapolated from wells in the western part of the basin, they concluded that strata at the base of the Isachsen Formation are within the mature facies for occurrence of wet gas and oil, whereas rocks below the base of Jurassic shale are within the organically metamorphosed facies. Baker et al. (1975) presented data supporting the contention that oil potential of Mesozoic rocks in the Sverdrup Basin was good, particularly for the Awingak Formation.

A.E. Foscolos analyzed several samples of Mesozoic marine shale collected from outcrops on Amund Ringnes and Cornwall islands. Most of the samples contain amounts of organic carbon in excess of 0.5 per cent, and some samples from the Kanguk and Savik formations (Upper Cretaceous and Jurassic, respectively) have amounts of organic carbon in the order of 5 per cent by weight. The amount of extractable hydrocarbons, however, is relatively low. These data suggest that the organic carbon content of the shale is largely terrigenous plant detritus, rather than marine-derived, and that the organic-rich pelites are more likely to serve as source-rocks for natural gas than for petroleum. It is emphasized, however, that this suggestion is based on preliminary analyses of surface samples and, at best, is only a first-order approximation of the source-rock potential of the surface pelitic formations. Also noteworthy is the fact that the per cent (by weight) of organic carbon in the samples and the amounts of kerogen are significantly greater in the lower part of each shale interval than in the middle and upper parts. (This could be a function of sedimentation rates; relatively greater amounts of organic material might have accumulated during subdued rates of terrigenous clastic sedimentation for the marine-transgressive, lower parts of the pelitic intervals.)

A genetic association of phosphorites and petroleum has been suggested (McKelvey, 1959). Powell et al. (1975) proposed that the high proportion of soluble organic matter in unaltered phosphorites may indicate that oils derived from phosphatic source beds are capable of migration at an early stage of diagenesis. Parts of the Jaeger Formation and equivalent pelitic strata are phosphatic on Cornwall Island and in the subsurface of Amund Ringnes Island, as well as in other widespread parts of Sverdrup Basin (Tozer and Thorsteinsson, 1964) and they overlie natural gas reservoirs along the southwestern margin of the basin.

Depths of burial of marine shales on Amund Ringnes and Cornwall islands may be estimated within reasonable limits: the top of the Kanguk Formation represents, approximately, a datum marking the end of regional subsidence and marine deposition in the central Sverdrup Basin (see section on structural geology). On southern Amund Ringnes Island, about 300 m of mainly nonmarine strata, composing part of the Eureka Sound Formation, lie conformably on Kanguk shale (Fig. 4, Sec. C-D). These are the youngest rocks of the conformable succession and, thus, represent a minimum depth of burial for the top of the Kanguk Formation. The minimum approximate depth of burial of any interval is the thickness of strata between that interval and the top of the Kanguk Formation, to which are added 300 m. For example, shale comprising the lower part of the Savik Formation probably was buried to depths in the range of 3600 to 4200 m.

Traps

A previous section dealt with variations in the degree of cementation of sandstone in association with localities of mafic intrusions.

Theoretical considerations and some local evidence indicate that diapirism in parts of the Ringnes islands probably began, at the latest, by Middle Triassic and proceeded at varying rates, dependent on the rate of sedimentary loading, through Mesozoic time. Development

Table 3. Engineering characteristics of surface bedrock, Amund Ringnes, Cornwall and Haig-Thomas islands

FORMATION OR MAP-UNIT	LITHOLOGY	ENGINEERING CHARACTERISTICS
Alluvium	Sand, silt, clay, gravel	Water-saturated and thixotropic in summer, particularly during runoff (June-July); poor to fair material for fill
Marine deposits	Clay, silt, sand, gravel	Water-saturated on coastal plains; widespread standing water; poor material for fill
Glacial-fluvial gravel	Gravel	Fairly well graded; fair to good fill material
Unnamed Paleocene/ Eocene sandstones	Carbonaceous sandstone	Poorly cemented to non-cemented; fair fill material
Eureka Sound Formation	Sandstone	Poorly cemented to non-cemented; highly permeable at surface; fair fill material
Kanguk Formation	Shale	Low permeability; swelling clays; extremely acidic; sulphurous; unsuitable for fill material
Hassel Formation	Sandstone	Poorly cemented; high surface permeability; fair fill material
Christopher Fm	Shale	Low permeability; swelling clays at some levels; slopes undergo extreme solifluction; moderately acidic; possible sulphate reaction with concrete; poor to unsuitable fill material
Isachsen Formation	Sandstone	High surface permeability; upland areas drain well in summer, providing best terrain for off-strip aircraft landings
Deer Bay Formation	Shale; minor sandstone	Low permeability; swelling clays; retains water; very poor fill material
Awingak Formation	Sandstone	High surface permeability; fair fill material
Ringnes Formation	Shale	Low permeability; poor fill material
Savik Formation	Shale	Very low permeability; swelling clays; retains water; pyritic; unsuitable for fill
Jaeger Formation	Sandstone	High surface permeability; fair to good fill material
Borden Island Fm	Sandstone	High surface permeability; fair to good fill material
Borden Island Fm/ Heiberg Fm	Sandstone	Well cemented at surface; low to fair surface permeability; good sub-base material
Heiberg Formation (Upper Member)	Sandstone	Poorly cemented to well cemented; low to high surface permeability; good fill material
Heiberg Formation (Lower Member)	Sandstone and shale	Moderate to high surface permeability; poor to fair fill material
Blaa Mountain Fm	Shale and sandstone	Low to moderate surface permeability; poor to fair fill material
Gabbro intrusives	Gabbro	Moderately fractured at surface, forming felsenmeer terrain; good to excellent sub-base material
Rocks composing diapirs	Gypsum, anhydrite, limestone, dolomite	Gypsum and anhydrite unsuitable for fill material; carbonate rocks moderately fractured, good fill material

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of deep roots of folds associated with halikinetic migration, therefore, may be quite old, despite the fact that rocks as young as Late Cretaceous are folded at the surface. Ovate periclinal culminations, believed to be the products of evaporite migration, were drilled in three localities: West Amund I-44, Amund Central Dome H-40, and Linckens Island P-46. All of those wells were dry.

Folds and faults on eastern Amund Ringnes Island were suggested to be products of latest Cretaceous - early Tertiary uplift of the eastern flank of Cornwall Arch. For intermediate and deep parts of the succession, these folds may have developed after the main phases of maturation and migration of hydrocarbons.

Land use

General engineering properties of surface geological units on Amund Ringnes, Cornwall and Haig-Thomas islands are presented in Table 3.

Permafrost commonly is no deeper than about 0.5 m below the ground surface, and disruption of the permafrost regime presents the most acute danger to land use in the islands.

Expansion of the Canadian Seismography Network into the Arctic Islands revealed that parts of the region have seismic activity. Engineering design and construction must anticipate earthquakes (Stevens and Milne, 1973).

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Appendix

PALEONTOLOGY

Fossils collected from Amund Ringnes, Cornwall, and Haig-Thomas islands have been examined by stratigraphic paleontologists of the Geological Survey of Canada (and other affiliations, as noted) and the following lists and comments are from their reports. The approximate stratigraphic positions of the collections are as indicated; the geographic locations are noted on the geological map.

Macropaleontology

Pennsylvanian
by W.W. Nassichuk

Limestone blocks in diapirs

GSC loc. C-22183 (near western margin, Amund Ringnes Piercement Dome; collected by H.R. Balkwill)
Branneroceras branneri (Smith)
Age: Early Pennsylvanian

Triassic
by E.T. Tozer

Blaa Mountain Formation

GSC loc. C-22237 (central Cornwall Island; collected by H.R. Balkwill)
Monotis sp., *M. scutiformis* group
Age: Middle Norian, Columbianus Zone

GSC loc. C-22219 (north-central Cornwall Island; collected by H.R. Balkwill)
Monotis ochotica densestriata (Teller)
Age: Late Norian

GSC loc. C-22236 (south-central Cornwall island; collected by H.R. Balkwill)
Monotis ochotica densestriata (Teller)
Age: Late Norian

GSC loc. C-33111 (west-central Cornwall Island; collected by D.G. Wilson)
Monotis ochotica (Keyserling)
Age: Late Norian

GSC loc. C-8199 (Panarctic Amund Central Dome H-40 core, depth 1575 - 1578 m)
Monotis ochotica (Keyserling)
smooth ammonoids (arcestids?) indet.
Age: Late Norian

GSC loc. C-8200 (Panarctic Amund Central Dome H-40 core, depth 1578 - 1581 m)
Monotis ochotica (Keyserling)
Age: Late Norian

Heiberg Formation (Lower Member)

GSC loc. C-26625 (west-central Cornwall Island; collected by H.R. Balkwill)
Monotis ochotica Keyserling s.l.
Age: Late Norian

Jurassic
by D.V. Ager
(University College of Swansea, Wales)

Heiberg Formation (Upper Member)

GSC loc. C-26636 (southwestern Cornwall Island; lens of red sandstone about 20 m below top of Heiberg Formation; collected by H.R. Balkwill)
Cirpa cf. *C. fronto* (Quenstedt)
Lobothyris cf. *L. punctata* (J. Sowerby)
Age: Early Jurassic, late Sinemurian to early Pliensbachian; perhaps earliest Pliensbachian (Jamesoni Zone)

by H. Frebold

Heiberg Formation (Upper Member)

GSC loc. C-22707 (along Jaeger River; float sample from lens of red sandstone about 60 m below mapped top of Heiberg Formation; collected by K.J. Roy)
Leioceras opalinum (Reinecke) imprints of small specimens
Pseudolioceras m'clintocki (Haughton)
Age: Early Bajocian (=Aalenian)

GSC loc. 90893 (along Jaeger River; lens of red sandstone about 60 - 40 m below mapped top of Heiberg Formation; collected by K.J. Roy)
Pseudolioceras sp. indet.
Inoceramus sp.
Variamussium sp. indet.
Age: Early Bajocian (=Aalenian)

Jaeger Formation

GSC loc. C-26634 (southwestern Cornwall Island; uppermost part of unit JjA to lower part of unit JjD, Jaeger Formation; collected by G. Ward)
Peronoceras spinatum (Frebold)
Peronoceras polare (Frebold)
Dactylioceras cf. *D. commune* (Sowerby)
Dactylioceras cf. *D. athleticum* (Simpson)
Pseudolioceras cf. *P. compactile*
Pseudolioceras sp. indet.
Harpoceras aff. *H. exaratum* (Young and Bird)
Age and comments: *Harpoceras* aff. *H. exaratum* (Young and Bird) indicate an early Toarcian age, more precisely Exaratum Subzone of the Falcifer Zone.

The next younger species are *Dactylioceras* cf. *D. commune* (Simpson) and *D.* cf. *D. athleticum* (Simpson), which belong in the Commune and perhaps Braunianus subzones of the middle Toarcian Bifrons Zone. The next youngest ammonites in this collection are *Peronoceras spinatum* (Frebold), *P. polare* (Frebold), *Pseudolioceras* cf. *compactile* (Simpson), and *P.* cf. *P. spitzbergenense* (Frebold); the *Pseudolioceras-Peronoceras* bed is tentatively assigned to the early part of the late Toarcian

GSC loc. 90892 (ridge near Jaeger River; red sandstone in unit JjD of Jaeger Formation; collected by K.J. Roy)
Pseudolioceras cf. *P. m'clintocki* (Haughton)
Inoceramus sp. indet.
Age: Early Bajocian (=Aalenian)

GSC loc. C-22703 (ridge near Jaeger River; red sandstone in unit JjB of Jaeger Formation; collected by K.J. Roy)
Pseudolioceras sp. Fragments of a species previously described as *Grammoceras*? sp. indet. (Frebold, 1960, p. 23, Pl. 12, figs. 5, 6, 7)
Age: Toarcian

GSC loc. C-26637 (southwestern Cornwall Island; lower part of unit JjB of Jaeger Formation; collected by H.R. Balkwill)
Dactylioceras sp. indet. Group of *D. commune*. Fragments
Age: Middle Toarcian

GSC loc. C-26626 (northwestern Cornwall Island; lower part of unit JjB of Jaeger Formation; collected by H.R. Balkwill)
Dactylioceras sp. indet. Fragments
belemnites
Age: Middle Toarcian

GSC loc. C-22704 (Jaeger River; partly float, from upper part of unit JjB of Jaeger Formation; collected by K.J. Roy)
Harpoceras sensu lato sp. indet.
Family Dactylioceratidae Hyatt. Several genera are present; too small and too poorly preserved to warrant identification
Pseudolioceras sp. indet. Fragment
belemnoids, small specimens
Age: Toarcian

GSC loc. 90895 (Jaeger River; lower part of unit JjD, Jaeger Formation; collected by K.J. Roy)
Peronoceras spinatum (Frebold)
Peronoceras polare (Frebold)
Pseudolioceras compactile (Simpson)
Age: Toarcian

GSC loc. C-26635 (southwestern Cornwall Island; unit JjD, Jaeger Formation; collected by H.R. Balkwill)
Pseudolioceras spp. indet.
Age: Middle or late Toarcian

GSC loc. 90896 (Jaeger River; lower part of unit JjD, Jaeger Formation; collected by K.J. Roy)
Pseudolioceras sp. indet.
Age: Middle or late Toarcian

GSC loc. C-26633 (northwestern Cornwall Island; unit JjD, Jaeger Formation; collected by H.R. Balkwill)
Leioceras cf. *L. opalinum* (Reinecke)
Leioceras? or *Ludwigia*? gen. et sp. indet.
Inoceramus sp.
Pecten sp. indet.
Age: Early Bajocian (=Aalenian)

GSC loc. C-22705 (Jaeger River, Cornwall Island; middle part of unit JjD, Jaeger Formation; collected by K.J. Roy)
Pseudolioceras cf. *P. m'clintocki* (Haughton), imprint
Inoceramus sp. indet., fragments
Erycites sp. indet., fragment
Age: Early Bajocian (=Aalenian)

GSC loc. C-26618 (Jaeger River, Cornwall Island; unit JjD, about 50 m below top of Jaeger Formation; collected by K.J. Roy)
Pseudolioceras aff. *P. m'clintocki*
Variamussium sp.
Age: probably early Bajocian (=Aalenian)

Savik Formation

GSC loc. C-22232 (northern Amund Ringnes Island; about 100 m above base of Savik Formation; collected by H.R. Balkwill)
Oxytoma jacksoni (Dompeckj)
Age: Early Bajocian (=Aalenian)

GSC loc. C-57613 (northern Amund Ringnes Island; about 160 m below top of Savik Formation; collected by H.R. Balkwill)
Cadoceras septentrionale latidorsata Frebold
Cadoceras sp. indet.
Age: Early Callovian

GSC loc. C-26629 (central Amund Ringnes Island; about 70 m below top of Savik Formation; collected by H.R. Balkwill)
Cadoceras septentrionale Frebold. This species is similar to *Cadoceras tolype* Buckman and *C. sublaeve* (Sowerby) (see Frebold, 1964, p. 7 - 9).
Cadoceras bodylevskyi Frebold (see Frebold, 1964, p. 10, 11)
Age: Early Callovian

GSC loc. C-22230 (southern Amund Ringnes Island; about 15 m below top of Savik Formation; collected by H.R. Balkwill)
Cadoceras sp. aff. *C. septentrionale* Frebold
Age: Early Callovian

by J.A. Jeletzky

Ringnes Formation

GSC loc. C-22234 (northern Amund Ringnes Island; lower part of Ringnes Formation; collected by H.R. Balkwill)
Buchia (Anaucella) concentrica (Sowerby) s.l.
Turritella-like gastropod
Age: some part of the *Buchia concentrica* zone of late Oxfordian to early Kimmeridgian age

GSC loc. C-22200 (central Amund Ringnes Island; about middle of Ringnes Formation; collected by H.R. Balkwill)

Buchia (Anaucella) concentrica (Sowerby) (large, flat, early forms)

Age: some part of the *Buchia concentrica* zone and of late Oxfordian to early Kimmeridgian age; probably from the upper (or possibly uppermost lower) Oxfordian part of *Buchia concentrica* zone

GSC loc. 81751 (central Amund Ringnes Island; about middle of Ringnes Formation; collected by geologists of Mobil Oil Canada)

cf. *Buchia* ex gr. *concentrica* (Sowerby)

Age: possibly late Oxfordian to early Kimmeridgian, but dating is tentative because of poor preservation

GSC loc. C-22199 (central Amund Ringnes Island; near top of Ringnes Formation; collected by H.R. Balkwill)

Buchia (Anaucella) concentrica (Sowerby)

Age: some part of the *Buchia concentrica* zone of late Oxfordian to early Kimmeridgian age

GSC loc. C-22251 (central Amund Ringnes Island; near top of Ringnes Formation; collected by H.R. Balkwill)

Buchia (Anaucella) concentrica (Sowerby) s.l.
Meleagrinella aff. *M. articostata* Zakharov
Cylindroteuthis (Communicobelus) sp. indet.

Age: some part of the *Buchia concentrica* zone of late Oxfordian to early Kimmeridgian age

GSC loc. C-22222 (central Amund Ringnes Island; at top of Ringnes Formation; collected by H.R. Balkwill)

Buchia mosquensis (von Buch) s.l.
indeterminate pelecypods

Age: some part of *Buchia mosquensis* s.l. zone and of a general mid-Kimmeridgian to early Portlandian (=early Early Volgian) age in terms of international standard stages

Awingak Formation

GSC loc. C-22228 (eastern Cornwall Island; upper middle part of the Awingak Formation; collected by H.R. Balkwill)

Pecten (Camptonectes) cf. *praecinctus* Spath
Pholadomya sp. indet.
?*Astarte* sp. indet.

Age: probably some part of the Late Jurassic (Oxfordian to Late Tithonian inclusive)

GSC loc. C-22231 (southern Amund Ringnes Island; upper middle part of the Awingak Formation; collected by H.R. Balkwill)

Buchia mosquensis (von Buch). Early forms, partly transitional to *Buchia (Anaucella) concentrica* Sowerby
a poor ?cardioceratid ammonite
Pecten (Camptonectes) praecinctus (Spath)
?*Astarte* (s.l.) sp. indet.
"Turbo" ex gr. *ferniensis* (Frebold)
indeterminate true belemnite (a phragmocone)

Age: Mid-Kimmeridgian (more likely) or (?)late Kimmeridgian; represents the lower (possibly basal part transitional to *Buchia (Anaucella) concentrica* zone) part of *Buchia mosquensis* s.l. zone

Deer Bay Formation

GSC loc. C-22248 (east-central Amund Ringnes Island; middle part of unit JKdA; collected by H.R. Balkwill)

?*Pavlovia* or ?*Dorsoplanites* sp. indet.
Buchia fischeriana (d'Orbigny)
Lima (Limea) sp. indet.

Age: most likely early part of the Late Volgian; zone of *Buchia fischeriana* (d'Orbigny) s.l. (see Jeletzky, 1966, p. 43)

GSC loc. 81737 (central Amund Ringnes Island; upper middle part of unit JKdA; collected by Mobil Oil Canada geologists)

indeterminate perisphinctid ammonites
Buchia fischeriana (d'Orbigny) s. str.
Lima (Limea) cf. *L. (L.) blackei* Cox
Modiolus sp. indet.

Age: *Buchia fischeriana* zone of the Late Volgian (see Jeletzky, 1966, p. 30)

GSC loc. C-22223 (central Amund Ringnes Island; upper part of unit JKdA; collected by H.R. Balkwill)

Buchia cf. *B. fischeriana* (d'Orbigny) s.l.
Cerithium-type gastropods
?*Oxytoma* sp. indet.

Age: tentatively early Late Volgian

GSC loc. C-22212 (eastern Amund Ringnes Island; from unit JKdB; collected by H.R. Balkwill)

Dorsoplanites sp. indet.
Buchia fischeriana (d'Orbigny)
Meleagrinella cf. *M. articostata* Zakharov

Age: most likely early part of Late Volgian

GSC loc. C-26630 (west-central Amund Ringnes Island; from marker JKdB; collected by H.R. Balkwill)

?*Pavlovia* or ?*Dorsoplanites* sp. indet.
Buchia fischeriana (d'Orbigny)
?*Mya* (s.l.) sp. indet.
?*Astarte* (s.l.) sp. indet.

Age: most likely part of Late Volgian; zone of *Buchia fischeriana* (d'Orbigny) s.l. (see Jeletzky, 1966, p. 43)

GSC loc. C-26624 (southeastern Cornwall Island; lower part of unit JKdC; collected by H.R. Balkwill)

Buchia cf. *B. fischeriana* (d'Orbigny)

Age: tentatively early Late Volgian

GSC loc. C-33978 (Jaeger River, eastern Cornwall Island; unit JKdC; collected by K.J. Roy)

Buchia cf. *B. fischeriana* (d'Orbigny) s.l. (a single, imperfectly preserved left valve)

Age: tentatively early part of the Late Volgian

GSC loc. C-22201 (south-central Amund Ringnes Island; middle part of unit JKdC; collected by H.R. Balkwill)

Buchia cf. *B. terebratuloides* (Lahusen) f. typ. and var. (Pavlow)
Buchia cf. *B. fischeriana* (d'Orbigny)

Age: probably some part (?lower) of *Buchia terebratuloides* s.l. and *Buchia* n. sp. aff. *okensis* fauna of the latest Jurassic (late Late Volgian or late Late Tithonian). In the Canadian Arctic Archipelago, this zone corresponds to the *Craspedites (?Taimyroceras) canadensis* and *Buchia unschensis* s. str. fauna occuring 304 m above the base of Deer Bay shale on Ellesmere Island

GSC loc. C-26628 (Jaeger River, eastern Cornwall Island; upper part of unit JKdC; collected by H.R. Balkwill)
Buchia n. sp. aff. *B. okensis* (Pavlow)
Buchia terebratuloides (Lahusen)
Buchia aff. *B. lahuseni* (Pavlow)
Buchia fischeriana (d'Orbigny) var. *B. trigonoides* (Lahusen)
Age: some part (?lower) of the uppermost Jurassic (uppermost Tithonian or uppermost Volgian) zone of *Buchia terebratuloides* s.l. and *Buchia. n. sp. aff. B. okensis* (see Jeletzky, 1971, p. 4, Fig. 2)

GSC loc. C-22710 (Jaeger River, eastern Cornwall Island; upper part of unit JKdC; collected by K.J. Roy)
Buchia n. sp. aff. *B. okensis* (Pavlow)
Buchia unschensis (Pavlow)
Buchia terebratuloides (Lahusen)
Buchia fischeriana (d'Orbigny)
Age: as for GSC loc. C-26628

GSC loc. C-22207 (southeastern Amund Ringnes Island; upper part of unit JKdC; collected by H.R. Balkwill)
Buchia sp. indet. of general early Early Cretaceous affinities (?*Buchia okensis* s.l.)
Age: early Early Cretaceous (Berriasian or ?Valanginian). Large *Buchia* fragments resemble those of giant forms of *Buchia okensis* f. typ. If so, the age would be early Berriasian. All fragments are, however, too poor to be certain of their specific affinities

GSC loc. C-26619 (western Cornwall Island; upper part of unit JKdC; collected by H.R. Balkwill)
Buchia sp. indet. (?of general Early Cretaceous affinities)
Age: early Early Cretaceous

GSC loc. C-22224 (central Amund Ringnes Island; marker JKdD; collected by H.R. Balkwill)
Buchia keyserlingi (Lahusen) f. typ.
Buchia cf. *B. uncitoides* (Pavlow) s.l.
Partischiceras sp. indet. (a phylloceratid ammonite)
Pleuromya sp. indet.
Age: Early Valanginian; *Buchia keyserlingi* zone (see Jeletzky, 1964, Table 1)

GSC loc. C-22252 (eastern Amund Ringnes Island; upper part undivided Deer Bay Formation; collected by H.R. Balkwill)
Buchia sp. indet. of general Early Cretaceous affinities
Lima (?*Limea*) sp. indet.
Age: early Early Cretaceous (Berriasian or Valanginan)

GSC loc. C-26631 (northern Amund Ringnes Island; about 100 m below top of Deer Bay Formation; collected by H.R. Balkwill)
Buchia tolmatschowi (Sokolow) (rare, ?early forms)
Buchia keyserlingi (Lahusen) (rare, half-grown specimens)
Buchia sp. indet.
Pholadomya sp. indet.
?*Donax* (s.l.) sp. indet.
Age: some part (?lower) of *Buchia tolmatschowi* zone of the Pacific Coast of North America (see Jeletzky, 1965, p. 35 - 43, Figs. 1, 2); some part of the early (exclusive of latest early) Valanginian

GSC loc. C-22245 (eastern Amund Ringnes Island; middle part of unit JKdE; collected by H.R. Balkwill)
Buchia pacifica Jeletzky
Buchia tolmatschowi (Sokolow) late forms transitional to *B.t.* var. *americana* (Sokolow)
Buchia cf. *B. inflata* (Toula)
Age: latest early or early middle Valanginian; lower part of the *Buchia pacifica* zone (i.e. *Buchia pacifica* subzone) of the Pacific Coast of North America (see Jeletzky, 1965, p. 43 - 49, Figs. 1, 2)

GSC loc. 85023 (northern Amund Ringnes Island; upper part of the Deer Bay Formation; collected by Mobil Oil Canada Limited geologists)
Polyptychites (?*Polyptychites*) ex aff. *P.* (? *P.*) *ascendens* Koenen
Buchia bulloides (Lahusen)
Buchia cf. *B. nuciformis* (Pavlow)
Age: late middle Valanginian

GSC loc. C-22198 (east-central Amund Ringnes Island; about 75 m below top of Deer Bay Formation; collected by H.R. Balkwill)
Buchia inflata (Toula) including *B. crassicollis*-like forms ("phase crassicollis" prevalent)
Buchia bulloides (Lahusen)
Age: middle to late Valanginian

GSC loc. C-22202 (eastern Amund Ringnes Island, near Geologist Bay; about 60 m below top of Deer Bay Formation; collected by H.R. Balkwill)
Buchia cf. *B. inflata* (Toula)
Buchia cf. *B. bulloides* (Lahusen)
Age: probably middle to late Valanginian, but cannot be dated definitely because of poor preservation

GSC loc. C-22195 (central Amund Ringnes Island; about 10 m below top of Deer Bay Formation; collected by H.R. Balkwill)
Buchia n. sp. aff. *B. inflata* (Toula)
Buchia bulloides (Lahusen)
Age: middle to late Valanginian (see Jeletzky, 1965, p. 52, 54)

GSC loc. C-22225 (western Amund Ringnes Island; several metres below top of Deer Bay Formation; collected by H.R. Balkwill)
Buchia n. sp. aff. *B. inflata* (Toula)
Buchia bulloides (Lahusen)
Age: middle to late Valanginian

GSC loc. C-22238 (western Amund Ringnes Island; at top of Deer Bay Formation; collected by H.R. Balkwill)
Buchia n. sp. aff. *B. inflata* (Toula)
Age: middle to late Valanginian

GSC loc. C-22239 (northwestern Amund Ringnes Island; near faulted contact with Isachsen Formation; collected by H.R. Balkwill)
Buchia inflata (Toula)
Age: middle to late Valanginian

Christopher Formation

GSC loc. C-22211 (eastern Amund Ringnes Island; from glauconitic sandstones at top of unit Kcl; collected by H.R. Balkwill)

?*Tancredis kurupana* Imlay

Age: possibly Albian

GSC loc. C-22253 (northern Amund Ringnes Island; several metres above base of unit Kcu; collected by W.V. Sliter)

"*Gastroplites*" (a new genus? ex aff. n. sp. A of Jeletzky, 1964)

Cleoniceras (Cleoniceras) n. spp. aff. *C. (C.) tailleuri* Imlay and *C. (C.) cleon* (d'Orbigny)

Cleoniceras (?*Grycia*) n. sp.

Beaudanticeras (Grantziceras) glabrum (Whiteaves)

Inoceramus anglicus Woods

Age: Middle Albian, possibly early Middle Albian

GSC loc. C-22214 (northeastern Amund Ringnes Island; upper part of unit Kcu; collected by H.R. Balkwill)

Panope ?*elongatissima* (McLearn)

Arctica (s.l.) sp. indet.

Nucula (s.l.) sp. indet.

?*Pinna* sp. indet.

Age: probably some part of the Albian

GSC loc. C-22217 (northern Amund Ringnes Island; about 3 - 12 m below top of the Christopher Formation; collected by H.R. Balkwill)

?*Pleuromya* sp. indet.

?*Panope kissoumi* (McLearn)

?*Arctica* (s.l.) sp. indet.

Age: possibly some part of the Albian

Kanguk Formation

GSC loc. C-22215 (northern Amund Ringnes Island; about 30 - 45 m above base of Kanguk Formation; collected by H.R. Balkwill)

Borissjakoceras sp. indet.

Scaphites (Scaphites) delicatulus Warren

Actinocamax aff. *A. plenus* (de Blaniville)

Inoceramus labiatus Schlotheim

Inoceramus aff. *I. pictus* Sowerby (small forms)

vertebrate bones

Age: Early Turonian (i.e. *Wati- noceras* and *Inoceramus labiatus* zone; see Jeletzky, 1968, p. 27, 28; 1970, p. 51, 52). The lot can be placed, furthermore, in the upper part (subzone) of the interregional *Watinoceras and Inoceramus labiatus* zone characterized by *Watinoceras reesidei* and *Scaphites (Scaphites) delicatulus* (see Jeletzky, 1968, p. 28; Cobban and Gryc, 1961)

GSC loc. C-22698 (northern Amund Ringnes Island; about 35 m above base of Kanguk Formation; collected by K.J. Roy)

Scaphites (Scaphites) delicatulus Warren

Otoscaphites cf. *O. seabeensis* Cobban and Gryc

Age: Early Turonian; see comments for GSC loc. C-22215.

Micropaleontology

Triassic
by Robertson Research (North America) Limited

Heiberg Formation (Upper Member)

GSC loc. C-37144 (southwestern Cornwall Island; about 100 m above base of Upper Member; collected by D.G. Wilson)

Ricciisporites spp.

Ricciisporites tuberculatus

Limbosporites lundbladii

Striatisaccus rhaeticus

Chasmatosporites sp.

Polycingulatisporites sp.

Circulina meyeriana

Duplexisporites problematicus

Ovalipollis sp.

Anemiidites spinosus

Dictyophyllidites sp.

Alisporites sp.

Protodiploxypinus sp.

Age: Late Norian - early Rhaetian

GSC loc. C-30132 (Jaeger River, east-central Cornwall Island; about 130 m above base of Upper Member; collected by K.J. Roy)

Ricciisporites sp.

Ricciisporites tuberculatus

Lycospora sp.

Age: tentatively Rhaetian

GSC loc. C-37148 (southwestern Cornwall Island; about 40 m below top of Upper Member; collected by D.G. Wilson)

Duplexisporites problematicus

Dictyophyllidites mortoni

?*Infernopollenites* sp.

Infernopollenites sp.

Alisporites sp.

Cycadopites sp.

Classopollis sp.

Polycingulatisporites sp.

Age: tentatively Late Triassic

Jurassic
by Robertson Research (North America) Limited

Heiberg Formation (Upper Member)

GSC loc. C-30135 (Jaeger River, east-central Cornwall Island; about 210 m above base of Upper Member; collected by K.J. Roy)

Osmundacidites wellmanii

Stereisporites sp.

Triancoraesporites comaumensis

Deltoidospora neddeni

Age: tentatively ?Jurassic

GSC loc. C-30138 (Jaeger River, east-central Cornwall Island; about 390 m above base of Upper Member; collected by K.J. Roy)

Ischyosporites marburgensis

Deltoidospora neddeni

Baculatisporites sp.

Araucariacites fissus

Polycingulatisporites mooniensis

Osmundacidites wellmanii

Contignisporites sp.

Eucommidites troedssoni
Alisporites sp.
Classipollis sp.
Cycadopites sp.
Schizosporis sp.
Concavisporites lunzensis
Baltisphaeridium sp.
Camarozonotriletes rudis
Circulina sp.
Vitreisporites pallidus
Pilosisporites cf. *P. trichopapillosus*
Marattisporites scabratus
Tsugaepollenites sp.
Cingutriletes sp.
Cyathidites australis
Densoisporites
Age: tentatively Early Jurassic

GSC loc. C-30139 (Jaeger River, east-central Cornwall Island; about 180 m below top of Upper Member; collected by K.J. Roy)
Alisporites thomasii
Deltoidospora neddeni
Vitreisporites pallidus
Osmundacidites wellmanii
Contignisporites sp.
Deltoidospora psilostoma
Eucommidites troedssoni
Foveosporites sp.
Biretisporites potoniaei
Dictyophyllidites mortoni
Araucariacites fissus
Ischyosporites marburgensis
Neoraistrickia elongatus
Anapiculatisporites dawsonensis
Lycopodiumsporites austroclavatidites
Age: tentatively Early Jurassic

GSC loc. C-37145 (southwestern Cornwall Island; about 115 m below top of Upper Member; collected by D.G. Wilson)
Gleicheniidites sp. cf. *delicatus*
Callialasporites sp.
Classopollis sp.
Cerebropollenites mesozoicus
Age: tentatively Jurassic(?)

GSC loc. C-30153 (Jaeger River, east-central Cornwall Island; about 50 m below top of Upper Member; collected by K.J. Roy)
Todiosporites minor
Classopollis sp.
Polycingulatisporites sp.
Cerebropollenites mesozoicus
Osmundacidites wellmanii
Vitreisporites pallidus
Foveosporites sp.
Sestrosporites sp.
Eucommiidites troedssoni
Age: tentatively Jurassic(?)

Cretaceous
by J.H. Wall

Christopher Formation

GSC loc. C-36868 (eastern Cornwall Island; isolated outcrop of dark grey shale; collected by H.R. Balkwill)
Haplophragmoides sp. cf. *H. sluzari* Mellon and Wall
"*Tritaxia*" *athabascensis* Mellon and Wall
Saracenaria sp. B of Stelck and Wall, 1956
Saracenaria spp., including large inflated form
Marginulinopsis collinsi Mellon and Wall
Marginulinopsis sp.
Pseudonodosaria sp. (one specimen)
Dentalina sp. (large incomplete specimen)
Astocolus sp. (one specimen)
Pyrulinoides sp. (one specimen)
Globulina lacrima canadensis Mellon and Wall
Globulina sp.
Globorotalites alaskensis Tappan (common)
Gavelinella stictata (Tappan)
Age: Early to Middle Albian
Environment: the diversity and dominance of calcareous Foraminifera suggest an environment in the middle or outer shelf zone

by W.S. Hopkins, Jr.

Christopher Formation

GSC loc. C-29928 (southwestern Amund Ringnes Island; estimated to be about 200 m below top of Christopher Formation; collected by H.R. Balkwill)
Sphagnum sp.
Lycopodium sp.
Cicatricosisporites spp.
Gleicheniidites sp.
Cyathidites sp.
Trilobosporites sp.
Cingulatisporites sp.
Appendicisporites sp.
Leptolepidites sp.
cf. *Eucommiidites* sp.
Podocarpidites sp.
Glyptostrobus sp.
Tsuga sp.
Taxodiaceae - Cupressaceae
miscellaneous bisaccate conifer pollen
Age: Early Cretaceous

Kanguk Formation

GSC loc. C-29929 (southwestern Amund Ringnes Island; several metres above base of Kanguk Formation; collected by H.R. Balkwill)
Lycopodium sp.
Gleicheniidites sp.
Tsuga sp.
Glyptostrobus sp.
cf. *Podocarpidites* sp.
Taxodiaceae - Cupressaceae
miscellaneous bisaccate conifer pollen
Tricolpites sp.
Retitricolpites sp.
miscellaneous phytoplankton
Age: Late Cretaceous

Eureka Sound Formation

GSC loc. C-21784 (southwestern Amund Ringnes Island; estimated to be about 210 m above base of Eureka Sound Formation; collected by H.R. Balkwill)
Appendicisporites sp.
Apiculatasporites sp.
Camarozonosporites sp.
Lycopodiacidites sp.
Lycopodiumsporites sp.

Gleicheniidites sp.
Cingutrilites spp.
Osmundacidites sp.
Cicatricosisporites sp.
Ginkgocycadophytus sp.
Tsugaepollenites sp.
Taxodiaceae - Cupressaceae
Glyptostrobus sp.
cf. *Metasequoia* sp.
Taxodium sp.
Podocarpus sp.
miscellaneous bisaccate conifer pollen
Aquilapollenites sp.
Triporites sp.
Tricolpites sp.
Age: Maastrichtian

Tertiary
by W.S. Hopkins, Jr.

Unnamed Paleocene-Eocene sandstone

GSC loc. C-19605 (central Cornwall Island; outlier of yellow-buff sandstone lying unconformably on Blaa Mountain Formation; collected by H.R. Balkwill and W.S. Hopkins, Jr.)
Deltoidospora sp.
Sphagnum antiquasporites Wilson and Meeker
Cyathidites minor Couper
miscellaneous bisaccate conifer pollen
Taxodiaceae
cf. *Juniperus* sp.
Taxodium sp.
cf. *Podocarpus* sp.
cf. Liliaceae
Tilia sp.
cf. *Carpinus* sp.
Castanea-type
cf. *Ulmus* sp.
cf. *Betula* sp.
Carya sp.
Paraalnipollenites sp.
Age: Late Paleocene to middle Eocene

GSC loc. C-19606 (central Cornwall Island; outlier of yellow-buff sandstone lying unconformably on Blaa Mountain Formation; collected by H.R. Balkwill and W.S. Hopkins, Jr.)
Laevigatosporites sp.
miscellaneous bisaccate conifer pollen
Tsuga sp.
cf. *Glyptostrobus* sp.
cf. Liliaceae
Carya sp.
Castanea-type
Tricolporopollenites spp.
Nyssa sp.
Tricolpites spp.
cf. *Betula* sp.
Alnus verus (Potonié) Martin and Rouse
Tilia sp.
cf. *Carpinus* sp.
Age: Late Paleocene to middle Eocene

GSC loc. C-19608 (southern Amund Ringnes Island; outlier of yellow-buff sandstone lying unconformably on Deer Bay Formation; collected by H.R. Balkwill)
Lycopodiacidites sp.
Laevigatosporites sp.
Cicatricosisporites sp.
Baculatisporites sp.
Deltoidospora sp.
Sphagnum antiquasporites Wilson and Webster
miscellaneous bisaccate conifer pollen
Tsuga sp.
Podocarpus sp.
Taxodiaceae
Tricolporopollenites sp.
Tricolpites spp.
cf. *Quercus* sp.
Pistillipollenites macgregorii Rouse
Aquilapollenites cf *A. spinulosus* Funkhouser
cf. *Carya* sp.
Age: Paleocene

ADDENDUM

This memoir was prepared and submitted for critical review in 1976. Some stratigraphic revisions were made following 1979 traverses on Cornwall Island and southern Amund Ringnes Island. New data and concepts, resulting from subsequent field and subsurface studies, additional wells, and reflection seismic programs in this area and other parts of Sverdrup Basin, require qualification of some of the material presented in the memoir.

Stratigraphy

Embry (1982, 1983a, 1983b), from basin-wide field and subsurface studies, delineated depositional sequences in the Sverdrup Basin Mesozoic succession, from which he revised stratigraphic nomenclature.

- Norian shales, assigned in this report to the Blaa Mountain Formation, have been renamed the Barrow Formation by Embry;
- Norian marine sandstones and shales (Lower Heiberg Member) have been renamed the Romulus Member of the Heiberg Formation;
- Norian – Pliensbachian, mainly non-marine sandstones (Upper Heiberg Member) have been renamed the Fosheim Member of the Heiberg Formation;
- Pliensbachian – Toarcian marine sandstones and shales (uppermost Heiberg Formation, Borden Island Formation, and members A and B of the Jaeger Formation) have been renamed the Remus Member of the Heiberg Formation;
- Toarcian – Rajocian shales on Cornwall Island (Member C of the Jaeger Formation) have been renamed the Jameson Bay Formation;
- Aelenian sandstones (Member D of the Jaeger Formation) have been renamed the Sandy Point Formation;
- Bajocian – Callovian shales of Cornwall Island (lower part of the Upper Savik Member) have been renamed the McConnell Island Formation;
- ?Callovian – Oxfordian unnamed sandstones of Cornwall Island (included in the Upper Savik Member) have been named the Hiccles Cove Formation;
- Oxfordian – Kimmeridgian black shales of Cornwall Island (upper part of the Upper Savik Member) have been named the Ringnes Formation (following Balkwill et al., 1977);
- Bajocian – Valanginian shales of northern Amund Ringnes Island (Upper Savik Member and Deer Bay Formation) have been renamed the Mackenzie King Formation, which is divisible in most outcrops and some wells as the McConnell Island Member (Bajocian – Callovian), Ringnes Member (Oxfordian – Kimmeridgian), and Deer Bay Member (Volgian – Valanginian).

Mobil Cornwall O-30

Mobil Cornwall O-30 (N77°29'47"; W94°38'58") was drilled and abandoned in summer 1979. The well spudded in Norian Barrow Formation shales (Blaa Mountain Formation of former usage) and reached a total depth of 3584 metres in probable Carboniferous siltstones. The well penetrated about 150m of Barrow Formation pelites, about 650m of Schei Point Formation (Anisian – Karnian) calcareous siltstones and shales, about 800m of Blind Fjord Formation (Lower Triassic) pelites and sandstones, and about 2000m of upper Paleozoic sandstones, siltstones, and shales. No hydrocarbon shows were reported from the well; no tests were conducted.

The very thick succession of Triassic and upper Paleozoic clastic rocks drilled at Cornwall indicates that the region now occupied by the southern part of Cornwall Arch was within the regional depositional low along the southern margin of the Sverdrup Basin depocentre during late Paleozoic and Early and Middle Triassic; there is no evidence in the stratigraphic succession that the site of the arch had any positive tendencies during those times.

Structural and Tectonic Interpretation

Industry reflection seismic profiles show clearly that halokinesis was active in central Sverdrup Basin by Middle Triassic time, and was intermittent from then to Late Cretaceous. The seismic profiles show also that regional unconformities, evident in outcrops and subsurface relationships at the basin margins (but stable in central parts of the basin) are enhanced at the flanks of some diapirs. Some of the structural relief across the diapirs is therefore a product of episodic differential basin deepening and filling.

Regional stratigraphic relationships indicate that a long-lasting tectonic hinge extended approximately east-west through the location of Belcher Channel. The local hinge element was part of a regional, horseshoe-shaped tectonic rim, encompassing the Ringnes Islands and most of Axel Heiberg Island, and open to the north in the region of Massey Sound (see Balkwill and Fox, 1982). The internal part of the hinge region, including Cornwall Island and Amund Ringnes Island, was a persistent depocentre, where deep-water facies are common and stratigraphic thicknesses are erratic because of continued syndepositional halokinesis. Therefore, very thick stratigraphic sections of some units, such as the Deer Bay Formation on the northern flank of Amund Ringnes Piercement Dome, probably should not be taken as representations of widespread regional thicknesses.

A re-evaluation of the timing and kinematics of the Eurekan Orogeny is in order. Regional stratigraphic evidence shows that an upward coarsening clastic wedge, comprising the Cretaceous part of the Eureka Sound Formation, migrated westward across Sverdrup Basin to the Arctic continental margin in Campanian and Maastrichtian. This sequence is now believed to be evidence of uplift of the eastern margin of the basin, as a prelude to regional Eurekan compression that extended until late Eocene or Oligocene. The Eurekan compressional structural system is a self-contained foreland belt, bounded on all sides by undeformed or little-deformed rocks. The Eurekan belt has a relatively simple structural style, lacking - at the surface - a thermally mobilized zone. Supracrustal shortening across the system of upright folds and detachments faults must be balanced by deep crustal shortening. It is now proposed (Balkwill, 1983) that uplift of Cornwall Arch was a response to regional compression: the arch is probably underlain by large reverse faults, which may penetrate to a mobilized zone deep in the crust; the normal fault geometries portrayed in Figures 4 and 26 are now considered unlikely. It is proposed, further, that Eurekan crustal compression and thickening, and uplift of Cornwall Arch took place on large listric faults that had acted as extension faults during early Sverdrup Basin rifting and subsidence. This form of structural inversion may apply to some other immense tectonic elements of central Sverdrup Basin, such as Princess Margaret Arch of Axel Heiberg Island and Grantland Uplift of Ellesmere Island (see Trettin and Balkwill, 1979).

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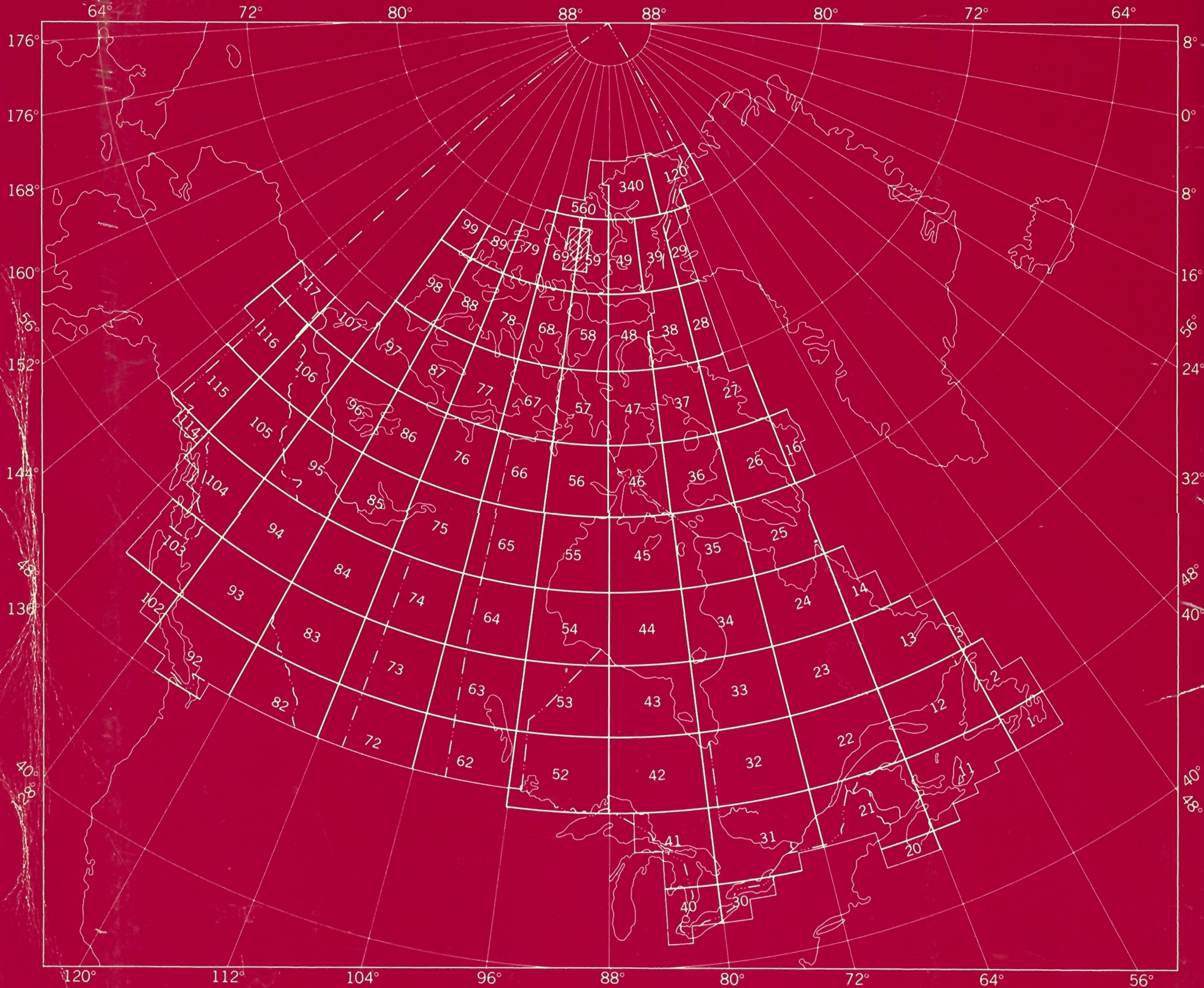
H.R. Balkwill
October, 1983



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