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GEOLOGY OF LOUGHEED ISLAND AND NEARBY SMALL ISLANDS DISTRICT OF FRANKLIN (PARTS OF 69C, 79D)

H.R. BALKWILL
W.S. HOPKINS, JR.
J.H. WALL

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Preface

Natural gas and oil were discovered at wells offshore from Lougheed Island in 1979 and 1980. These discoveries, combined with earlier drilling at King Christian Island and at Sabine Peninsula, Melville Island, confirm the existence of a wide area having hydrocarbon potential that extends northeastward through western Sverdrup Basin.

This report, based on field work carried out in 1976, presents surface and subsurface data and interpretations for the thick Mesozoic rock succession of the Lougheed Island area and describes their stratigraphy in relation to the succession at King Christian Island and Sabine Peninsula.

R.A. Price
Director General
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OTTAWA, December 1982

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GEOLOGY OF LOUGHEED ISLAND AND NEARBY SMALL ISLANDS, DISTRICT OF FRANKLIN (PARTS OF 69C, 79D)

Abstract

A succession of Lower and Upper Cretaceous terrigenous clastic rocks, about 1540 m thick, is exposed on Lougheed Island and nearby small islands; the exposed rock units are the Isachsen, Christopher, Hassel, Kanguk, and Eureka Sound formations. Two exploratory wells drilled on Lougheed Island penetrated Mesozoic rocks to the level of the Lower Triassic Bjorne Formation. The Mesozoic succession at Lougheed Island is significantly thinner than it is eastward toward the central part of the Sverdrup Basin.

A syncline with gently dipping limbs plunges southward toward central Lougheed Island. Small flexural-flow folds, with enigmatic origins, are present on Edmund Walker Island.

Regional studies indicate that favourable prospects for hydrocarbons should exist in the environs of Lougheed Island: the island is about midway between proven large natural gas fields at King Christian Island and at Sabine Peninsula (Melville Island); and the subsurface rocks should have general levels of organic maturation, reservoir quality, and geological structure comparable with those fields.

Résumé

Une succession de roches clastiques terrigènes du Crétacé inférieur et du Crétacé supérieur, d'environ 1540 m d'épaisseur, affleure sur l'île Lougheed et les petites îles proches; les unités lithostratigraphiques exposées sont les formations d'Isachsen, Christopher, Hassel, Kanguk et Eureka Sound. Deux puits d'exploration forés sur l'île Lougheed ont traversé les roches mésozoiques jusqu'au niveau de la formation de Bjorne, du Trias inférieur. Sur l'île Lougheed, la succession Mésozoique est considérablement plus mince qu'à l'est, en direction du centre du bassin de Sverdrup.

Un synclinal, caracterisé par des flancs de faible inclinaison, plonge vers le sud en direction du centre de l'île Lougheed. De petits plissements en flexure, d'origine mystérieuse, ont été découverts sur l'île Edmund Walker.

Ce qu'on connaît de la région indique qu'il pourrait y avoir des gisements prometteurs d'hydrocarbures aux environs de l'île Lougheed: celle-ci se situe à mi-chemin entre les vastes champs de gaz natural, aux reserves prouvées, de l'île Roi-Christian et de la péninsule Sabine (île Melville); d'autre part, son sous-sol possède sans doute des caractères comparables à ceux des champs gazéifères, du point de vue de la maturation des dépôts organiques, de la qualité des réservoirs, et de la structure géologique.

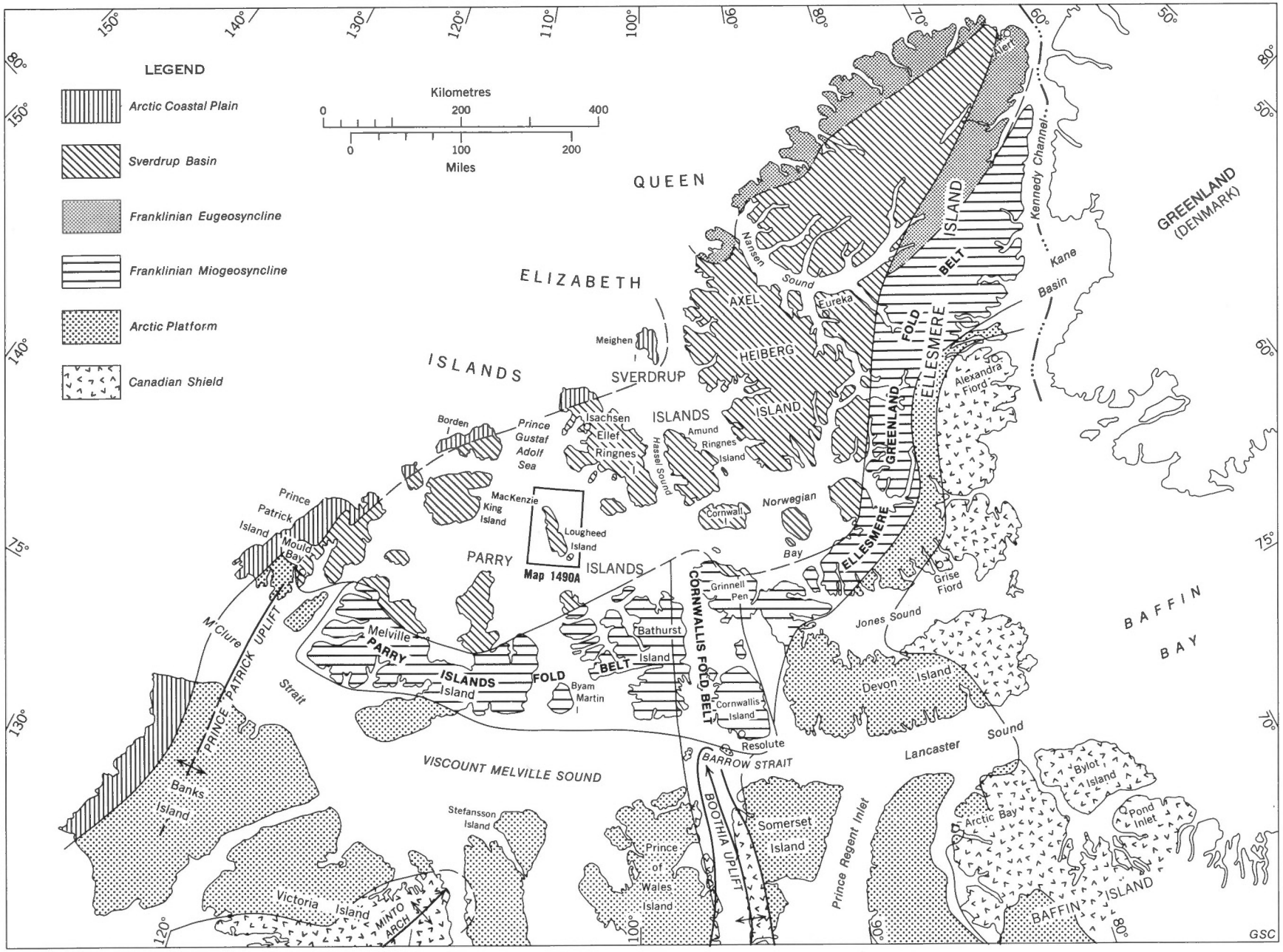


FIGURE 1a. *Geological provinces, Queen Elizabeth Islands and environs.*

GEOLOGY OF LOUGHEED ISLAND AND NEARBY SMALL ISLANDS, DISTRICT OF FRANKLIN (PARTS OF 69C, 79D)

INTRODUCTION

Lougheed Island is a north-northwest - elongated island with an area of about 1070 km^2. It is the largest island of the Findlay Group, which also includes Edmund Walker, Grosvenor, the Patterson Islands and a small low sandflat named Stupart Island in the shallow channel between Lougheed Island and Edmund Walker Island. The Findlay Group is in the west-central part of the Queen Elizabeth Islands, Canadian Arctic Archipelago (Fig. 1a).

There are no residents on the Findlay Islands. Resolute, Cornwallis Island (Fig. 1a) is the nearest convenient logistic centre. The islands are snow-covered from September until late June or early July, so that the time available for examining the outcrop is restricted to part of July and August. During that interval most of the ground surface is so soft and wet that it is unsuitable for landings by aircraft, even if they are equipped with oversize, low-pressure tires. Helicopter transportation is the most satisfactory means of access for geological study.

Part of the Findlay Group of islands was sighted from what is now known as Cameron Island (Fig. 1a) in April, 1853, by Lieutenant Sherard Osborn, a member of Sir Edward Belcher's 1852-54 expedition in search of the missing party of Sir John Franklin (Belcher, 1855). In his diary, Osborn (in British Parliamentary Papers, 1855) named the newly discovered land Paterson Island. Two areas of land, named Finlay Land and Paterson Island, appear on Belcher's (op. cit.) map of the region. Paterson Island is depicted as a small island east of Finlay Land, which is indicated to be larger, but of indefinite extent. The islands were not visited until August, 1916, when Vilhjalmur Stefansson's Canadian Arctic Expedition landed on the large island later to be named Lougheed Island for Sir James A. Lougheed, a member of the federal cabinet. Stefansson (1921) surmised that Belcher's Finlay Land was the high island south of Lougheed Island, now named Edmund Walker Island, and that the most southeasterly of the islands was Osborn's Patterson Island. (In the years between publication of Belcher's map and Stefansson's expedition, spelling of the names on British Admiralty charts changed back and forth from Finlay to Findlay and from Paterson to Patterson. Stefansson spelled them Findlay and Patterson).

Findlay Island was named after J.H. Findlay, an eminent English cartographer of the mid-nineteenth century. We could find no record of the person for whom Patterson Island was named. The other islands of the group were named as follows: Edmund Walker, for a prominent Canadian financier who supported Stefansson's early work; Grosvenor, for Gilbert Grosvenor, Director of the National Geographic Society, who arranged preliminary financing of Stefansson's expedition before it was taken over by the Government of Canada; and Stupart Island, for Sir Robert Stupart, Director of the Meteorological Service of Canada at the time of the expedition.

Stefansson noted that there are coal deposits on the southeastern part of Lougheed Island. A brief geological study of part of the island was made by B.F. Glenister and R. Thorsteinsson in 1955 (Glenister and Thorsteinsson, 1963), during a reconnaissance of the Canadian Arctic Archipelago by the Geological Survey of Canada (Fortier et al., 1963). Two deep exploratory wells have been drilled on Lougheed Island: Sun KR Panarctic et al. Skybattle Bay C-15 (T.D. 3658m*), completed in 1971; and Panarctic Tenneco et al. Pat Bay A-72 (T.D. 3230 m), completed in 1975. Both wells were dry.

This report is based on field work carried out in 1976 (Balkwill, Hopkins and Wall, 1977) when the Findlay Group was visited by the writers from a base camp on Mackenzie King Island (Fig. 1a). Data and observations are based on ground traverses, aerial observations from helicopters, aerial photo interpretation, and examination of outcrop and well samples and geophysical well logs. Because geophysical data, other than well logs, were not available to the writers, subsurface interpretations of structure and regional stratigraphy were weakened.

We gratefully acknowledge the help of A.E. Foscolos, who made X-ray mineralogical determinations, pilot F.E. Hall, Kenting Helicopters, and G.D. Hobson and personnel of the Polar Continental Shelf Project who assisted field logistics.

PHYSIOGRAPHY

Lougheed Island is in the central part of the Sverdrup Lowland, a physiographic region of low relief developed mainly on poorly consolidated, gently dipping Mesozoic sedimentary rocks (Bostock, 1970, p. 18, and Map 1254A). Roots (1963) and Glenister and Thorsteinsson (1963) described some of the physical features of Lougheed Island and neighbouring islands.

The islands have smooth, low, moundlike profiles (Fig. 2) developed in poorly indurated, gently folded Cretaceous shales and sandstones. Flat, low, water-strewn plains form parts of the western and southeastern coasts of Lougheed Island. A ridge in the north-central part of Lougheed Island is slightly more than 120 m above sea level. Elsewhere the elevations are generally less than 60 m above sea level. The crest of Edmund Walker Island is about 135 m above sea level. Short streams, not adjusted to geological structure, drain the islands. In the central part of Lougheed Island there are wide flat areas, at elevations slightly below 30 m, underlain by alluvial sand. The deposits seem likely to have formed during a geologically recent drainage regime when base level was higher than at present, possibly during postglacial marine incursion. Recent marine shells are at scattered elevations throughout the island, giving evidence that most or all of the island has recently emerged.

Terrain in the central part of Lougheed Island has large-scale, north-northwest - striking fluted ridges. The topography is partly a result of the strike of bedrock, but may be accentuated from glacial erosion. An isolated sinuous ridge of pebbly sand, a few metres high and several metres wide, extends about 1.5 km near the southeastern coast. The ridge resembles an esker, as implied by Roots (1963, p. 529). No other features suggestive of glacial erosion or construction were observed.

Permafrost is generally about 0.5 m below the ground surface. Solifluction takes place actively on most sloping surfaces in summer.

REGIONAL SETTING

Lougheed Island is in the southwestern part of Sverdrup Basin (Fig. 1a). The basin is a northeast-southwest elongated pericratonic depression containing a succession of marine and nonmarine sedimentary rocks which range from Lower Carboniferous to Tertiary (Thorsteinsson and Tozer, 1970a, b; Plauchut, 1971; Balkwill, 1978). Sverdrup Basin strata are superposed on middle Paleozoic and older rocks that were variously folded and faulted, locally intruded and

* A factor of 1 foot = 0.3048 m was used in converting well footages to metres.

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. TrJh: Heiberg (Souther, 1963)
15. Trba: Blaa Mountain (Troelsen, 1950)
16. Trs: Schei Point (Tozer, 1963d)
17. Trbl: Blind Fiord (Tozer, 1961, 1963c)
18. Trb: Bjorne (Tozer, 1963d)

GAS FIELDS

A. Hecla
B. Drake
C. Wallis
D. King Christian
E. Thor
F. Kristoffer
G. Jackson Bay

FIGURE 1b. *Arctic Archipelago and approximate locations of Mesozoic type sections, and locations of natural gas fields, Sverdrup Basin.*

metamorphosed, and uplifted and eroded during the mid-Paleozoic Ellesmerian Orogeny (Trettin et al., 1972).

The Sverdrup Basin succession is mainly concordant in the axial region; there are unconformities along the eastern and southern basin margins and the northwestern rim that record several late Paleozoic and Mesozoic phases of gentle uplift and truncation. The depocentre, where the succession is about 13 000 m thick, lies in the region of western Axel Heiberg Island, northern Amund Ringnes Island, and eastern Ellef Ringnes Island (Fig. 1a). Gabbro dykes and sills, and basalt flows as old as Carboniferous and as young as early Late Cretaceous, are important elements of the succession in the depocentral region. Sverdrup Basin rocks were folded, faulted, and epeirogenically uplifted during a succession of tectonic phases, collectively named the Eurekan Orogeny, that extended from Late Cretaceous through Miocene. As a result of that tectonism, Upper Cretaceous and Tertiary, partly syntectonic deposits lie unconformably on Mesozoic and older rocks within and adjacent to the basin.

Upper Paleozoic strata on the margins of Sverdrup Basin are mainly carbonates and sandstones (Thorsteinsson, 1974). The axial succession is mainly shale, but there are widely distributed halite and anhydrite beds near the base (Davies, 1975; Davies and Nassichuk, 1975). Meneley et al. (1975) proposed that a midbasin carbonate platform separated a western evaporite basin (Barrow Basin) from an eastern evaporite basin (Axel Heiberg Basin) during part of late Paleozoic time.

Mesozoic rocks of Sverdrup Basin are almost entirely terrigenous clastics. The Mesozoic succession consists of alternating lithic packages of nonmarine (largely deltaic) mature sandstones, and marine shales and siltstones. Sediments comprising that succession migrated to the basin mainly from the eastern and southern margins and also, in lesser amounts, from the northwest. As a result of loading by the thick succession of Mesozoic beds, upper Paleozoic evaporites migrated and locally pierced overlying beds as stocks and walls (Gould and deMille, 1964). The Mesozoic succession from Lougheed Island westward consists of units that are mostly thinner than equivalent units to the east. The Mesozoic stratigraphic hinge separating western and eastern parts of the basin is about coincident with the location of the late Paleozoic midbasin platform proposed by Meneley et al. (op. cit.), so it is convenient to refer to the western part of the basin as the Barrow segment and the eastern part as the Axel Heiberg segment (Balkwill, 1978).

Exposed rocks on Lougheed Island and adjacent small islands consist of a conformable succession, about 1540 m thick, of Lower and Upper Cretaceous terrigenous clastic rocks (see Table of Formations). In order upward, the exposed Cretaceous units are the Isachsen, Christopher, Hassel, Kanguk, and Eureka Sound formations.

Skybattle Bay C-15 and Pat Bay A-72 were spudded in the Hassel Formation and drilled through closely similar successions of Mesozoic rocks. The deepest rocks penetrated in both wells are shales and sandstones that are probably Lower Triassic and are assigned to the Bjorne Formation. Skybattle Bay C-15 is the deeper of the two wells, so the following descriptions and comments regarding subsurface stratigraphy are based on samples and logs from that well.

The following sections describe the subsurface rocks at Skybattle Bay C-15, and the surface rocks of Lougheed Island in ascending order of units, beginning with the Bjorne Formation (see Table of Formations). Stratigraphic age assignments are from paleontological determinations by Robertson Research (North America) Limited (Clowser et al., 1974), and by J.A. Jeletzky, E.T. Tozer, W.W. Brideaux, W.S. Hopkins, Jr. and J.H. Wall (Appendix).

Existing Sverdrup Basin stratigraphic nomenclature (Thorsteinsson and Tozer, 1970b) evolved mainly from reconnaissance surface studies of basin-marginal sections. Drilling in axial parts of the basin and some detailed surface stratigraphic studies demonstrate that the nomenclature should be revised for some parts of the succession (for example, see Henao-Londoño, 1977a, and Balkwill, Wilson and Wall, 1977). Generally the nomenclature should be expanded to distinguish some important lithologic levels now unrecognized. But satisfactory revision of nomenclature requires basinwide surface and subsurface assessment, much beyond the scope of this paper. Therefore no new stratigraphic nomenclature is introduced here, but some important intraformational units are emphasized.

STRATIGRAPHY

Triassic

Bjorne Formation

The type section of the Bjorne Formation (Tozer, 1961, 1963a) (Fig. 1b) consists of about 500 m of fine- to medium-grained, buff, red, and brown, partly ferruginous quartzose sandstone. The formation lies disconformably on Permian strata and is overlain conformably by Middle Triassic sandstones (Schei Point Formation). Bjorne sandstones outcrop widely along the eastern and southern margins of Sverdrup Basin. The formation grades basinward to siltstone and shale composing the Blind Fiord Formation (Tozer, 1963b), which contains abundant Early Triassic (Griesbachian to Spathian)* marine fossils (Thorsteinsson and Tozer, 1970a, Fig. X-10).

The succession between 2973 and 3658 m (T.D.) in Skybattle Bay C-15 is assigned to the Bjorne Formation (Fig. 3). Chip samples from that succession consist of the following lithologies: very fine to fine-grained, light grey-buff, quartzose, calcite-cemented sandstone, with some grains of white and grey chert, grey feldspar, and glauconite; red-brown, clayey, slightly micaceous, slightly calcareous siltstone; and medium grey-brown, clayey, slightly pyritic siltstone.

The gamma ray and sonic log curves indicate that those lithologies alternate as layers of less than 1 m to about 6 m thick (Fig. 4a). Sandstone is dominant in the lower part of the succession; siltstone and shale are more abundant than sandstone nearer the top.

From palynology, Clowser et al. (1974) suggested that the succession from 3139 m to the bottom of the well at 3658 m is Lower Triassic, commenting: "*Triadispora* spp. and *Aratrisporites* spp. are rare or absent, and the occurrence of *Alisporites cymbatus* below 10,500' (3200 m) supports a Lower Triassic, Spathian or older age. Typical basal Triassic (Griesbachian) assemblages were not recorded and it is presumed that drilling terminated in sediments of 'mid' Lower Triassic age." The interval from the top of the Bjorne Formation to 3139 m was considered by Clowser et al. (op. cit.) to be ?Middle to Lower Triassic.

Marine rocks considered coeval with the Bjorne Formation near the southeastern margin of Sverdrup Basin contain macrofossils that range from early Griesbachian to Spathian (Thorsteinsson and Tozer, 1970a, Fig. X-10).

A few foraminifers are present in well samples from the succession, but Clowser et al. (op. cit.) suggested they had caved from higher levels, and concluded that the sediments accumulated in supralittoral, or possibly littoral, environments. This is supported by the abundant red

* Mesozoic stages are given in Figure 13.

TABLE 1
Table of Formations

SYSTEM OR SERIES	FORMATION	APPROXIMATE THICKNESS Metres (Feet)	LITHOLOGY
QUATERNARY	*Alluvium, marine deposits*		*Unconsolidated clay, silt, sand*
	UNCONFORMITY		
UPPER CRETACEOUS	*EUREKA SOUND FORMATION*	60 (200) a	*Light buff-grey, medium- to coarse-grained quartz sandstone; carbonized wood fragments*
	? *UNCONFORMITY*		
	KANGUK FORMATION	201 (660) a	*Black clay shale with jarosite clay beds; buff sandstone beds in lower part*
LOWER AND UPPER CRETACEOUS	*HASSEL FORMATION*	304 (1000) b	*Light buff to tan quartz sandstone; black shale beds in upper part*
LOWER CRETACEOUS	*CHRISTOPHER FORMATION*	681 (2235) c	*Dark olive-grey and dark grey silty shale; orange concretions in lower part; sandstone beds in upper part*
	ISACHSEN FORMATION	344 (1130) c	*Buff-grey and tan quartz sandstone; very thin coal beds*
UPPER JURASSIC AND LOWER CRETACEOUS	*DEER BAY FORMATION*	304 (1000) c	*Dark grey to black, silty, partly sandy, partly sideritic shale*
UPPER JURASSIC	*AWINGAK FORMATION*	106 (350) c	*Light buff-grey quartz sandstone; thin siltstone and silty shale beds*
LOWER, MIDDLE AND ? UPPER JURASSIC	*SAVIK FORMATION*	257 (845) c	*Dark olive-grey clay shale and dark grey silty shale; some glauconite sandstone*
UPPER TRIASSIC AND LOWER JURASSIC	*HEIBERG FORMATION (Upper Member) and BORDEN ISLAND FORMATION (Undivided)*	158 (520) c	*Light buff-grey quartz sandstone; chert granules; brown-grey siltstone; dark grey shale*
UPPER TRIASSIC	*HEIBERG FORMATION (Lower Member)*	68 (225) c	*Buff quartz sandstone; red-brown and grey-brown siltstone and shale*
	BLAA MOUNTAIN FORMATION	155 (510) c	*Dark green-grey silty shale*
MIDDLE AND UPPER TRIASSIC	*SCHEI POINT FORMATION*	658 (2160) c	*Light green-grey, partly calcareous quartz sandstone and siltstone; very thin bioclastic limestone beds*
LOWER AND ? MIDDLE TRIASSIC	*BJORNE FORMATION*	684 (2245) c	*Light grey-buff quartz sandstone; red-brown siltstone; grey-brown siltstone and shale*

a Thickness estimated from outcrops

b Thickness partly estimated from outcrops, and from Sun KR Panarctic *et al.* Skybattle Bay C-15

c Thickness from Sun KR Panarctic *et al.* Skybattle Bay C-15

GSC

interbeds, which indicate probable repeated emergence and oxidation. The presence of glauconite, however, indicates that some of the beds are marine.

The Bjorne Formation at Cameron Island (Fig. 1b) consists almost entirely of sandstone, lacking marine fossils (Kerr, 1974); at western Melville Island the formation has some conglomeratic beds (Trettin and Hills, 1966). The Bjorne succession at Lougheed Island, with its thin alternations of sandstones and shales, and with red beds and glauconite, might represent deposition on a tide-influenced lower delta plain of a northeastward-sloping Early Triassic fluvial system. Farther northeastward, at King Christian Island (Fig. 1b), the Lower Triassic succession is mostly fine-grained siltstone and shale and is entirely marine (Balkwill and Roy, 1977).

Schei Point Formation

At the type locality, along the southeastern margin of Sverdrup Basin, (Fig. 1b), the Schei Point Formation (Tozer, 1961, 1963a, c) comprises about 180 m of very calcareous siltstone, which grades locally to bioclastic, silty and sandy limestone. There are phosphatic nodules in the lower part of the formation and some dark grey shales near the base. The formation contains marine fossils and is considered by Tozer (op. cit., and in Thorsteinsson and Tozer, 1970a, Fig. X-10) to be the Middle and Upper Triassic basin-marginal sandy equivalent of a very thick basin-central succession of dark, partly calcareous shale (Blaa Mountain Formation).

The succession between 2314 and 2973 m in Skybattle Bay C-15 is assigned to the Schei Point Formation. The 559 m thick succession consists of two parts. The upper part, between 2314 and 2777 m is mainly light green-grey, very fine grained quartz sandstone, with some chert and glauconite grains, and calcite cement. Within that interval as well are medium grey, calcareous, fissile, siltstone chips, and light grey, bioclastic (pelecypods and crinoids) limestone fragments. The log character of the upper interval (Fig. 5) suggests that the subsurface rocks are thin interbeds of sandstone, siltstone and limestone. From 2777 to 2973 m, the Schei Point Formation consists mainly of dark brown, partly fissile, slightly to moderately calcareous siltstone, with some bioclastic limestones. Dark brown phosphatic pellets, about 1 mm in diameter, are present in siltstone chip at 2843 m. The log profiles suggest that the lower part of the formation has repetitions of fine- to coarse-grained siltstone coarsening upward, with some abrupt intercalations of limestone (as notably at 2973 m).

The top of the Schei Point Formation is marked by an abrupt lithological contact between shale and sandstone at 2314 m (Fig. 5.).

Bivalve fragments were collected from well cuttings at these levels: 2609 - 2612 m; 2627 - 2630 m; and 2780 - 2792 m. E.T. Tozer (pers. com., 1977) suggested the fragments are of halobiids (thin-shelled bivalves), and that the rocks are Middle or Upper Triassic.

Clowser et al. (1974) reported that metacopid ostracodes, known to range from upper Karnian to Norian, are present to a level about 2408 m; and further, from ostracodes and palynomorphs, that the section from 2350 to 2682 m is likely Karnian; from 2682 to 2835 m is probably Ladinian; and from 2835 m to the base of rocks included here with the Schei Point Formation is probably Anisian. The Schei Point Formation near the eastern margin of Sverdrup Basin is considered to range from Anisian to Karnian on the basis of the enclosed macrofaunas (Thorsteinsson and Tozer, 1970a, Fig. X-10).

The Schei Point Formation outcrops at Borden Island (Tozer and Thorsteinsson, 1964) and at Cameron Island (Tozer, 1961). The formation has abundant bioclastic limestone beds and quartz sandstones with calcite cement. Those characteristics are completely lacking or insignificant in other Mesozoic formations of Sverdrup Basin. The Schei Point Formation at Lougheed Island likely accumulated on a stable, oxygenated, shallow-marine platform, occasionally swept by storms or strong tides, that included most of Sverdrup Basin west of Maclean Strait. This relatively persistent regime was superposed on the Early Triassic lower delta plain on which the underlying Bjorne sandstone and fine clastics accumulated. Eastward from Lougheed Island, as at King Christian Island, the succession equivalent to the Schei Point Formation consists of pelitic marine clastics (Balkwill and Roy, 1977), indicating that the transition from the platform to deeper marine regimes was abrupt.

Blaa Mountain Formation

The name Blaa Mountain Formation (Troelsen, 1950; Tozer, 1961, 1963c) is applied to the very thick succession of partly calcareous dark shales, siltstones, and subordinate sandstone, containing Middle and Late Triassic marine fossils, in the axial part of Sverdrup Basin (Fig. 2). On eastern Axel Heiberg Island the formation is about 2475 m thick. In outcrops in the eastern part of the basin, the Blaa Mountain Formation lies abruptly on the Blind Fiord Formation and grades upward to sandstones and shales of the Lower Member of the Heiberg Formation. Blaa Mountain pelites grade laterally to calcareous, partly bioclastic, quartzose siltstones and sandstones of the Schei Point Formation at the basin margins (Thorsteinsson and Tozer, 1970a, Fig. X-10).

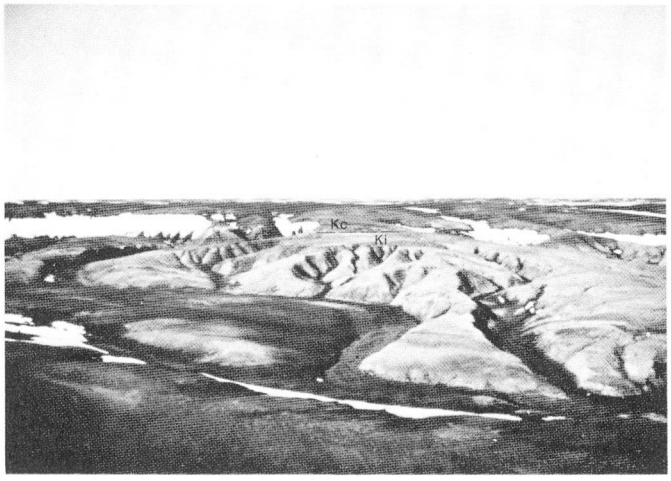


FIGURE 2. *Southwestward view, northern Lougheed island.*

The succession between 2160 and 2314 m in Skybattle Bay C-15 is almost entirely marine shale; to distinguish those shales from sandstones above and below, the succession is assigned to the Blaa Mountain Formation.

Well chips from the Blaa Mountain interval consist mainly of dark green-grey, papery to splintery, slightly micaceous, silty shale, with traces of fine pyrite crystals at some levels, and some pelecypod fragments.

Log profiles (Fig. 5) suggest that the succession has thinly intercalated shale and siltstone beds, and that the grain size increases upward. The upper and lower contacts of the formation are abrupt.

Pelecypod fragments at 2265 - 2268 m, 2274 - 2277 m, and 2304 - 2307 m were suggested to be halobiids by E.T. Tozer (pers. com., 1977) and the enclosing shales were assigned to Middle or Upper Triassic. Clowser et al. (1974) reported that relatively rich and diverse foraminiferal assemblages, characteristic of Norian and older strata, were encountered at 2201 m. They stated further that typical Norian palynomorphs are present in the lower part of the succession, and that the occurrence of *Foveolatitriletes potonei* at 2170 - 2188 m may indicate the top of the Norian in the section.

At Cornwall Island (Fig. 1b), shales and siltstones, assigned by Balkwill (in press) to the Blaa Mountain Formation, contain macrofaunas as young as Late Norian. From this, and the paleontological evidence from Skybattle Bay C-15, the upper part of the formation is recognized as younger in the central and western parts of Sverdrup Basin than in the eastern part, where the youngest macrofaunas collected are late Karnian (Thorsteinsson and Tozer, 1970a, Fig. X-10).

Our assignment of shales between 2160 and 2314 m to the Blaa Mountain Formation may not be very statisfactory, because basinward (eastward) from Skybattle Bay C-15 there are almost certainly other thick tongues of Middle and Upper Triassic marine shale in the Schei Point sandstone succession. The separate tongues could be distinguished by unique names to avoid indiscriminate use of the name Blaa Mountain Formation for shale tongues that might be present at several levels in the Middle and Upper Triassic column.

The foraminifers and ostracodes in the Blaa Mountain Formation led Clowser et al., (1974) to suggest that the rocks represented shallow-marine environments of deposition, with possible shallowing upward from 2201 m. The pelitic sediments were probably deposited at the distal front of a large delta prograding westward, represented in the eastern part of Sverdrup Basin by Norian sandstones and shales comprising the Lower Member of the Heiberg Formation (Fig. 6).

Heiberg Formation (Lower Member)

At the type section at Buchanan Lake, Axel Heiberg Island (Fig. 1b), the Heiberg Formation (Souther, 1963; Tozer, 1961) consists of a Lower Member, about 1095 m thick, of alternating beds of marine sandstone and shale, and an Upper Member, about 495 m thick, consisting mainly of carbonaceous nonfossiliferous sandstone. At the type section, Souther (op. cit.) placed the Heiberg - Blaa Mountain contact at the level where sandstone is more abundant than shale.

Interbedded sandstones and shales between 2091 and 2160 m in Skybattle Bay C-15 are assigned to the Lower Member of the Heiberg Formation. Sandstones in that interval are light grey buff to medium grey, and very fine to medium grained. The grains are mostly subangular quartz, with minor amounts (less than 5%) of light grey chert grains, pale green glauconite, and small angular carbonaceous fragments. The sandstones have good intergranular porosity; they are partly cemented by sparry calcite, and some levels have grey clay cement. Chips from intervening pelitic beds (Fig. 7) consist of medium grey-brown and red-brown, slightly micaceous siltstone, and red-brown and dark olive-grey, papery shale.

Sandstones picked as the base of the Lower Member of the Heiberg Formation lie abruptly on Blaa Mountain silty shales (Fig. 7). The top of the unit is picked at the base of a thick interval of sandstone assigned to the Upper Member of the Heiberg Formation.

Clowser et al. (1974) reported that the interval from 2079 to 2180 m, which includes rocks here assigned to the Lower Member of the Heiberg Formation, is probably barren of in situ foraminifers. They considered palynomorphs indicative of a Rhaetian age to extend from the upper part of the unit (between 2079 and 2097 m) to the lower part of the unit near a level of 2161 m. If the Lower Member of the Heiberg Formation is mainly Rhaetian at Skybattle Bay C-15, it is younger than at the type locality (Fig. 1b), where it is upper Norian (Tozer, 1961). This is consistent with conclusions, in the previous section, that the top of the Blaa Mountain Formation is diachronous, being progressively younger southwestward across Sverdrup Basin (Fig. 6).

Although foraminifers are apparently absent, the succession assigned here to the Lower Member of the Heiberg Formation resembles in many aspects Lower Heiberg rocks in other places that are considered proximal delta front deposits (Balkwill, in press).

Triassic and Jurassic

Heiberg Formation (Upper Member) and Borden Island Formation (undivided)

At the type section (Fig. 1b), the Upper Member of the Heiberg Formation (Souther, 1963; Tozer, 1961, 1963c) consists mainly of fine- to coarse-grained quartz sandstone, with intercalations of siltstone and carbonaceous shale. The unit lacks marine macrofossils. Souther (op. cit.) estimated that the member is about 500 m thick. This thickness included an 85 m thick diabase sill, and about 51 m of red and buff sandstone at the top of the sandstone succession that Tozer (1963c) later assigned to the Borden Island Formation (Tozer and Thorsteinsson, 1964; Balkwill, in press) (Lower Jurassic). Pliensbachian fossils were found in the Borden Island Formation of eastern Sverdrup Basin several years after Thorsteinsson and Tozer published their 1970 stratigraphic chart (Fig. 7).

The type section of the Borden Island Formation (Fig. 1b) consists of about 60 m of greenish buff, glauconitic, partly red sandstone, with Sinemurian ammonites, lying disconformably on Schei Point (Karnian) sandstones.

The sandstone-dominated succession from 1932 to 2091 m in Skybattle Bay C-15 is assigned to the Upper Member of the Heiberg Formation - Borden Island Formation (undivided). That succession consists of two prominent sandstones. The upper sandstone lies between 1932 and 2001 m. It consists of light buff-grey, fine to very coarse grained quartz sandstone, with some rounded grey chert granules in the upper 30 m. At some levels there are grey and white chert grains in red-brown hematitic clay matrix. The sandstone has fair to good intergranular porosity, although it has some clay cement throughout and is tightly cemented by pyrite at some levels in the upper part. The upper sandstone, which has an abrupt blocky log signature (Fig. 7), lies abruptly below Savik Formation shales, and

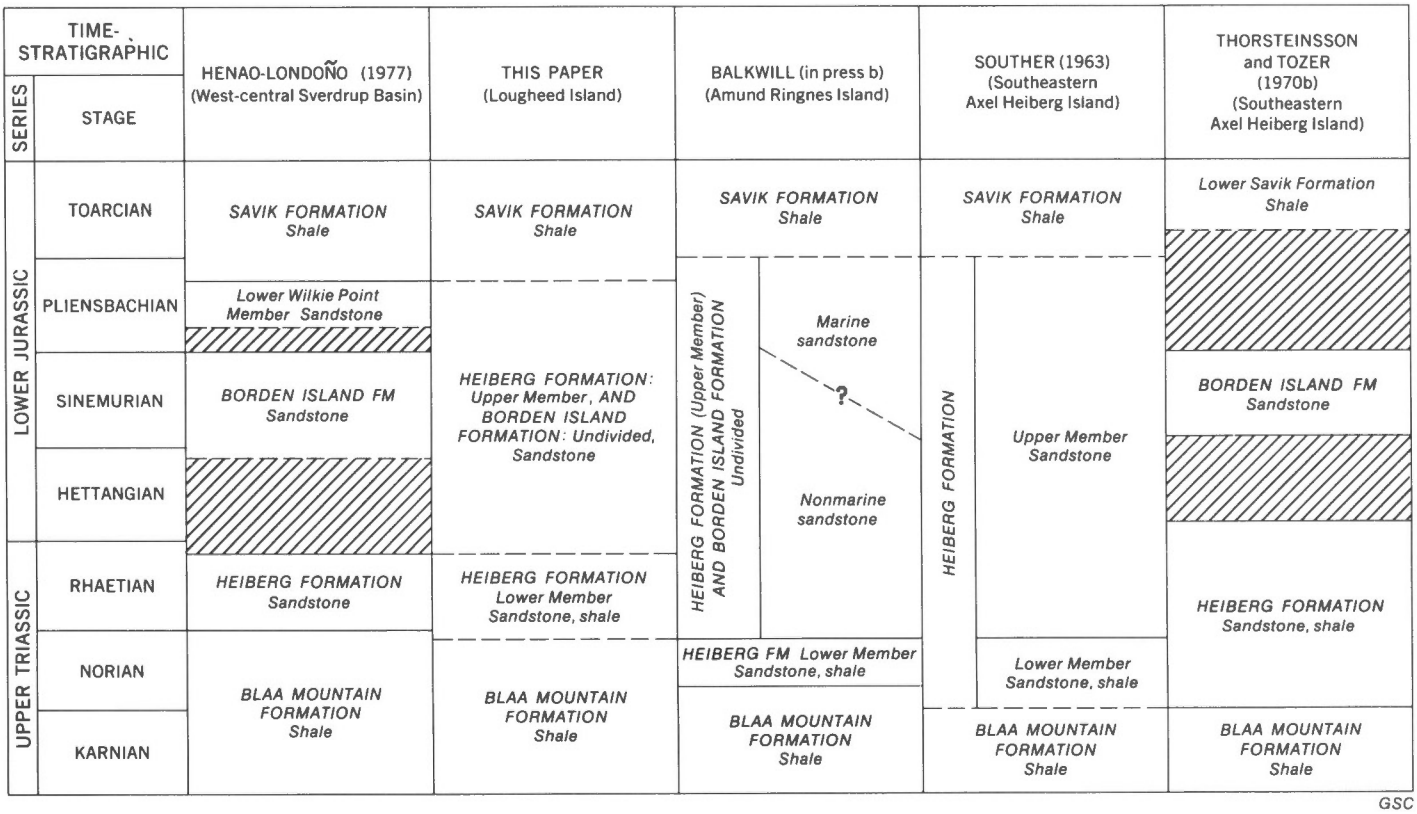


FIGURE 6. *Development of Upper Triassic and Lower Jurassic stratigraphic nomenclature, Sverdrup Basin.*

grades to underlying intra-Heiberg siltstones and shales. Chips from the interval between 2001 and 2043 m are brown-grey siltstone.

The lower sandstone, from 2043 to 2091 m, consists of fine- to medium-grained quartz sandstone, with abundant white and grey chert pebbles to 5 mm in diameter in the upper part. The sandstones are partly cemented by brown siderite, but generally have good intergranular porosity.

From palynology, Clowser et al. (1974) suggested that sandstones from 1932 to 1984 m are Upper Pliensbachian intercalated marine and nonmarine rocks. They considered rocks from 1984 m to the base of the sandstone-dominated succession to the Lower Liassic (Pliensbachian and older Lower Jurassic), and from the absence of in situ microfaunas to be nonmarine.

The Upper Member of the Heiberg Formation is a thick, distinctive map unit of nonmarine sandstones in the eastern part of Sverdrup Basin (Thorsteinsson and Tozer, 1970a, Fig. X-10), and along the southern margin of the basin as far west as Cornwall Island (Balkwill, in press). Youngest diagnostic marine fossils beneath the sandstones are Late Norian. At the top of the sandstone succession, locally, there are discontinuous, partly red, partly fossiliferous (Sinemurian and Pliensbachian) marine sandstones, which have been mapped as the Borden Island Formation (Thorsteinsson and Tozer, 1970a, Fig. X-10; Balkwill, in press). Recognition in outcrops of the Borden Island Formation depends largely on the presence of the foregoing criteria, which are not discernible in some wells. Distinction between the Borden Island Formation and Upper Member of the Heiberg Formation is therefore not attempted in Skybattle Bay C-15.

The Heiberg Formation represents a Late Triassic and probably Early Jurassic phase of great sand influx, directed to Sverdrup Basin mainly from the eastern and southeastern margins. The resultant Upper Triassic - Lower Jurassic wedge of sandstones thins westward from the proximal deposits of Ellesmere and Axel Heiberg islands. Intercalated marine sandstones and shale of the Lower Member are probably delta front and delta marginal deposits. Largely nonmarine sandstones of the Upper Member may be mostly deposits of braided, delta plain distributaries. The Borden Island Formation, where it is present, contains marine fossils, signalling initial Jurassic marine transgression and reworking of underlying Heiberg sandstone terrains.

Jurassic

Savik Formation

At the type section, the Savik Formation (Souther, 1963; Tozer, 1963c) consists of a succession of green-grey shale containing early Bajocian ammonites, overlain by black silty shale with Oxfordian ammonites. Tozer (op. cit.) named the lower succession "Lower Savik" and the upper succession "Upper Savik", and suggested that an Upper Bajocian through Callovian hiatus separates the two units at the type section. Near the basin margins, marine sandstones (Jaeger Formation in the eastern part of the basin and Wilkie Point Formation in the western part) separate the lower and upper Savik shale successions. In the central part of the basin there are late Bajocian, Bathonian, and early Callovian faunas (late Callovian macrofossils have not been found) in thick shale succession (Thorsteinsson and Tozer, 1970a, Fig. X-12). Parts of the Middle Jurassic succession are probably quite condensed in some places (Balkwill, in press).

Predominantly dark to medium olive-grey, slightly silty, partly sideritic, papery shales between 1675 and 1932 m in Skybattle Bay C-15 are assigned to the Savik Formation. Between 1762 and 1783 m, and between 1868 and 1882 m there are chips of very fine grained, glauconitic, slightly pyritic sandstone and siltstone; these levels are marked also by prominent deflections on the log profiles. No intraformational divisions are attempted here for the Savik Formation, but some aspects of the succession may have important implications for regional correlation.

Clowser et al. (1974) suggested that shales to about 1695 m are upper Oxfordian-Kimmeridgian, and that the underlying succession to about 1780 m (which includes the upper of the thin intraformational sandstone-siltstone levels) may be Callovian-Oxfordian. Examination of samples from 1698 m, 1716 m, and 1750 m supports those age assignments (Appendix). The shales containing those fossils are predominantly dark grey, and resemble dark grey upper Savik shales in other parts of Sverdrup Basin, which contain macrofossils ranging from Callovian (Balkwill, in press) to lower Oxfordian (Tozer, 1963c).

Clowser et al. (op. cit.) suggested that Bathonian microfloras are present in samples from 1780 to 1814 m; that foraminifers and palynomorphs from 1814 to 1841 m are Bajocian, and from 1841 to 1896 m are Toarcian. All of those age assignments are consistent with the age of lower Savik shales which outcrop in western Sverdrup Basin, and with recognition that the intraformational sandstone-siltstone beds are distal tongues of the Wilkie Point (or Jaeger) sandstone (see Thorsteinsson and Tozer, 1970a, Fig. X-12).

An important element of Sverdrup Basin Jurassic stratigraphy is introduced by the assignment of a Pliensbachian age by Clowser et al. (op. cit.) to shales from 1896 m to the base of rocks here considered the Savik Formation. Pliensbachian macrofossils have not been collected from outcrops of lower Savik shales. However, macrofossils in sandstones immediately beneath the shales are progressively older westward, and the shales can be expected reasonably to be as old as Pliensbachian.

Foraminifers from the Savik Formation samples in Skybattle Bay C-15 are indicative of shallow-marine depositional sites. This is consistent with conclusions regarding the Savik Formation in other parts of the Sverdrup Basin, where the formation represents an Early to early Late Jurassic phase of rather subdued, shallow-marine accumulation (Balkwill, 1978).

Awingak Formation

The type section of the Awingak Formation (Souther, 1963; Tozer, 1963c; Balkwill, Wilson and Wall, 1977) (Fig. 1b) consists of about 300 m of intercalated sandstone and shale, lying conformably between Savik Formation and Deer Bay Formation shales. The formation is distributed over wide areas of eastern Sverdrup Basin (Thorsteinsson and Tozer, 1970a), and also along the southern basin margin as far west as Cornwall Island (Balkwill, in press). K.J. Roy (pers. com., 1977) reports that the lower part of the formation is present in the core of a tight syncline on northern Cameron Island (Fig. 1b). This observation, and assignment of beds in Skybattle Bay C-15 to the formation, expands the known distribution of the Awingak Formation much farther westward than previously.

The 107 m thick sandstone-dominated succession in Skybattle Bay C-15, between 1568 and 1675 m is assigned to the Awingak Formation (Fig. 8). That succession consists of three intervals, which from samples and log profiles are indicated to coarsen upward from dark grey shaly siltstones to light buff-grey, medium-grained, porous sandstones. The sandstones have abundant angular carbonaceous fragments and a few white and light grey chert grains. Each sandstone interval is overlain rather abruptly by the succeeding interval of shale; the upper sandstone is overlain abruptly by the Deer Bay Formation.

The Awingak Formation contains few diagnostic macrofossils in any part of Sverdrup Basin. Late Oxfordian or early Kimmeridgian faunas are present in beds about

225 m above the base of the formation at the type section (Souther, 1963); and faunas collected from the uppermost part on Axel Heiberg Island are dated as late Early Volgian (Thorsteinsson and Tozer, 1970a, Fig. X-12). The upper beds of the formation of Cornwall Island (Fig. 1b) contain Late Volgian faunas, which are the youngest faunas known from the formation (Balkwill, in press). Clowser et al. (1974) considered microfaunas and palynomorphs in the interval from 1585 to 1713 m to be late Oxfordian-Kimmeridgian, and the fossils above the 1585 m level to be early Tithonian (approximate Early Volgian). From this evidence, the Awingak Formation in Skybattle Bay C-15 is approximately coeval with the formation in the eastern part of Sverdrup Basin, but the top is slightly older than at Cornwall Island.

From studies of Awingak and correlative rocks in south-central Sverdrup Basin, Balkwill, Wilson and Wall (1977) concluded that the formation represents the deposit of a large delta that prograded northward from the southeastern basin re-entrant; the axis of the delta was positioned near eastern Cornwall Island, and consequently the formation is thickest there (about 570 m) and the top is younger than elsewhere. Northward and northwestward from those thick proximal deposits, the lower and middle parts of the formation grade rather abruptly into a succession of silty, partly sandy, Oxfordian-Kimmeridgian shales with distinctively huge and colourful mudstone concretions, recently named the Ringnes Formation (Balkwill, Wilson and Wall, 1977). Upper Awingak sandstones grade basinward to Volgian shales composing the lower part of the Deer Bay Formation.

Jurassic and Cretaceous

Deer Bay Formation

Heywood (1957) named the Deer Bay Formation (Stott, 1969; Henao-Londoño, 1977a; Balkwill, in press) for black, silty Upper Jurassic and Lower Cretaceous marine shales in northern Ellef Ringnes Island (Fig. 1b). He was unable to examine the lower part of the shale succession, and did not designate a type section for the formation. Stott (op. cit.) mapped the base of the formation in the type region at the top of lower Callovian sandstones, thus including as part of the Deer Bay Formation some shales that are correlative with the upper part of the Savik Formation and the Ringnes Formation. Henao-Londono (op. cit.) concluded that there is a basin-wide unconformity between Middle and Upper Jurassic strata, and suggested expansion of the base of the Deer Bay Formation to that level. Balkwill (op. cit.) restricted the Deer Bay Formation to the shale succession lying between the Awingak Formation (or coeval Ringnes shales) and Isachsen Formation sandstones (Fig. 9). With this variability of definition, it is clear that Upper Jurassic - Lower Cretaceous stratigraphic nomenclature of Sverdrup Basin needs systematic revision. For this paper, the name Deer Bay Formation is applied to shales lying between Awingak and Isachsen sandstones.

The base of the formation in Skybattle Bay C-15 was picked at 1568 m, at the abrupt contact of the shales with Awingak sandstones (Fig. 8). From that level to 1263 m chip samples consist mainly of dark grey to black, slightly to moderately silty, partly sideritic and partly pyritic, papery shales. Some sandy siltstones and silty sandstones are present between the levels of 1489 and 1512 m. Deer Bay Shales are very abruptly overlain by Isachsen Formation sandstones.

The Deer Bay Formation in the central and eastern parts of Sverdrup Basin (if restricted to shales between the Isachsen and Awingak formations) ranges from lower Upper Volgian to upper Valanginian (Thorsteinsson and Tozer, 1970a, Fig. X-12).

Clowser et al. (1974) suggested that the Jurassic-Cretaceous boundary lies about the 1375 m level in Skybattle Bay C-15. Some microfaunas at the 1359 m level indicate the boundary may be slightly higher (Appendix). The uppermost Deer Bay strata are probably Valanginian. The top of the Deer Bay Formation over wide areas of central and eastern Sverdrup Basin is interpreted as Valanginian from the macrofaunas within it (Kemper, 1977); the Deer Bay - Isachsen formational contact in the central part of the basin is approximately isochronous, and thus a valuable datum for correlation (Fig. 3).

Shales comprising the lower part of the Deer Bay Formation beneath Lougheed Island contain microfaunas indicative of shallow-marine conditions; they probably represent deposition at the front of deltas which, shoreward, graded into the sands comprising the Awingak Formation. Similarly, the upper part of the Deer Bay Formation was deposited as prodelta muds in front of Isachsen delta lobes. A prominent sandstone in the middle of the Mould Bay Formation of the western part of Sverdrup Basin spans the Jurassic-Cretaceous boundary (Thorsteinsson and Tozer, 1970a, Fig. X-12) (Fig. 9). Thin, fine-grained sandstones and siltstones about the 1494 m level in Skybattle Bay C-15 may also span that boundary (Clowser et al., 1974) and may be distal sandstone tongues coeval with sandstones of the Mould Bay Formation.

Cretaceous

Isachsen Formation

In the type region (Fig. 1b), the Isachsen Formation (Heywood, 1957; Tozer and Thorsteinsson, 1964) is about 900 m thick, and consists mainly of quartzose, partly carbonaceous, fine to very coarse grained sandstone. The formation lies conformably on Deer Bay shales and is overlain conformably by Christopher Formation shales (Fig. 2).

Sandstones of the middle and upper parts of the Isachsen Formation are the oldest rocks exposed on Lougheed Island. The sandstones have a maximum outcrop thickness of about 270 m in a poorly exposed, arcuate outcrop belt around the northern coast of the island. A complete succession of the formation, about 344 m thick, was penetrated in Skybattle Bay C-15 between depths of 919 and 1263 m.

The upper several metres of the formation in outcrops are fine-grained, light to medium brown-grey, tan-weathering, calcite-cemented quartzose sandstones. The sandstones are very thin bedded, partly laminated, and have platy splitting. There are abundant carbonaceous fragments and plant fragment impressions on bedding surfaces. Several metres below the top of the formation there are a few black, lustrous coal beds, each of which is a few centimetres thick. Beneath the calcite-cemented beds, the formation consists mainly of light buff-grey, fine- to medium-grained, thin beds of quartz sandstone weakly cemented by clay. Although the grains are almost entirely quartz, there are also some grey and white chert, angular black carbonaceous fragments, and abundant white mica on some bedding surfaces. There are some lenticular carbonaceous shale layers about 5 cm thick. No thick coal beds were observed. Some of the sandstones have high-angle tabular cross-strata.

Samples and log curves from the upper part of the Isachsen Formation in Skybattle Bay C-15 indicate that the formation there consists of thick (as great as 15 m) alternations of carbonaceous, poorly cemented quartz sandstone, and shaly carbonaceous and micaceous siltstone. The lower part of the Isachsen Formation in C-15 is coarse grained, particularly the lower 30 m (Fig. 3) which contain quartz and chert pebbles about 4 mm in diameter. The sandstones lie abruptly on the Deer Bay Formation.

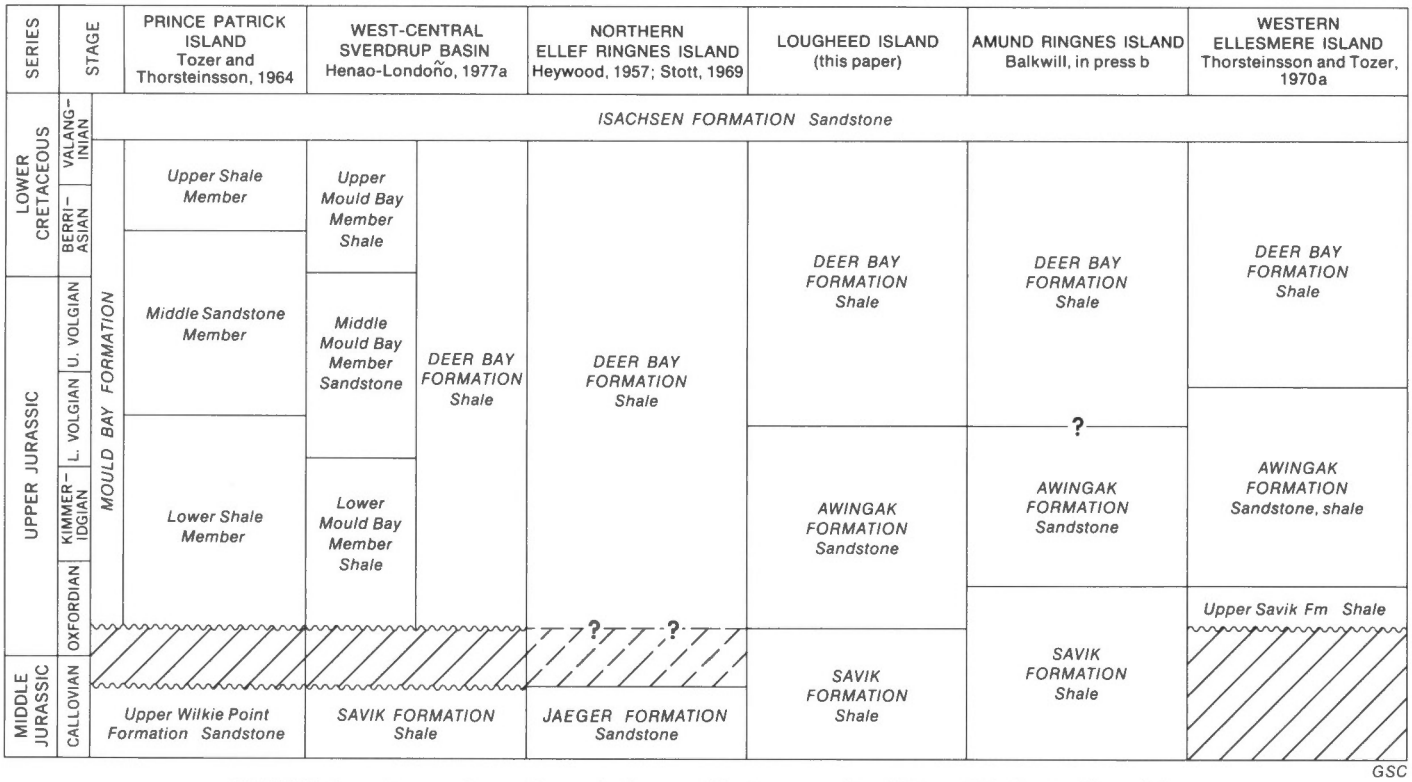


FIGURE 9. *Upper Jurassic and Lower Cretaceous (to Valanginian) stratigraphic nomenclature, Sverdrup Basin.*

No invertebrate macrofossils were observed in the Isachsen Formation. Clowser et al. (1974) reported that well cuttings are barren of microfaunas to about 1067 m, below which an interval of shale about 30 m thick contains Aptian foraminifers and dinoflagellates. This indicates that there are marine shales within the Isachsen Formation which were not observed in outcrops. The lithology and sedimentary structures of the lower and upper parts of the Isachsen Formation suggest that the sediments were deposited mostly by braided streams on delta plains that lacked large inter-channel flood basins or swamps. The thick interval of coarse sandstone at the base of the formation (Fig. 3) has an abrupt, blocky log signature, commonly interpreted as representing delta front sandstones.

The Isachsen Formation is one of the thickest and most widely distributed lithologic units in the Arctic Archipelago. In the central part of Sverdrup Basin the formation is about 1000 m thick. The base, from widespread macrofaunal control, is upper Valanginian (Thorsteinsson and Tozer, 1970a, Fig. X-12; Kemper, 1977; Balkwill, in press), which is the age suggested for the base of the formation on Lougheed Island (Appendix). Diagnostic fossils have not been collected from the top of the formation, or from overlying Christopher Formation marine shales and, as a result, the precise age of the Isachsen-Christopher contact is uncertain. The oldest reported Christopher Formation macrofossils are possibly Aptian (Jeletzky, reported by Stott, 1969). Beyond the margins of Sverdrup Basin the Isachsen Formation oversteps Mesozoic and Paleozoic rocks. At Banks Island, basal Isachsen beds are Aptian, or possibly Barremian (Plauchut and Jutard, 1976). The Isachsen succession there is thin but very coarse grained, and was deposited from a fluvial system that shed detritus to Sverdrup Basin through the southwestern basin re-entrant at Eglinton Island (Fig. 1) (Miall, 1975).

The presence of mid-Isachsen marine shales in Skybattle Bay C-15 is an important aspect of Sverdrup Basin stratigraphy and paleogeography. Eastward from Lougheed Island the formation is mostly sandstone and no marine shales are known (Roy, 1973); westward the formation is thin and shaly. We suggest, from regional biostratigraphy and from subsurface facies studies by A.F. Embry (pers. com., 1978), that the part of the Isachsen Formation above the Aptian marine shales grades westward to marine shales comprising the lower part of the Christopher Formation (Fig. 3).

Christopher Formation

The type section of the Christopher Formation (Heywood, 1957; Tozer and Thorsteinsson, 1964) is in northern Ellef Ringnes Island (Fig. 1b), where the formation consists of about 900 m of silty shale with some glauconitic sandstones in the middle and calcareous sandstones near the top.

A complete succession of the Christopher Formation, penetrated in the Skybattle Bay C-15 well, is 681 m thick.

Basal Christopher beds in northern Lougheed Island consist of dark olive-grey to dark grey, silty, papery shales, which lie abruptly and conformably on Isachsen sandstones (Fig. 2). The lower several tens of metres have some brown-grey, calcite-cemented, quartz sandstone beds about 2 m thick, and large (about 2 m long) bright buff-orange - weathering, calcareous mudstone concretions, partly with cone-in-cone structures. The interiors of the concretions have silicified wood fragments and clusters of pyrite crystals. The sandstones contain some broken small pelecypods. Dark shales above the calcareous concretions contain dark brown round ironstone nodules about the size of tennis balls.

Shales comprising the upper part of the formation are dark grey to black, partly silty, partly pyritic, and have small (less than 0.5 m long) dark red-brown, calcareous ironstone concretions. Some weathered surfaces have white sulphate encrustations from oxidation of pyrite, particularly evident

on the southeast-facing slope of Edmund Walker Island. In the upper 75 m, approximately, there are thin beds of olive-green to buff, very fine to fine-grained, weakly cemented, partly glauconitic quartz sandstone. The sandstone beds help to outline tight folds on Edmund Walker Island. Sandstone beds are thicker and more abundant upward as a transitional succession to the overlying Hassel Formation. Near Skybattle Bay, a 15 m thick interval of buff-yellow quartz sandstone in the upper part of the Christopher Formation helps to delineate the eroded core of a northward-plunging anticline (Map 1490A).

Log profiles from Skybattle Bay C-15 (Fig. 3) indicate that there are no appreciably thick subsurface sandstones in the formation, except near the base and top. High velocity peaks on the sonic log in the lower part of the formation probably mark subsurface levels of calcite-cemented sandstones observed in surface exposures in the northern part of the island.

Basal Christopher beds lie abruptly on Isachsen sandstones. The upper contact, with the Hassel Formation, was picked at 238 m in Skybattle Bay C-15, at the base of conspicuous deflections in the log profiles (Fig. 3).

Rocks exposed on Grosvenor and Patterson islands are olive-grey, silty shales with large orange-buff concretions, closely resembling the lower part of the Christopher Formation on Lougheed Island.

The Christopher Formation at Lougheed Island and environs may range from Aptian to Middle Albian. Some fragments of large pelecypods, resembling *Inoceramus*, were collected from the upper part of the formation, but they were not sufficiently well preserved to be identifiable (J.A. Jeletzky, pers. com., 1976). *Tropaeum* of Aptian age has been tentatively identified from lower Christopher strata at Mackenzie King Island (Fig. 1b). The youngest macrofaunas from the formation in the region are late Middle Albian, from Ellef Ringnes Island (identifications by J.A. Jeletzky, reported by Stott, 1969, p. 26). Microfaunas from the formation on Lougheed Island are Early to Middle Albian (Appendix).

Mid-Christopher glauconitic sandstone is present in the eastern and central parts of Sverdrup Basin as far west as King Christian Island (Balkwill and Roy, 1977). The sandstone allows mappable distinction of an informal olive-grey, lower Christopher subunit from an upper dark grey subunit. Possible early Middle Albian faunas have been collected from the dark upper shales just above the sandstone. The glauconitic sandstone is not discernible on Lougheed Island, nor was it observed by the writers at Sabine Peninsula (Fig. 1b). Consequently, there seems to have been little Middle Albian sand influx to the basin from the southwestern margin. Nevertheless the lower and upper Christopher shales at Lougheed Island resemble the lower and upper parts of the formation in the Ringnes Islands.

Hassel Formation

At the type region, Ellef Ringnes Island (Fig. 1b), the Hassel Formation (Heywood, 1957; Hopkins and Balkwill, 1973; Balkwill, in press) consists of about 550 m of brightly coloured quartz sandstone.

Hassel Formation sandstones underlie large parts of central and southern Lougheed Island and the north-facing slope of Edmund Walker Island. Skybattle Bay C-15 and Pat Bay A-72 wells were spudded in the upper part of the formation. The formation is estimated to be about 300 m thick from graphic calculations and from the thickness of the parts penetrated in the wells.

The Hassel Formation consists mainly of light buff-grey to tan, fine- to medium-grained quartz sandstone. The lower part of the formation, which is transitional from the underlying Christopher Formation, has some very thin, dark grey shale intercalations, resembling upper Christopher shales. The middle part of the formation is almost entirely buff-grey, fine- to coarse-grained, clay-cemented sandstone, with some lenses of pebbles (to about 5 mm in diameter) in shallow relict channels. There is abundant carbonaceous detritus on bedding surfaces, and some thin carbonaceous shale and siltstone beds. No thick coal beds were observed. Thin to medium sets of high-angle, tabular cross-strata are common in the middle part of the formation. About 100 m below the top there are some thin beds that are cemented by red-brown hematitic clay. Red fragments of the resistant ferruginous beds form a lag veneer on the modern erosional surface.

The upper 75 m, approximately, consist of thin to medium beds of buff-yellow, weakly cemented, partly glauconitic quartz sandstone, with some parallel laminations, some thin sets of moderate- to low-angle cross-strata, and some relict scour channels, and at some levels abundant articulated pelecypods. The sandstones are very abruptly intercalated with black, pyritic, very acidic (pH values range from about 2.6 to 3.6), weakly indurated clay shales (Fig. 10). The black shale beds have yellow and white sulphate encrustations on some surfaces. In this way the sandstone-dominated Hassel Formation is gradational to the overlying shale-dominated Kanguk Formation. The contact between the formations was mapped at the level at which shale is the dominant lithology.

Paleontological evidence from the central part of Sverdrup Basin indicates that the Hassel Formation there ranges possibly from Upper Albian to Cenomanian (Hopkins and Balkwill, 1973).

Shallow-marine pelecypods were collected from Hassel sandstones at two locations on Lougheed Island (GSC locs. C-57559 and C-57628), but they are not diagnostic of a particular Cretaceous stage (Appendix). Dinoflagellates from GSC localities C-60018 and C-60019 are considered by W.W. Brideaux (Appendix) to be early Late Cretaceous (Cenomanian-Turonian). A sample from GSC locality C-60278 contained sparse radiolarians (mostly referable to *Spongodiscus*) and rare algal cysts. Calcareous foraminifers are absent in the shales, possibly because they were leached in the extremely acidic rocks.

In the central part of Sverdrup Basin, the Christopher and Hassel Formations are gradational as intercalated shale and sandstone; but there are no marine shales in the upper part of the Hassel Formation, and the contact with the Kanguk shales is very abrupt. Early Turonian ammonites were collected from beds about 50 m above the base of the Kanguk Formation at Amund Ringnes Island (Balkwill, in press). If the upper part of the Hassel Formation at Lougheed Island is as young as Turonian, as microfloral evidence cited above suggests, then it may be coeval with lower Kanguk shales of the Ringnes Islands. The Hassel Formation at Sabine Peninsula (Fig. 1b) has shale intercalations throughout, and the formation is not as thick as it is at Lougheed Island. From the foregoing regional considerations it is possible that the upper Hassel sandstones at Lougheed Island prograded to Sverdrup Basin from western (or northwestern) sources. Miall (1975, p. 574) concluded that the Cenomanian and Turonian were times of significant uplift beyond the southwestern margin of Sverdrup Basin on Banks Island (Fig. 1b).

Intercalated sandstones and shales in the lower part of the Hassel Formation may have accumulated at the front of an Albian delta, which in Late Albian prograded through the region of Lougheed Island. Mid-Hassel sandstones, which have insignificant amounts of fine clastics or coal, and lack marine fossils, are possibly products of braided delta distributary channels. The upper part of the formation, with intercalated marine sandstones and shales, some hematitic clay beds, relict scour channels, and low-angle cross-strata,

and with articulated pelecypods, indicates that the sediments accumulated on a shallow-marine surface that underwent occasional emergence and oxidation, and abrupt alternations of energy. A tidal flat might provide such an environment.

FIGURE 10. *Upper part of Hassel Formation, western Lougheed Island; intercalated light buff sandstone and black shale.*

Kanguk Formation

Upper Cretaceous marine dark shales lying between the Hassel Formation and sandstones of the Eureka Sound Formation in Sverdrup Basin are referred to as the Kanguk Formation (Souther, 1963; Fricker, 1963; Balkwill and Hopkins, 1976). The type section is at Kanguk Peninsula, Axel Heiberg Island (Fig. 1b).

The Kanguk Formation is poorly exposed over the low terrain of southern Lougheed Island. From graphic calculations the formation is estimated to be about 200 m thick, but this is tenuous because reliable measurements of bedding dips are difficult to obtain from the soft wet shales. The Kanguk Formation lies gradationally above the sandstone-dominated Hassel Formation; the base of the Kanguk was mapped at the level where shale is more abundant in the succession than sandstone.

The lower 100 m, approximately, of the Kanguk Formation consists of intercalated shale and sandstone with marine microfloras. The shales are black, cohesive, papery, pyritic, and clay rich; they have white sulphate surface encrustations. The air in places underlain by the shales has a sulphurous odour. Buff-yellow, fine-grained, weakly cemented (by clay) quartz sandstone beds, generally less than 2 m thick, are interbedded with the shales. Sandstone beds decrease in abundance upward, although about 100 m above the base of the Kanguk Formation there is an interval of buff to tan, parallel-bedded quartz sandstone several metres thick, delineated as a marker on Map 1490A. The sandstone has carbonaceous detritus on bedding surfaces.

The upper part of the Kanguk Formation appears to consist entirely of black, cohesive, acidic, sulphurous-smelling marine clay shale, with very thin (mostly less than 2 cm) parallel beds of light yellow jarositic clay. Some black, hard, lustrous coal beds, about 1 cm thick, lie in the shales not far above the upper sandstone beds. Black uppermost Kanguk shales are overlain abruptly by light buff-grey sandstones of the Eureka Sound Formation.

No macrofossils were observed in Kanguk strata. Microfaunas from the formation are almost entirely siliceous or chitinous, consisting of radiolarians, sponge spicules, and algal cysts. The processed residues in aqueous solution yielded pH readings indicative of a relationship between low values and lack of calcareous microfossils. No calcareous forms were recovered from six samples of Kanguk shales, which had an average pH of 2.53. By comparison, 14 samples of Christopher Formation shales had an average pH of 7.06, and they contain diverse foraminiferal faunas.

The shale and sandstone of the lower part of the formation, as at GSC locality C-60039, is suggested to be Turonian or lower Senonian from the enclosed microfloras (Appendix). Senonian or possibly Campanian radiolarians were recovered from shales just below the marker sandstone at GSC locality C-60275. A sample (GSC loc. C-57556) from beds a few metres below Maastrichtian sandstones of the Eureka Sound Formation contained microfloras, including dinoflagellates, suggestive of a Cenomanian-Turonian age. The upper part of the Kanguk Formation on Lougheed Island therefore seems to be truncated northward, so that in the central part of the island Campanian and some older beds are absent beneath a sub-Eureka Sound unconformity.

At the type section and at other places in the central part of Sverdrup Basin, the Kanguk Formation consists of two parts: lower shales, possibly ranging from Cenomanian to lower Santonian, which are black, slightly silty, and pyritic, and which have very thin beds of yellow jarositic clay; and upper shales, ranging possibly from lower upper Santonian to upper Campanian or lower Maastrichtian, which are brown-grey, very silty, and which have few tuffaceous clay beds (Fig. 11). Those intra-Kanguk lithologies are not evident on Lougheed Island. The succession there is more like parts of Banks Island (Miall, 1975) where a Campanian sandstone, derived locally from small uplifts, is present in the Kanguk Formation.

Eureka Sound Formation

The Eureka Sound Formation (Troelsen, 1950; Tozer, 1963c) was named for Upper Cretaceous and lower Tertiary, mainly nonmarine sandstones, siltstones, and shales in the eastern part of Sverdrup Basin (Fig. 1b) originally stated to be "younger than the last orogeny" (Troelsen, 1950, p. 78). As mapping in the Arctic Archipelago progressed, the formational name came to be applied to Upper Cretaceous and lower Tertiary rocks in a wide variety of structural-stratigraphic settings: in the Eureka Sound area, Ellesmere Island, the formation is very thick (about 3000 m) and is partly a syntectonic clastic wedge within the Eurekan Fold Belt (Bustin, 1977); small grabens within Paleozoic rocks south and east from Sverdrup Basin contain a few tens of metres of lower Tertiary sandstones that have been assigned to the Eureka Sound Formation (e.g. Kerr, 1974); and the lower Tertiary and uppermost Cretaceous part of the continental terrace wedge beneath the Arctic Coastal Plain has as much as 839 m of strata that have been assigned to the formation (Miall, 1975, p. 579).

The Eureka Sound Formation lies on black Kanguk shales over small irregularly shaped areas of south-central Lougheed Island. The formation is about 60 m thick. After a foot traverse of southern Lougheed Island in 1955, Glenister and Thorsteinsson (1963) suggested that most of southern

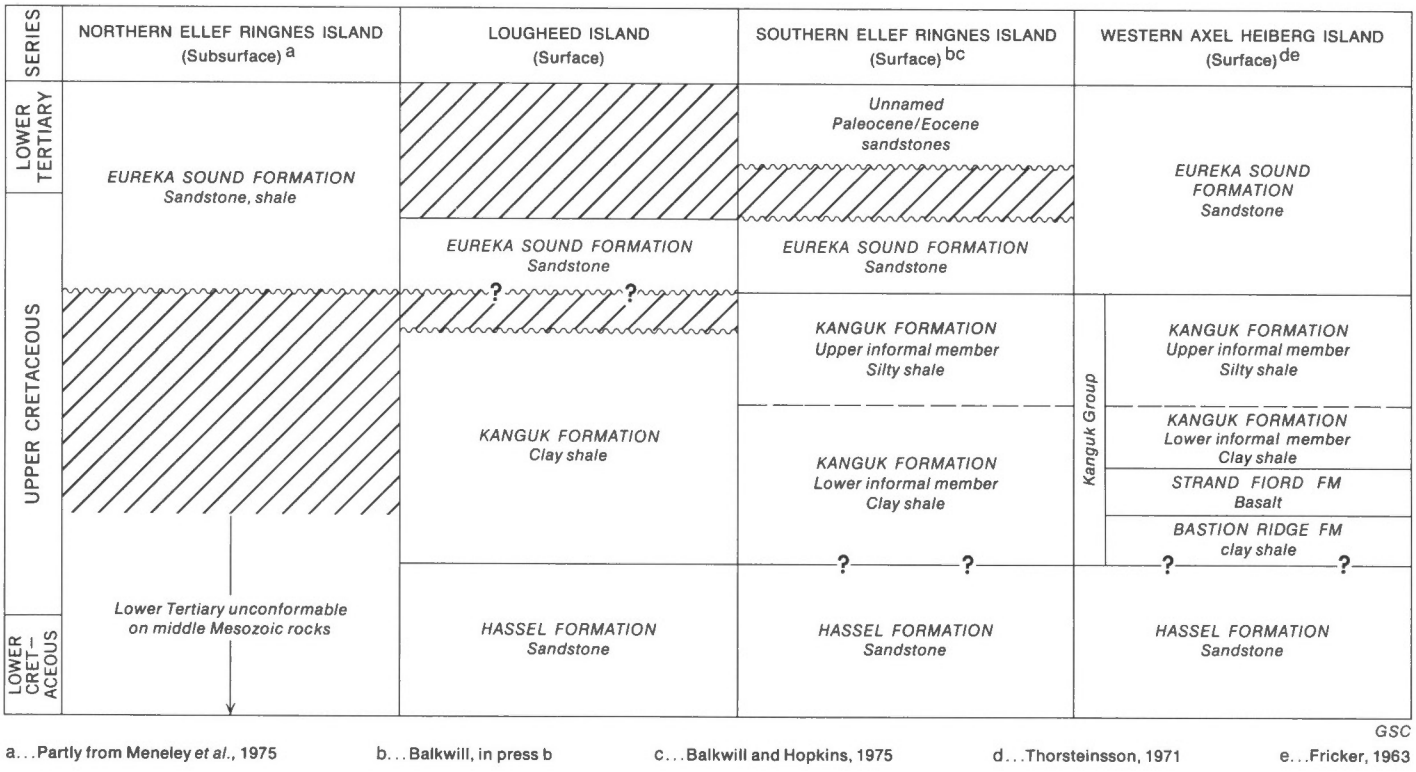


FIGURE 11. *Upper Cretaceous regional stratigraphy, western Sverdrup Basin.*

Lougheed Island is underlain by the Eureka Sound Formation. Subsequently, the formation was interpreted to underlie most of the island and, further, it was assigned to the Tertiary, as much of the formation is in its type region (Douglas, 1969).

Eureka Sound sandstones are light buff-grey, and medium to coarse grained. The grains are principally subangular quartz, with about 5 per cent rounded chert grains and, on bedding surfaces, abundant angular carbon fragments. The sandstones are weakly cemented by clay. There are some relict scour channels with pebbly sandstone lenses, and some thin (about 3 cm) black carbonaceous shale beds, and carbonized log fragments as long as 2 m.

A sample collected from GSC locality C-60043, directly above possible Cenomanian or Turonian shales, contained Maastrichtian palynomorphs. The base of the Eureka Sound Formation may therefore be above an intra-Cretaceous unconformity. Eureka Sound rocks on southern Ellef Ringnes Island lie gradationally on the Kanguk Formation and there is no evidence of a hiatus (Fig. 11). In wells beneath the Arctic Coastal Plain of Ellef Ringnes Island, Maastrichtian Eureka Sound beds lie above a great hiatus; underlying strata are Lower Cretaceous or Upper Jurassic (Meneley et al., 1975). It is not obvious at present whether the possible unconformity beneath the Eureka Sound Formation at Lougheed Island was physically connected with the Late Cretaceous uplifted terrain of Sverdrup Rim, or whether it was a response to local tectonism.

Quaternary

Uncompacted sand, silt, and clay are delineated on Map 1490A by the symbol Q in places where bedrock is completely obscured. Alluvial deposits underlie floodplains along the modern coast and some relict floodplains in the central part of the island. Some of the alluvial materials have been reworked by shore processes as beach ridges and other marine deposits northward from Skybattle Bay and at Cape Rondon.

A sinuous low ridge near the southeastern coast may be an esker (Roots, 1963, p. 529).

Subangular to subrounded cobbles and boulders, to about 40 cm in diameter, lie at lower elevations on the modern erosional surface. In some places there are clusters of coarse clasts; in others there are solitary clasts. The clasts are commonly striated, they are of such diverse lithologies as sandstone, chert, carbonates, and igneous and metamorphic rocks. They may be glacially derived materials which were ice-rafted to Lougheed Island during a higher stand of sea level.

Stratigraphic Summary

Approximate mean rates of accumulation of Mesozoic rock-stratigraphic units at Lougheed Island are presented in Figure 12. Sparse or nondiagnostic biostratigraphic control at some levels in the succession imposes limitations on the value of the results. Nonetheless, silty shales comprising the Christopher Formation accumulated faster than any other unit in the column, and the Savik and Kanguk Formations, which are dominantly clay shales, accumulated appreciably slower than other units. These extremes hold for the same units in the central part of Sverdrup Basin (Balkwill, in press).

The Mesozoic succession is appreciably thinner at Lougheed Island than at King Christian Island (Fig. 3) and terranes eastward from there. This is partly because there is a great thickness of Triassic shales basinward (eastward) from Lougheed Island, and partly because some Mesozoic units (particularly the sandstone formations) thicken eastward. A long-lived Mesozoic stratigraphic hinge between Lougheed Island and King Christian Island is therefore

indicated. Differential subsidence across the hinge probably resulted from deep crustal processes. Boothia Uplift, a northward-striking, basement-cored horst, recurrently active in Paleozoic time, is southward and in an echelon position from the hinge (Fig. 1a), but there is no evidence at present that the elements are physically linked. The hinge has an important bearing on hydrocarbon exploration: the level of organic maturation for given rock-stratigraphic units west of the hinge is significantly lower than for the same units in the thick succession east of the hinge.

Samples of sandstone from the Isachsen, Hassel, and Eureka Sound formations, and from the sandstone marker within the Kanguk Formation, were analyzed by X-ray diffraction. Each of the samples consists almost entirely of quartz, with traces to about 2 per cent each, of feldspar and kaolinite. The highly quartzose sandstone formations on Lougheed Island must have been derived from older mature sandstone terrains.

STRUCTURAL GEOLOGY

Structural Elements

A syncline (Lougheed Syncline) with gently dipping limbs (2 to 5 degrees), and a sinuous axial trace, plunges gently (about 20 m per km) south-southeastward from the northern coast of Lougheed Island. The syncline terminates in the central part of the island at a cluster of low-amplitude, northward-striking folds.

A northwestward-plunging anticline at Skybattle Bay is at least 15 km long and has a surface amplitude of a few hundred metres. The Sun KR Panarctic Skybattle Bay C-15 well was drilled on strike with the crest of the fold. The eastern limb of the anticline is not overturned, as indicated previously (Balkwill, Hopkins and Wall, 1977). (That erroneous conclusion was reached because a westward-dipping, upright sandstone bed near the top of the Christopher Formation was mistaken for the overturned base of the Hassel Formation.)

A narrow syncline in the Eureka Sound Formation and upper part of the Kanguk Formation of east-central Lougheed Island strikes northeastward, contrasting with the predominantly northward to northwestward grain of the island.

The structural grain of Edmund Walker Island is northeastward. The Christopher-Hassel formational contact dips gently and uniformly northwestward; but upper Christopher shales and sandstones are intricately folded as northwestward-facing, asymmetrical folds, with approximate wave lengths of several tens of metres and amplitudes of several metres (Fig. 13). Those relatively small folds are nearly perpendicular to Lougheed Syncline and to other large, upright, northwestward-striking folds in Mesozoic rocks in neighbouring parts of Sverdrup Basin, such as the Ringnes Islands (Stott, 1969) and King Christian Island (Balkwill and Roy, 1977).

Interpretation

Large anticlinal swells and evaporite-cored diapirs in the southwestern part of Sverdrup Basin can be explained as products, directly or indirectly, of halokinetic migration of deeply buried, ductile, Carboniferous evaporites (Gould and deMille, 1964; Balkwill, 1978). The halokinetic structures may have originated in early or middle Mesozoic and continued to evolve with Mesozoic depositional loading. The axial traces of the anticlinal swells strike west-northwestward to northwestward. Meneley et al. (1975) proposed that, during part of Carboniferous time, Sverdrup

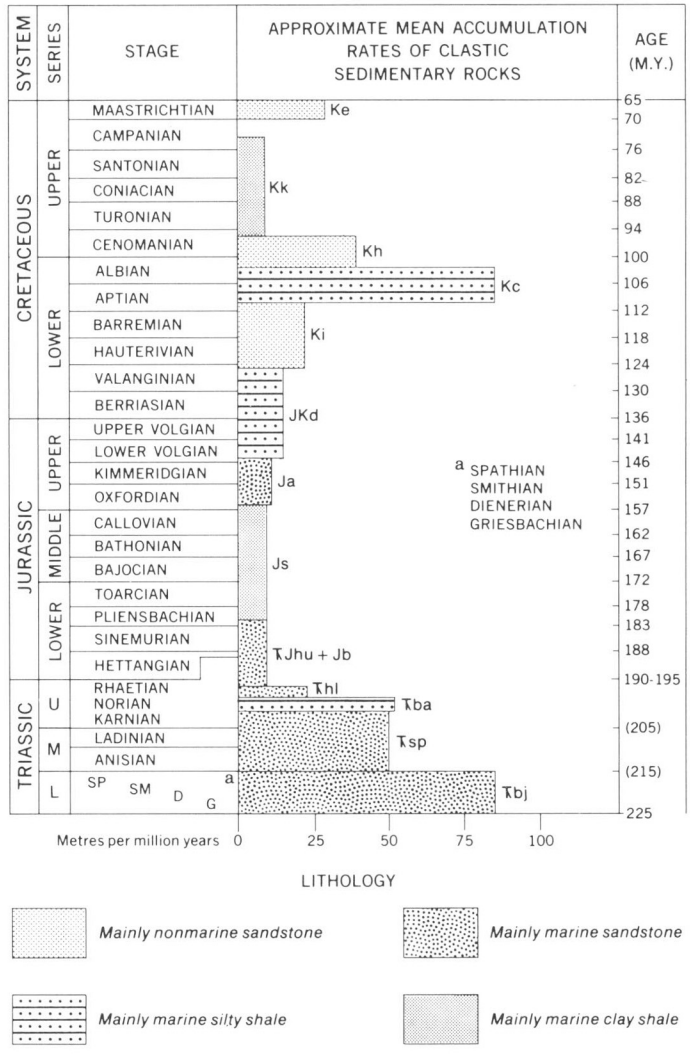


FIGURE 12. Approximate mean accumulation rates (m/Ma) for Mesozoic sedimentary rocks, Lougheed Island.

FIGURE 13. Disharmonic flexural-flow folds, upper part of Christopher Formation, Edmund Walker Island.

Basin was segmented into southwestern and eastern evaporite basins by a northward-striking mid-basin carbonate platform, approximately in the region of Lougheed Island; according to this concept, evaporite piercements are absent at Lougheed Island because there is an insufficiently thick (or absent) mother evaporite layer at depth. The large gentle folds comprising Lougheed Syncline and the anticline at Skybattle Bay might, however, be responses to regional evaporite movement.

Unconformities at the margins of Sverdrup Basin are products of recurrent basinward tilting and uplift of parts of the northern rim. One of the most significant unconformities along the northern rim of the basin is at the base of Maastrichtian rocks, which in places lie on Jurassic and Triassic strata (Meneley et al., 1975). The intra-Cretaceous, sub-Maastrichtian unconformity at Lougheed Island may be a subtle manifestation of that structure, basinward from the northwestern rim.

The origin of northeast-striking folds on Edmund Walker Island is not clear. They are exposed in a southeastward-facing erosional slope, and therefore cannot be products of recent gravitational downslope mass flow. There is not sufficient evidence to determine if they are ice-thrust structures from Pleistocene glaciation. The style of the structures and their northwestward-facing asymmetry suggest that they were generated by ductile flow from a structurally high domain south of Edmund Walker Island. Large positive gravity anomalies lie westward and southward from southern Lougheed Island (Sobczak and Weber, 1970), supporting the possibility that large offshore structures may have influenced development of the small folds. Other northeastward-striking structural elements in western Sverdrup Basin include the small fold on Lougheed Island, an Early Cretaceous diabase dyke in Carboniferous rocks at Sabine Peninsula (Haimila and Balkwill, 1978), magnetic lineaments between Ellef Ringnes Island and Mackenzie King Island (Bhattacharyya, 1968), folds and faults in Mesozoic rocks of northern Ellef Ringnes Island (Stott, 1969) and, from interpretations of earthquakes, some possible recent strike-slip faults between Lougheed Island and Sabine Peninsula (Hasegawa, 1977) (Fig. 14). Whether all or any of the northeast-striking elements are genetically related is presently conjectural.

ECONOMIC GEOLOGY

Coal

In 1917, Stefansson's companions found a vein of coal on southern Lougheed Island, which they described (Stefansson, 1921) as "a hill of coal". The Stefansson party used some of the coal as fuel. From those descriptions the hill containing the coal beds was named Coal Hill, and 1:1,000,000-scale maps of the region carried the notation 'surface coal deposits' (see Belcher Channel, World Aeronautical Chart, 1968, Department of Energy, Mines and Resources, Canada). The name Coal Hill and the map notation are somewhat misleading. The writers observed only a few coal belts at the locality, none thicker than a few centimetres. The coal beds are in the Hassel and Kanguk formations. The occurrence of coal in the latter unit is particularly interesting because the shales above and below the thin coal beds contain abundant dinoflagellates and radiolarians and are clearly marine deposits. A coal sample from the Kanguk formation was examined by P.F. Gunther (pers. com., 1977) who commented that the material is lignite, containing two macerals, vitrinite and resinite; and further, the reflectance value is exceptionally low (0.30 ± 0.01), indicating minor burial.

No coal beds greater than a few centimetres thick were observed in the Isachsen Formation. Some carbonaceous shale beds are about 1 m thick; from a distance they resemble thick coal beds.

Uranium

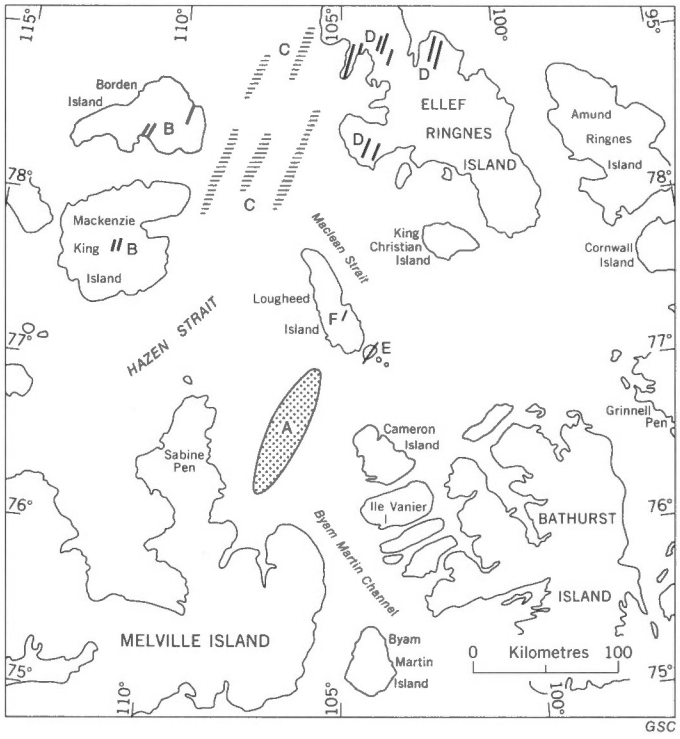
Sandstones containing appreciable amounts of felsic volcanic clasts are considered most favourable for deposition of epigenetic uranium (Gabelman, 1971). Surface samples from sandstone-dominant formations on Lougheed Island are composed almost entirely of quartz, and are therefore not promising as potential uranium host rocks.

Gas and Oil

Lougheed Island lies about midway between Sabine Peninsula and King Christian Island, the two principal areas of hydrocarbon discovery in the Sverdrup Basin (Fig. 1b).

No oil or natural gas seeps were observed during reconnaissance traverses of Lougheed Island and the nearby small islands.

At the time of writing, two dry boreholes, Sun KR Panarctic Skybattle Bay C-15 and Panarctic Tenneco et al. Pat Bay A-72, had been drilled on Lougheed Island, both of which penetrated the succession to the level of Middle or Lower Triassic strata. Well data are presented in Table 2.



Byam Martin Channel earthquake swarm (Hasegawa, 1977) ..... A
Faults, Mackenzie King and Borden Islands (Tozer and Thorsteinsson, 1964) ..... B
Magnetic anomalies, Prince Gustaf Adolf Sea (Bhattacharyya, 1968) C
Faults, northern Ellef Ringnes Island (Stott, 1969) ..... D
Folds, Edmund Walker Island (this paper) ..... E
Fold, Lougheed Island (this paper) ..... F

FIGURE 14. *Northeast-striking structural elements, western Queen Elizabeth Islands.*

TABLE 2

Well Data

WELL NAME	LOCATION	SPUDDED	COMPLETED	GROUND ELEVATION		K.B.		T.D.		STATUS
				metres	(feet)	metres	(feet)	metres	(feet)	
Sun KR Panarctic *et al.* Skybattle Bay C-15	77°14'12.5"N 105°05'57"W	4-1-71	11-18-71	24.08	(79)	30.48	(100)	3657.6	(12 000)	Dry and abandoned
Panarctic Tenneco *et al.* Pat Bay A-72	77°21'01.6"N 105°26'57.0"W	2-28-75	5-1-75	17.07	(56)	23.77	(78)	3230.88	(10 600)	Abandoned observation well

GSC

Source rocks

Mesozoic marine shales in western Sverdrup Basin that might serve as source rocks for hydrocarbons include the Kanguk, Christopher, Deer Bay, Savik, and Blaa Mountain formations (and some parts of the coeval Schei Point Formation) and the Blind Fiord Formation. Amounts of organic carbon in those pelitic successions are commonly great enough for the rocks to be considered potential hydrocarbon sources (Henao-Londoño, 1977b). Upper Carboniferous and Permian rocks in the axial part of Sverdrup Basin are probably marine pelites, but the distribution and lithologies of those rocks are not well known (Thorsteinsson and Tozer, 1970a, Fig. X-8).

A critical parameter for hydrocarbon potential is the depth of burial of possible source rocks. Significantly, two lines of evidence indicate that minimal thicknesses of strata were removed from the region of Lougheed Island by Cenozoic erosion: the greatest preserved thickness of the Eureka Sound Formation (the youngest formation in west-central Sverdrup Basin) is about 700 m, at western Ellef Ringnes Island (Fig. 1b); and reflectance values of the coal sample from the Kanguk Formation (which lies directly beneath the Eureka Sound Formation) are exceptionally low, indicating very shallow burial.

Snowdon and Roy (1975) analyzed drill cuttings from Sverdrup Basin wells by gas chromatography. They concluded that, for the region of Lougheed Island, rocks above the base of the Isachsen Formation fall within the immature organic metamorphic facies (where dry gas and some heavy oil are anticipated); rocks beneath the base of Triassic strata fall within the metamorphosed facies (where dry gas and condensate are expected); and rocks between those levels are within the mature facies (where wet gas and oil are most likely to occur). Their predicted levels of hydrocarbon occurrence do not take into account the possibilities of secondary migration.

Baker et al. (1975) presented data supporting the contention that oil potential of Mesozoic rocks in the basin is good, particularly for the Awingak Formation.

From chemical studies, Henao-Londoño (1977b) concluded that Sverdrup Basin is essentially a gas-prone area. He suggested that the small amounts of oil recovered from wells and surface seeps in western Sverdrup Basin originated in Upper Triassic rocks, and that the large gas accumulations (Fig. 1b) are probably from Jurassic and Upper Triassic source rocks.

Following several methods of chemical analysis, Powell (1978) recognized the following facies of organic metamorphism in Sverdrup Basin rocks: undermature, marginally mature, mature, and overmature; and further, he placed the onset of the marginally mature zone at approximately 1500 m, and the transition from mature to overmature facies at about 4200-4500 m. Applied to the Lougheed Island subsurface succession, the marginally mature level would be expected approximately within the Deer Bay Formation, and the mature-overmature transition in the lower part of the Bjorne Formation or beneath it. Powell also pointed out that, locally, the levels of organic maturation in the succession are raised significantly by heating from intrusion by large mafic dykes and sills. Such intrusions, as young as Late Cretaceous, are most abundant and are highest in the stratigraphic column in the axial part of the basin at western Axel Heiberg Island (Fig. 1b). From there, outward to the margins of the basin, the intrusions are present at progressively lower stratigraphic levels (Balkwill, 1978). No mafic rocks were penetrated in wells on Lougheed Island.

Reservoir rocks

Possible Mesozoic reservoir rocks beneath Lougheed Island are the Awingak Formation, Heiberg Formation (Upper Member) and Borden Island Formation (undivided), Schei Point Formation and Bjorne Formation. Each of those sandstone units contains significant hydrocarbons at locations in western Sverdrup Basin; in most cases the units are gas-bearing (Henao-Londoño, 1977a).

The sandstone succession here assigned to the Heiberg Formation (Upper Member) - Borden Island Formation (undivided) is the reservoir for gas in fields at King Christian Island, Ellef Ringnes Island, and at Sabine Peninsula (Fig. 1b). Henao-Londoño (1977a) informally named the upper part of the interval the "King Christian sand" in the King Christian - Ellef Ringnes region. That succession has particularly good potential where it is porous, because it lies between Upper Triassic and Jurassic rocks with high potential as hydrocarbon sources.

Meneley et al. (1975) postulated that an Upper Carboniferous carbonate facies extends northward under Lougheed Island, separating coeval evaporite deposits to the southwest and east. The existence of the carbonate facies has not been confirmed by drilling, and its possible potential as a reservoir tract is thus uncertain.

Migration and traps

Geochemical studies, cited in foregoing sections, indicate that significant generation of hydrocarbons began only when Sverdrup Basin rocks were buried to depths greater than about 1500 m. From those studies, migration from Upper Triassic and Lower and Middle Jurassic shales began about Aptian or Albian, when sediments of the Christopher Formation were being deposited on the Sverdrup Basin floor, and continued from that time to the present.

Traps for gas fields at King Christian Island and western Ellef Ringnes Island, and possibly also at Sabine Peninsula, are large ovate anticlines that are probably cored by evaporites at depth, but not pierced by evaporites as diapirs. The structures may have begun to evolve as early as Triassic, from deep migration of ductile Carboniferous

evaporites under a thick load of upper Paleozoic and Triassic rocks. Rates of movement of the ductile evaporites should be partly a response to the rates of sedimentary loading. Sediments comprising the Christopher Formation accumulated faster than any other Sverdrup Basin unit (Fig. 12 and Balkwill, 1978). Consequently, halokinetic structures were probably being developed while hydrocarbons were being generated. With present data, the large structures on Lougheed Island cannot be demonstrated to be direct responses to halokinesis; but other explanations for their origin are less satisfactory.

Land Use

Permafrost is generally no deeper than about 0.5 m below the ground surface in the Findlay Group of islands. Disruption of the permafrost regime is the most acute danger to land use in the islands.

The Christopher Formation and particularly the Kanguk Formation contain expansive clays and are generally unsuitable for fill material. The Kanguk shales are extremely acidic and would be quite deleterious to concrete and steel structures if in direct contact with them. The Isachsen Formation and parts of Hassel Formation might serve as useful fill materials. There are no large gravel deposits on the islands.

The western Queen Elizabeth Islands have low to moderate seismic activity (Stevens, 1974). Engineering design and construction should anticipate earthquakes.

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Appendix

PALEONTOLOGY

Fossils collected from Lougheed Island and nearby small islands were examined by stratigraphic paleontologists of the Geological Survey of Canada and the following lists are from their reports. The approximate stratigraphic positions of the collections are as indicated; the geographic locations are noted on the geological map.

Macropaleontology

Triassic
by E.T. Tozer

Schei Point Formation

GSC loc. C-62999 (Sun KR Panarctic et al. Skybattle Bay C-15, 9120 - 9260 ft)
halobiid fragments
Age: Middle or Late Triassic

GSC loc. C-62998 (Sun KR Panarctic et al. Skybattle Bay C-15, 8620 - 8630 ft)
coquinoid rock
Age: probably Late Triassic

GSC loc. C-62997 (Sun KR Panarctic et al. Skybattle Bay C-15, 8560 - 8570 ft)
bivalve fragments, probably halobiids
Age: probably Middle or Late Triassic

Blaa Mountain Formation

GSC loc. C-62996 (Sun KR Panarctic et al. Skybattle Bay C-15, 7560 - 7570 ft)
bivalve fragments, probably halobiids
Age: probably Middle or Late Triassic

GSC loc. C-62995 (Sun KR Panarctic et al. Skybattle Bay C-15, 7460 - 7470 ft)
bivalve fragments, probably halobiids
Age: probably Middle or Late Triassic

GSC loc. C-62994 (Sun KR Panarctic et al. Skybattle Bay C-15, 7430 - 7440 ft)
bivalve fragments, probably halobiids
Age: probably Middle or Late Triassic

Cretaceous
by J.A. Jeletzky

Christopher Formation

GSC loc. C-57625 (Lougheed Island, about 200 m below top of Christopher Formation; 77°40'30"N, 105°42'W)
Beudanticeras (Grantziceras) affine (Whiteaves)
Age and correlation: Late Early or early mid-Albian

Hassel Formation

GSC loc. C-57628 (Lougheed Island, upper part of Hassel Formation; 77°29'30"N, 105°15'W)
Arctica (sensu lato) sp. indet.
?*Pholadomya* (sensu lato) sp. indet.
Age and correlation: ?Cretaceous. Cannot be dated any closer. GSC loc. C-57628 is interesting in indicating the either shallow-marine or lagoonal to estuarine environment of deposition for the upper beds of the Hassel Formation on Lougheed Island.

Micropaleontology

Jurassic
by J.H. Wall

GSC loc. C-30225 (subsurface samples from Sun KR Panarctic et al. Skybattle Bay C-15; depths in feet below K.B.)

Savik Formation

5800 - 5810 Foraminifera:
Ammodiscus cheradospirus (Loeblich and Tappan)
Haplophragmoides spp., mostly small forms
Ammobaculites spp.
Trochammina sp. cf. *T. kosyrevae* - one specimen
Lenticulina audax Loeblich and Tappan - one specimen
L. sp. cf. *L. splendita* Beljaevskaja
L. spp.
Darbyella sp. - one specimen
Marginulinopsis sp. - one specimen
Dentalina sp. - one specimen

Ostracoda:
Aparchitocythere sp. - one specimen
?*Eucytherura* sp.
Age: Late Jurassic, probably Oxfordian
Environment: marine, shallow, inner shelf

5740 - 5750 Foraminifera:
Ammodiscus cheradospirus (Loeblich and Tappan)
Haplophragmoides spp., mostly small forms unlike the large *H. canui* at higher levels
Lenticulina limpida Dain
L. spp.
Darbyella sp. - one specimen
Pseudonodosaria brandi (Tappan)
Age: Late Jurassic, probably Oxfordian
Environment: marine, shallow, inner shelf

5630 - 5640 Foraminifera:
Bathysiphon sp.
Ammodiscus thomsi Chamney
Haplophragmoides canui and cf. *canui* Cushman
Ammobaculites sp. cf. *A. alaskensis* Tappan
A. sp., very large, compressed, tapering with low chambers
Trochammina gryci Tappan - one specimen
T. sp. cf. *T. kosyrevae* Levina - one specimen
Eomarssonella paraconica Levina - one specimen
Lenticulina iatriensis Dain - one specimen
L. semipellucida Dain - one specimen
L. sp.
Marginulinopsis sp. - one specimen
Pseudonodosaria sp. - one specimen

Ostracoda:
Aparchitocythere sp. - one specimen
Age: Late Jurassic, probably late Oxfordian to early Kimmeridgian
Environment: marine, shallow, inner shelf

5570 - 5580 Foraminifera:
Ammodiscus cheradospirus (Loeblich and Tappan)
Haplophragmoides canui and cf. *canui* Cushman
Ammobaculites spp., including the very large species in 5630-5640 ft interval
Trochammina canningensis Tappan - one specimen
T. sp. cf. *T. kosyrevae* Levina
Lenticulina iatriensis Dain - one specimen
L. spp.
?*Pseudonodosaria* sp. - fragment

Age: Late Jurassic, probably Kimmeridgian
Environment: marine, shallow, inner neritic, possibly fairly turbid

Deer Bay Formation

4730 - 4740 Foraminifera:
Arenoturrispirillina intermedia Chamney
A. sp. cf. *A.* sp. of Chamney (1971, Pl. 18, Fig. 2)
Haplophragmoides canui and cf. *canui* Cushman
Ammobaculites sp. cf. *A. multiformis* Dain
A. sp. ex. gr. *syndascoensis* Scharovskaja
Gaudryina milleri Tappan
Riyadhella sp.
Age: Late Jurassic, probably late Kimmeridgian to early Volgian, based on the occurrences of *Arenoturrispirillina* spp.
Environment: marine, shallow, inner neritic to near shore, possibly fairly turbid

4660 - 4670 Foraminifera:
Arenoturrispirillina jeletzkyi Chamney
A. waltoni Chamney
Haplophragmoides canui and cf. *canui* Cushman
Ammobaculites sp. cf. *A. multiformis* Dain
Gaudryina milleri Tappan
Lenticulina spp.
Age: Late Jurassic, probably late Kimmeridgian to early Volgian, based on the occurrences of *Arenoturrispirillina* spp.
Environment: same as for interval 4730-4740

4510 - 4520 Foraminifera:
Ammodiscus sp. cf. *A. cheradospirus* (Loeblich and Tappan) - fragments
Haplophragmoides canui and cf. *canui* Cushman
Ammobaculites spp.
Trochammina gryci Tappan
Gaudryina milleri Tappan
G. sp.
Lenticulina spp.
Age: Late Jurassic, probably Volgian, based on highest occurrence of *Gaudryina milleri*, calibrated with megafaunal occurrence at Buchanan Lake, Axel Heiberg Island (Jeletzky, 1976)
Environment: marine, shallow, inner neritic to near shore, possibly fairly turbid

4460 - 4470 Foraminifera:
Haplophragmoides sp. cf. *H. canui* Cushman
Gaudryina topagorukensis Tappan - one specimen
Lenticulina sp., small - one specimen
Saracenaria phaedra Tappan - one specimen
Globulina sp. - one specimen
Age: Late Jurassic(?), based on single occurrences of *G. topagorukensis* and *S. phaedra*

Cretaceous
by J.H. Wall

GSC loc. C-30225 (subsurface samples from Sun KR Panarctic et al. Skybattle Bay C-15; depths in feet below K.B.)

Deer Bay Formation

4250 - 4420 Foraminifera:
Ammodiscus thomsi Chamney - fragments
Ammodiscus sp. - fragments
Haplophragmoides canui and cf. *canui* Cushman
?*Reophax* sp., coarse-grained fragments
Recurvoides sp.
Age: Early Cretaceous, Neocomian, probably Valanginian, based mainly on absence of Late Jurassic forms. Interval does not contain any diagnostic foraminiferal species.
Environment: marine, shallow, inner neritic to near shore, possibly fairly turbid

4150 - 4210 Foraminifera:
Bathysiphon sp. - possible caving from Christopher Formation
Miliammina or *Psamminopelta* sp. - possible caving, as above
Haplophragmoides canui and cf. *canui* Cushman
H. spp. - small and nondescript forms
Recurvoides sp. cf. *R. sublustris* Dain
Uvigerinammina sp. - two specimens - similar to form from upper part of Deer Bay Formation on Amund Ringnes Island
Age: Early Cretaceous, Neocomian, Valanginian
Environment: marine, shallow, inner neritic to near shore, possibly fairly turbid

Christopher Formation

GSC loc. C-60311 (Lougheed Island, near base of Christopher Formation; 77°43'30"N, 106°02'W)
Foraminifera (agglutinated):
Hippocrepina barksdalei (Tappan)
Ammodiscus sp., small - one specimen
Glomospirella sp. - one specimen
Haplophragmoides sp. cf. *H. sluzari* Mellon and Wall
"*Tritaxia*" *athabascensis* Mellon and Wall
megaspore - one
siliceous sponge spicules
bone fragments
Age: Early Cretaceous, Albian
Environment: marine, inner shelf
pH: 7.3

GSC loc. C-60312 (Lougheed Island, lower part of Christopher Formation; 77°43'N, 105°58'W)
Foraminifera (agglutinated):
Haplophragmoides sp. cf. *H. sluzari* Mellon and Wall
"*Tritaxia*" *athabascensis* Mellon and Wall
foraminifer (calcareous) - ?*Cribroelphidium* sp.
tooth of unknown affinity
Age: Early Cretaceous, Albian
Environment: marine, inner shelf
pH: 7.6
Note: ?*Cribroelphidium* is a modern foraminifer and represents recent contamination. Modern pelecypod shells were observed on the surface at this locality.

GSC loc. C-60313 (Lougheed Island, lower part of Christopher Formation; 77°42'N, 105°45'W)
Foraminifera:
Bathysiphon sp.
Hippocrepina sp.
Ammodiscus sp. of Stelck et al., 1956 - one specimen
Haplophragmoides sp. cf. *H. sluzari* Mellon and Wall
Ammobaculites sp. - one specimen
"*Tritaxia*" *athabascensis* Mellon and Wall
Nodosaria sp. - isolated chambers
Dentalina (?) dettermani Tappan - one chamber
Dentalina spp. - two terminal fragments, one probably is *D. praecommunis* Tappan
Marginulinopsis collinsi Mellon and Wall

Saracenaria projectura Stelck and Wall - one specimen
S. trollopei Mellon and Wall
S. sp. B of Stelck et al., 1956
Globulina lacrima canadensis Mellon and Wall
G. sp.
Spirillina sp.
Conorbina sp. of Tappan, 1962
Serovaina loetterlei (Tappan)
Quadrimorphina ruckerae (Tappan)
Age: Early Cretaceous, Early to Middle Albian
Environment: marine, neritic (probably about middle shelf)
pH: 3.95

GSC loc. C-60314 (Lougheed Island, lower part of Christopher Formation, about 9 m above C-60313)
Foraminifera (agglutinated):
Hippocrepina barksdalei (Tappan)
Ammodiscus sp. - one specimen
Haplophragmoides sp. cf. *H. sluzari* Mellon and Wall
Gaudryina sp.
"Tritaxia" *athabascensis* Mellon and Wall
Age: Early Cretaceous, Early to Middle Albian
Environment: marine, neritic, probably inner shelf if absence of calcareous component was a primary condition. As field sample was rubbly and collected 'wet', it is quite possible that any calcareous forms, which may have been present, could have been destroyed.
pH: 7.1

GSC loc. C-60316 (Lougheed Island, middle part of Christopher Formation; 77°40'30"N, 105°42'W)
Foraminifera (agglutinated):
Hippocrepina barksdalei Tappan
Ammodiscus sp. of Stelck et al., 1956
Haplophragmoides gigas minor Nauss
H. sp. cf. *H. sluzari* Mellon and Wall
shell fragments
Age: Early Cretaceous, Early to Middle Albian
Environment: marine, inner shelf
pH: 7.1

GSC loc. C-60319 (Lougheed Island, near top of Christopher Formation; 77°12'N, 105°01'30"W)
Foraminifera (agglutinated)
Bathysiphon sp.
Saccammina sp.
Ammodiscus sp. of Stelck et al., 1956 - one specimen
Miliammina sp. - one specimen
Haplophragmoides gigas minor Nauss
H. sp. cf. *H. sluzari* Mellon and Wall
"*Tritaxia*" *athabascensis* Mellon and Wall
Age: Early Cretaceous, Early to Middle Albian
Environment: marine, inner shelf
pH: 6.3

GSC loc. C-60326 (Lougheed Island, beds transitional to Hassel Formation; 77°40'N, 105°41'W)
Foraminifera:
Bathysiphon sp. - one specimen
Haplophragmoides sp. cf. *H. sluzari* Mellon and Wall
Lenticulina bayrocki (?) Mellon and Wall - corroded specimens
Age: Early Cretaceous, Albian
Environment: marine, shallow
pH: 7.5

GSC loc. C-60333 (Grosvenor Island, isolated outcrop; 77°05'N, 103°52'W)
Foraminifera:
Verneuilinoides sp. small - one specimen
Globulina lacrima canadensis Mellon and Wall - one specimen
Quadrimorphina ruckerae (Tappan)
Globorotalites alaskensis Tappan
Gavelinella stictata (Tappan)
algal cysts
Age: Early Cretaceous, Early to Middle Albian
Environment: marine, neritic
pH: 7.6

Hassel Formation

GSC loc. C-60278 (Lougheed Island, middle to upper part of formation; 77°15'N, 105°12'W)
sparse radiolarians, mostly referable to *Spongodiscus (Spongodiscus)*
rare algal cysts
Age: Late Cretaceous
Environment: marine
pH: 3.2

GSC loc. C-60328 (Lougheed Island, upper part of formation; 77°29'30"N, 105°36'W)
algal cysts, circular and fusiform
siliceous sponge spicules
pyritized rods - organic(?) origin
Age: indeterminate
Environment: probably marine
pH: 2.65

Kanguk Formation

GSC loc. C-60275 (Lougheed Island, about 15 m below sandstone marker; 77°12'N, 104°27'30"W)
Radiolaria:
Spongodiscus (Spongodiscus) sp. cf. *S. (S.) renillaeformis* Campbell and Clark - abundant
?*Cenosphaera* sp.
Age: Late Cretaceous, Senonian, possibly Campanian
Environment: marine, moderate depth

GSC loc. C-60324 (Lougheed Island, lower part of formation; 77°12'30"N, 104°51'W)
Radiolaria:
Spongodiscus (Spongodiscus) spp.
?*Cenosphaera* sp.
algal cysts, circular and fusiform
Age: Late Cretaceous
Environment: marine
pH: 2.05

GSC loc. C-60325 (Lougheed Island, upper middle part of formation; 77°12'30"N, 104°47'W)
Radiolaria:
Spongodiscus (Spongodiscus) sp. cf. *S. (S.) renillaeformis* Campbell and Clark
S. (S.) sp.
?*Cenosphaera* sp.
rare algal cysts
one siliceous sponge spicule
Age: Late Cretaceous, Senonian, possibly Campanian
Environment: marine
pH: 2.55

Cretaceous
by W.S. Hopkins, Jr.

Christopher Formation

GSC loc. C-60034 (Lougheed Island, upper part of formation; 77°33'N, 105°14'W)
Sphagnum sp.
Sestrosporites sp.
Cicatricosisporites sp.
Gleicheniidites sp.
Lycopodium sp.
Classopollis sp.
Vitreisporites sp.
Podocarpus sp.
Comments: Small and poorly preserved microfloras; but the sample contained recognizable dinoflagellates which W.W. Brideaux dates as Middle Albian-?Late Albian.

GSC loc. C-60040 (Lougheed Island, at top of formation; 77°40'N, 104°51'W)
Comments: Abundant kerogen, no palynomorphs. A few poorly preserved dinoflagellates suggest an Albian age (W.W. Brideaux, pers. com.)

GSC loc. C-27342 (Lougheed Island, at top of formation; 77°09'N, 104°50'W)
Comments: Little real stratigraphic subdivision of pollen and spores is possible. The assemblage appears to be Albian in age, which is compatible with the field interpretation.

Hassel Formation

GSC loc. C-27344 (Edmund Walker Island, near base of formation; 77°08'N, 104°09'W)
Comments: This sample contained a large, but indifferently preserved microflora. On the basis of phytoplankton and spores, I have little hesitation in suggesting an Albian age for the assemblage.

GSC loc. C-60018 (Lougheed Island, upper part of formation; 77°15'N, 105°12'W)
Sphagnum sp.
Cicatricosisporites sp.
Osmunda sp.
Lycopodium sp.
Podocarpus sp.
Tricolpites sp.
Comments: Contains Santonian or Turonian-Coniacian dinoflagellates (W.W. Brideaux pers. com.)

GSC loc. C-60019 (Lougheed Island, upper part of formation; 77°31'N, 105°31'W)
Gleicheniidites sp.
Sphagnum sp.
Osmunda sp.
Lycopodium sp.
?*Metasequoia* sp.
Comments: Contains Cenomanian-Turonian dinoflagellates (W.W. Brideaux, pers. com.)

GSC loc. C-60016 (Lougheed Island, upper part of formation; 77°23'N, 104°59'W)
Lycopodiacidites sp.
Gleicheniidites sp.
Sphagnum sp.
Tricolpites sp.
cf. syncolpate pollen grain
Comments: Limited palynomorphs, but appears to be lower Upper Cretaceous

GSC loc. C-60042 (Lougheed Island, near top of formation; 77°27'N, 105°28'W)
Sphagnum sp.
Osmunda sp.
Cicatricosisporites sp.
cf. *Metasequoia* sp.
cf. *Glyptostrobus* sp.
Extratriporopollenites sp.
cf. syncolpate pollen grain
Comments: A few dinoflagellates indicate an age of Late Albian to ?Cenomanian.

Kanguk Formation

GSC loc. C-60038 (Lougheed Island, at base of formation; 77°13'N, 104°58'W)
Lycopodiacidites sp.
Sphagnum sp.
Deltoidospora sp.
cf. syncolpate pollen grain
Comments: The syncolpate pollen grain suggests a Cenomanian age for this sample.

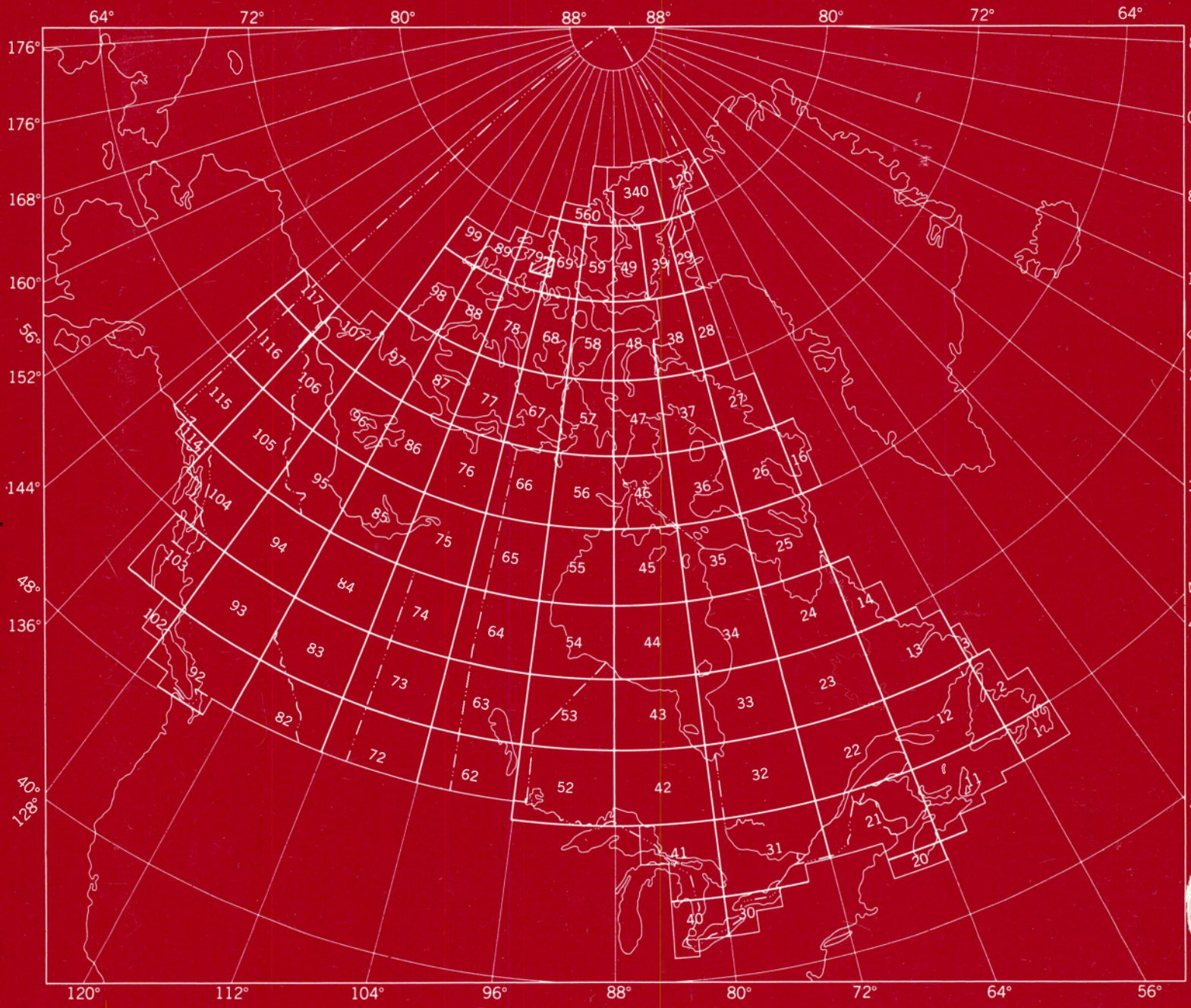
GSC loc. C-60039 (Lougheed Island, lower part of formation; 77°12'30"N, 104°51'W)
Deltoidospora sp.
Osmunda sp.
Sphagnum sp.
Lycopodium sp.
Lycopodiacidites sp.
Cicatricosisporites sp.
Vitreisporites sp.
Tricolpites sp.
syncolpate pollen grains
Comments: Both the pollen-spore flora and the contained dinoflagellates (W.W. Brideaux, pers. com.) suggest a Turonian or early Senonian age.

GSC loc. C-57554 (Lougheed Island, lower part of formation; 77°12'N, 104°39'W)
Deltoidospora sp.
Lucopodiacidites sp.
Glyptostrobus sp.
Tricolpites sp.
Retitricolpites sp.
Syncolpites sp.
Comments: I would suggest a Cenomanian-Turonian age for this microflora. This interpretation is supported by the dinoflagellate assemblage (W.W. Brideaux, pers. com.)

GSC loc. C-57556 (Lougheed Island, several metres below base of Eureka Sound Formation; 77°23'30"N, 104°53'W)
Sphagnum sp.
Inaperturopollenites sp.
Sequoiapollenites sp.
Syncolpites sp.
Comments: Same remarks as for C-57554. W.W. Brideaux (pers. com.) suggests this sample is somewhat younger than C-57554.

Eureka Sound Formation

GSC loc. C-60043 (Lougheed Island, basal beds of formation; 77°20'45"N, 104°57W)
Sphagnum sp.
Podocarpus sp.
Metasequoia sp.
Extratriporopollenites sp.
Aquilapollenites sp.
cf. *Kurtzipites* sp.
Wodehouseia spinata sp.
Typha sp.
Comments: This is a Maastrichtian sample and appears essentially equivalent to the Eureka Sound Formation from Malloch Dome, Ellef Ringnes Island.



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