Paleozoic Evaporites of the Canadian Arctic Archipelago

G. R. Davies
Institute of Sedimentary and Petroleum Geology
Calgary, Alberta, Canada

ABSTRACT

Evaporites of Cambrian, Ordovician, Silurian, Devonian, Mississippian to Pennsylvanian, and Early Permian ages are exposed on the Arctic Islands. Of these evaporites, the thickest and most widespread are the Ordovician Baumann Fiord and Bay Fiord formations, and the Mississippian-Pennsylvanian Otto Fiord Formation. The Otto Fiord Formation is the source of numerous diapirs within the Sverdrup depositional basin.

INTRODUCTION

Sedimentary rocks of evaporitic origin are widespread both temporally and spatially in the Paleozoic stratigraphic succession exposed on islands of the Arctic Archipelago north of 72°N latitude (Fig. 1). This paper is a short review of known occurrences of Arctic evaporites based on published and unpublished descriptions, but excluding confidential information from drilling and other classified sources. The review is not exhaustive; references quoted will lead to additional sources of information. Some data from my own field work with W. W. Nassichuk is included in the description of upper Paleozoic units.

TECTONIC SETTING AND STRATIGRAPHIC FRAMEWORK

The regional setting and stratigraphy of the Arctic Islands have been reviewed recently by Thorsteinsson and Tozer (1970), Christie and others (1972), and Trettin and others (1972). The major tectonic or tectono-sedimentary divisions (Fig. 1) are:

a. the Precambrian Shield of crystalline and sedimentary rocks,

b. the Arctic Stable Platform fringing the Shield, and covered by a blanket of relatively undeformed Cambrian to Devonian sediments,

c. the Franklinian Geosyncline of Cambrian to Devonian age, divisible into an axial, flysch-dominant trough (the Hazen Trough), a northwestern, tectonically-active geanticlinal shelf, and a relatively quiescent southeastern miogeanticlinal shelf,

d. the Sverdrup Basin of Mississippian to Tertiary age, superimposed on the geosynclinal trough axis, and divisible (for the upper Paleozoic) into an axial evaporite-shale belt or trough, marginal carbonate shelves on each side of the trough, and mixed carbonate-clastic belts along the eastern and southern basin margins.

The major regional tectonic events affecting the Paleozoic rocks were the Ellesmerian Orogeny in Late Devonian to Early Mississippian time, terminating the Franklinian depositional episode, and the Eurekan Orogeny in mid-Tertiary time, primarily affecting the Sverdrup Basin succession.

TIME-STRATIGRAPHIC REVIEW OF PALEOZOIC EVAPORITES, ARCTIC ISLANDS

Pre-paleozoic

Gypsum and anhydrite of late Precambrian (Hadrynian) age are exposed in several formations of the Shaler Group on Victoria Island (Thorsteinsson and Tozer, 1962, p. 31–35). Associated rocks are carbonates and detrital sediments of shallow water aspect.

Cambrian

Known exposures of Cambrian evaporites are limited to thin beds of gypsum and anhydrite within the Middle Cambrian Ooyahgah Formation (Fig. 2) at Dundas Harbour on southeastern Devon Island (Kurtz, McNair, Wales, 1952), and from the same or equivalent formation near Grise Fiord on southeastern Ellesmere Island (R. L.

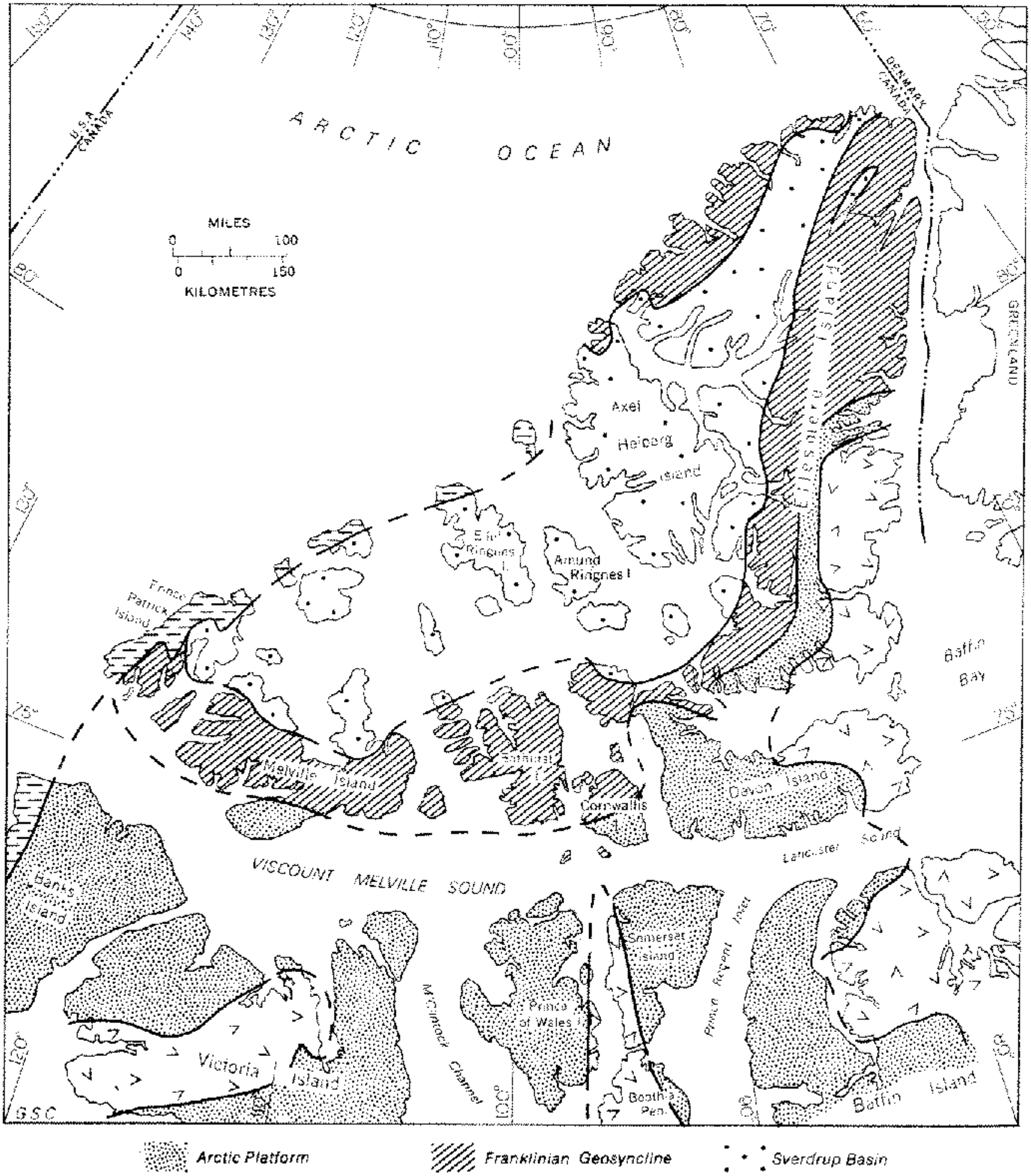

Figure 1. Island nomenclature and major tectono-sedimentary subdivisions of the Canadian Arctic Archipelago (after Thorsteinsson and Tozer, 1970; Trettin and others, 1972). The three major tectonic subdivisions containing Paleozoic rocks are identified in the legend. Precambrian rocks marking northerly extensions and arches of the Canadian Shield are shown by random-v symbols; Tertiary and younger sediments of the Arctic Coastal Plain, flanking the western islands, are shown by broken lines.

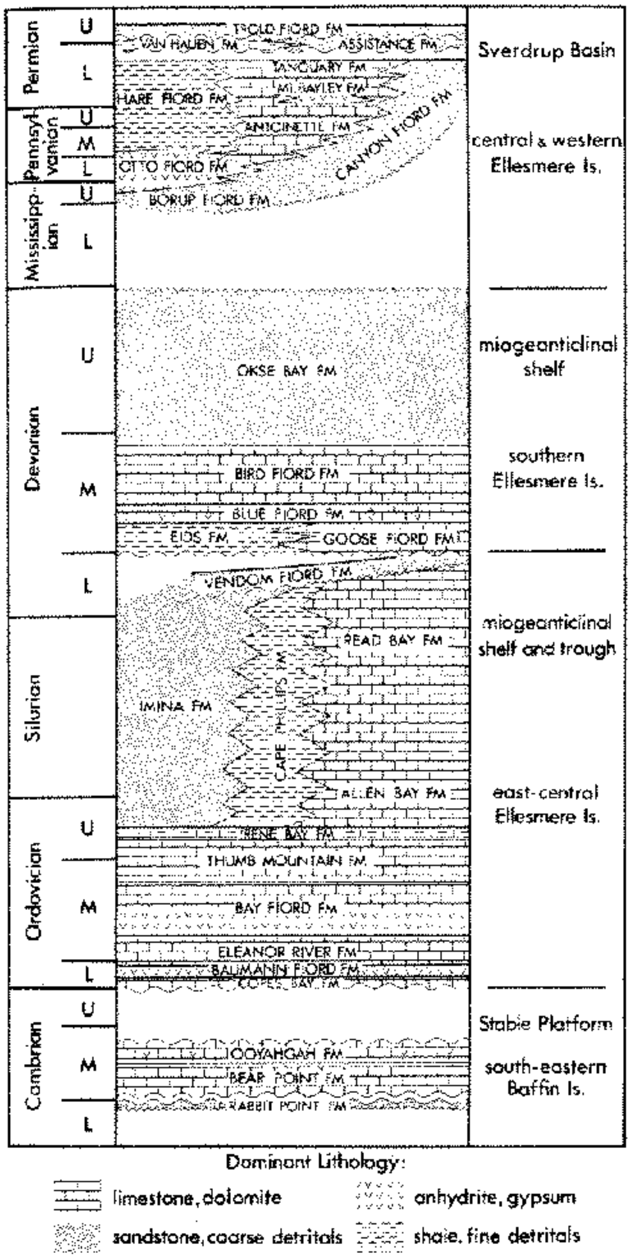

Figure 2. Composite and simplified stratigraphic column for selected parts of the Paleozoic succession exposed on islands of the Arctic Archipelago. The right-hand column identifies the area and tectono-sedimentary subdivision for the adjacent section of the stratigraphic column. Sources of stratigraphic data of each section are referenced in the text.

Christie, 1973, personal communication). The Ooyahgah Formation forms part of a carbonate-dominant Lower Paleozoic sequence deposited on the Stable Platform, flanking the Precambrian Shield and its northerly extensions.

Ordovician

The oldest Ordovician evaporites in the Arctic Islands belong to the Baumann Fiord Formation (Kerr, 1967b) of Early Ordovician age (Fig. 2). The Baumann Fiord is exposed on eastern and southern Ellesmere Island (Kerr, 1968), and southwestward to Cornwallis Island (Thorsteinsson and Kerr, 1968), where it forms the exposed core of a large central dome. The Baumann Fiord Formation is about 750 m thick in the type area on eastern Ellesmere Island; about 600 m of this thickness is anhydrite with cyclically-interbedded carbonates, some stromatolitic (Mossop, 1972, 1973). The formation is part of the miogeanticlinal shelf sequence of the Franklinian Geosyncline. The anhydrite grades westward into shallow-water shelf carbonates, while to eastward it thins, becomes sandier, and may pass to an unconformity close to the shelf-craton margin. Mossop (1972) interprets the Baumann Fiord evaporite-carbonate units to be a succession of sabkha cycles. A halite facies of the Baumann Fiord is not exposed; some interpretations link the subsurface halite below Bathurst Island, here assigned to the Bay Fiord Formation, to the Baumann Fiord.

The next youngest and most extensive Ordovician evaporite unit is the Bay Fiord Formation (Kerr, 1967b) of Middle Ordovician age (Fig. 2), the basal formation of the Cornwallis Group. The Bay Fiord is exposed in eastern and southern Ellesmere Island, and southwestward to Cornwallis Island and Bathurst Island. In the type area on eastern Ellesmere Island (Kerr, 1968), the Bay Fiord Formation contains gypsum and anhydrite in the lower part of a 500 m thick section of argillaceous and dolomitic limestone, siltstone and shale. The Bay Fiord lies within the carbonate-dominant miogeanticlinal shelf succession southeastward of the Franklinian trough, approximately co-extensive with the older Baumann Fiord Formation. On Cornwallis Island, carbonate breccias in the Bay Fiord exposures are interpreted as solution-collapse breccias (Thorsteinsson and Kerr, 1968) due to removal of halite. More than 1,000 m of halite apparently equivalent to the exposed Bay Fiord sulphates occur in the subsurface of eastern Bathurst Island (Dominion Explorers, Canso and others, Bathurst Caledonian River, J-34 well); this thickness may be in part an expression of tectonic or diapiric processes. Diapirism by Bay Fiord evaporites is suggested by exposed anhydrite cores on Bathurst Island (Kerr, in press). The Bay Fiord evaporites played an important role as a detachment zone during mid-Paleozoic Ellesmerian folding and the development of the Parry Island and Cornwallis Fold Belts structural junction (Workum, 1965; Kerr, in press). They also may have played a role in the history of lead-zinc sulphide mineralization in the overlying Middle Ordovician Thumb Mountain Formation on Little Cornwallis Island.

On northern Ellesmere Island, exposures of gypsum near M'Clintock Inlet have been assigned to the late Middle to Late Ordovician Cape Discovery Formation by Trettin (1969a, p. 15). This occurrence is of interest as it is the only known evaporite from the tectonically-active northwestern geanticlinal shelf sequence of the Franklinian Geosyncline.

Silurian

Widespread and thick dolomite breccias in the mid-Silurian Cape Crauford Formation and to a lesser extent in the middle or early Silurian part of the underlying Baillarge Formation exposed on northwestern Baffin Island suggest solution of pre-existing evaporites (Trettin, 1969b). Probable gypsum molds in some of the associated dolomites support this interpretation, as does the occurrence of gypsum interbeds in outcrops of Silurian Read Bay Formation carbonates (Norris, 1963) across Prince Regent Inlet on eastern Somerset Island. These breccias and evaporites are part of the blanket of lower and middle Paleozoic carbonate-dominant rocks of the Arctic Stable Platform.

Along the northern coast of Somerset Island, lenticular beds of gypsum are interbedded in argillaceous limestone of the Read Bay Formation, here apparently of late Silurian age (McMillan, 1963). This gypsum may be correlatable with gypsum exposed along the east coast of Somerset Island (Norris, 1963).

Devonian

Known Devonian evaporites are restricted in distribution to eastern and southern Ellesmere Island (Fig. 1), within the paleogeographic area of the Franklinian miogeanticlinal shelf. The oldest evaporite, apparently of Early Devonian age, comprises a few beds of gypsum, one 2.5 m thick, in an unnamed "red and green siltstone unit" near Canyon Fiord on Ellesmere Island (Trettin, 1973). This unit lies below an unconformity which in turn is overlain by the Vendom Fiord Formation (Kerr, 1967a). This is a post-tectonic red-bed unit also of Early Devonian age, and restricted to a small area of eastern Ellesmere Island. It is composed of about 500 m of interbedded sandstone, siltstone and anhydrite, with a major anhydrite unit about 20 m thick.

Younger Devonian gypsum occurs on the east side of Goose Fiord in southern Ellesmere Island, where an interbedded succession of dolomite, mudstone and gypsum has been assigned to the Blue Fiord Formation (Fig. 2) as late Middle Devonian in age (McLaren, 1963, p. 326).

Mississippian-Pennsylvanian

Latest Devonian to Early Mississippian time saw the close of deposition in the Franklinian Geosyncline, and tectonic deformation and erosion of its sedimentary fill. Subsequent late Paleozoic deposition of marine and non-marine sediments was restricted to the Sverdrup Basin.

The major evaporite unit in the Sverdrup Basin is the Otto Fiord Formation (Thorsteinsson and Tozer, 1970; Thorsteinsson, in press), of Late Mississippian to Early Pennsylvanian (Namurian to Bashkirian) age (Fig. 2). The Otto Fiord Formation is exposed in normal stratigraphic succession on Ellesmere and Axel Heiberg Islands, but is also exposed as the anhydrite cores of diapirs on Ellesmere, Axel Heiberg, Amund Ringnes, Ellef Ringnes and Melville Islands, thus following a NE-SW trending axial belt some 800 km long. This distribution coincides with the Central Shale Belt facies division of Thorsteinsson and Tozer (1970).

At the type area near van Hauen Pass on Ellesmere Island, the Otto Fiord Formation consists of at least 400 m of interbedded anhydrite and limestone (Fig. 3A, B); shale is a minor component restricted to the upper part of the formation. In the Krieger Mountains and the Blue Mountains of Ellesmere Island, closer to the eastern margin of the central trough, the Otto Fiord anhydrites are interbedded with thick, crossbedded sandstones (Fig. 3C, D), laminated mudstones and biogenic carbonates, totalling 500 m or more in thickness.

Where it is exposed near Hare Fiord on Ellesmere Island, the basal anhydrites of the Otto Fiord Formation interfinger with fluvio-marine red beds and peritidal to shallow marine carbonates, and grade laterally into basinal limestones and shales (Fig. 2). The Otto Fiord is overlain by argillaceous limestones and shales of the Hare Fiord Formation, the principal Pennsylvanian to Lower Permian trough-filling unit. The contact between the Otto Fiord and Hare Fiord formations, apparently conformable in nature, is diachronous. The uppermost Otto Fiord anhydrite becomes younger from west to east and from south to north within the outcrop area on west-central Ellesmere Island.

Carbonate interbeds forming part of the sulphate-carbonate cycles in the Otto Fiord Formation vary in thickness from a few tens of centimetres to beds having mound-like topography with a maximum thickness of about 20 m (Fig. 3B). The thicker beds and mounds contain a varied fauna of foraminiferids, sponges, crinoids, bryozoans, bivalves, ammonoids, brachiopods, trilobites, and other groups, with some algal elements. Namurian and Bashkirian ammonoids discovered in several diapirs more than 300 kilometres southwest of Ellesmere Island are the same as ammonoids found in carbonate interbeds within the type section of the Otto Fiord Formation (Davies and Nassichuk, 1972).

Nodular mosaic is the most common fabric in anhydrite units of the Otto Fiord Formation. In some well-exposed anhydrite-carbonate cycles 6 m to 8 m thick, the anhydrite grades upward from nodular mosaic at the base, into well-bedded anhydrite with beds 10 cm to 15 cm thick (Fig. 3E), and then back into nodular mosaic (Fig. 3F) below the next carbonate unit. Some of the well-preserved anhydrite beds reveal a distinct vertical fan or V-shaped arrangement of inclusion-defined structures apparently pseudomorphic after coarse crystalline gypsum. Sequential analysis through some of these anhydrite beds for Ca,

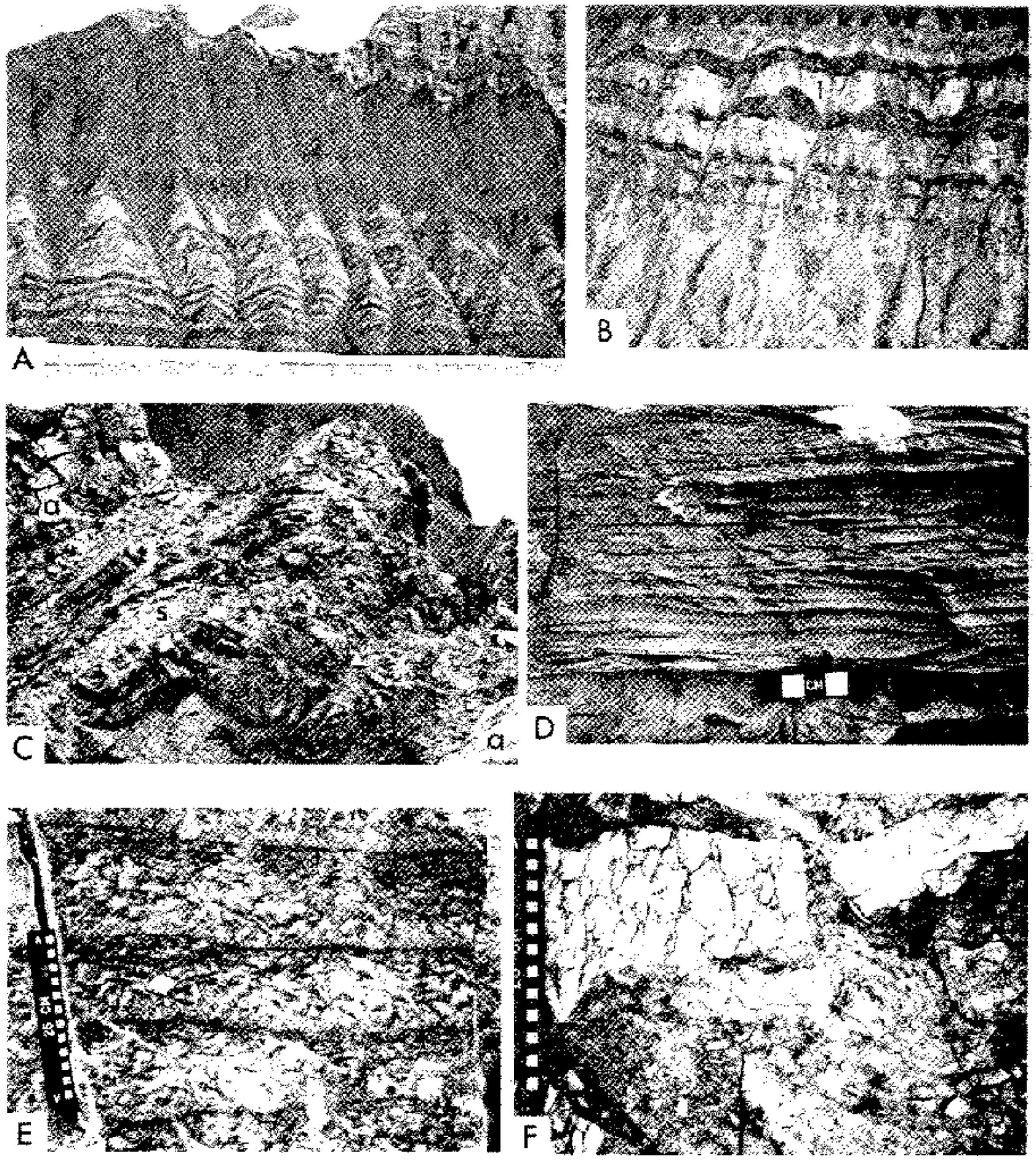

Figure 3. A. Otto Fiord Formation anhydrite with cyclical limestone interbeds (1) overlain by basinal argillaceous limestones and shales of the Hare Fiord Formation (2), in turn grading into regressive carbonate tongues of the Nansen Formation (3) Hare Fiord glacier in foreground. North side, eastern Hare Fiord, Ellesmere Island.

B. Cyclic carbonate interbeds and mound horizon, Otto Fiord Formation. Mounds (1) are up to 20m thick, appear to have accumulated in multiple growth stages, and contain a mixed "normal" marine fauna. Hematite-rich beds of red anhydrite (2) coincide stratigraphically with the upper levels of the mounds, but pinch out in the immediate vicinity of the mounds. Van Hauen Pass, central Hare Fiord, Ellesmere Island.

C. Sandstone interbed in upper part of the Otto Fiord Formation. Sandstone is variably crossbedded, channelled to laminated, sometimes glauconitic; some beds contain scattered fusulinids and other bioclasts, and often grade up into bioclastic carbonate "capping" beds. s–sandstone; a–anhydrite. *Southern Blue Mountains, Ellesmere Island.*

D. Detail of ripple crossbedded sandstone in C, showing load casting at base of bed.

E. Bedded anhydrite in Otto Fiord Formation. Lower part of each bed contains irregular to linear structures, defined by inclusions, which may be pseudomorphs after gypsum crystals. Upper part of each bed contains more inclusions, and has an irregular nodular mosaic fabric. Van Hauen Pass, central Hare Fiord, Ellesmere Island.

F. Anhydrite breccia in upper part of the anhydrite unit of the Otto Fiord Formation. Underlying undisturbed anhydrite grades upward from bedded type as in E to nodular mosaic fabric similar to that in larger clasts of breccia. The breccia is confined to one stratigraphic level, and does not affect the overlying carbonate bed; it may be a solution-collapse breccia. Same locality as E.

Sr, Mg, Fe and Zn, and for stable S isotopes, reveal a number of complex trends not yet deciphered. Average Sr content of the anhydrite is 1,070 ppm.

The Otto Fiord Formation evaporites served as the major detachment zone for folding and thrusting during the mid-Tertiary Eurekan Orogeny. It was also the source of the more than 100 diapirs and fold piercement structures which lie along the axial zone of the Sverdrup Basin; a complete historical and literature review of these diapirs is given by Thorsteinsson (in press). Movement of some of these diapirs and evaporite intrusives apparently was triggered by the Eurekan Orogeny, while others may have been active in early Mesozoic time. The presence of an Otto Fiord halite facies below the thick Mesozoic fill of the central Sverdrup Basin is dependent for proof on drilling information. Geophysical data suggest a halite core to several of the circular anhydrite-capped diapirs. Surface indications of halite are restricted to saline springs from at least two areas on Axel Heiberg Island, and to cubic molds and casts apparently pseudomorphic after halite crystals in sandstone interbeds of the Otto Fiord on Ellesmere Island and in at least one diapir.

Gypsum and anhydrite of Middle Pennsylvanian or younger age, (thus slightly younger than much of the Otto Fiord Formation), are exposed in the vicinity of M'Clintock Inlet on the north coast of Ellesmere Island (Trettin, 1969a, p. 53–54, Map-unit 11). This unnamed formation, which has a maximum thickness of about 180 m, may be part of a northern extension of the Sverdrup Basin (Fig. 1), or it may lie outside the depositional limits of that basin.

Permian

The second major late Paleozoic evaporite unit in the Sverdrup Basin is the Mt. Bayley Formation (Thorsteinsson and Tozer, 1970; Thorsteinsson, in press) of Early Permian age (Fig. 2). The Mt. Bayley is exposed in a narrow belt paralleling the eastern margin of the Sverdrup Basin in central Ellesmere Island. It is composed of anhydrite with carbonate and detrital interbeds, and may reach 250 m or more in thickness. It is underlain and overlain by shallow-water, shelf-type bioclastic carbonates and detrital sediments. The Mt. Bayley anhydrites thicken westward across the shelf and there may be older, that is late Pennsylvanian, at the base. There is no evidence for a halite facies of the Mt. Bayley, nor does it appear to have contributed to diapirism in the Sverdrup Basin. It may, however, have played a part in dolomitization of shelf carbonates westward or troughward of the Mt. Bayley evaporite belt.

CONCLUSION

Evaporites ranging in age through every period from Cambrian to Permian are exposed on the islands of the Canadian Arctic Archipelago. Evaporitic maxima occurred in Ordovician and Mississippian to Pennsylvanian time. Paleozoic evaporites have played major roles as detachment zones during mid-Paleozoic and Tertiary orogenies, and as a source of diapiric intrusives; some may have played secondary roles in metallic sulphide mineralization and in dolomitization of associated carbonates.

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